HHS Public Access

Author manuscript

Dis Colon Rectum. Author manuscript; available in PMC 2023 August 01.

Published in final edited form as:

Dis Colon Rectum. 2022 August 01; 65(8): 1052–1061. doi:10.1097/DCR.0000000000002223.

Unbundling Bundles: Evaluating the Association of Individual Colorectal Surgical Site Infection Reduction Bundle Elements on Infection Rates in a Statewide Collaborative

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Abstract

BACKGROUND: Surgical site infection reduction bundles are effective but can be complex and resource intensive. Understanding which bundle elements are associated with reduced surgical site infections may guide concise bundle implementation.

OBJECTIVE: To evaluate the association of individual surgical site infection reduction bundle elements with infection rates.

DESIGN: Post-hoc analysis of a prospective cohort study

SETTING: Illinois Surgical Quality Improvement Collaborative hospitals

PATIENTS: Elective colorectal resections at participating hospitals from 2016–2017

INTERVENTIONS: 16-element colorectal surgical site infection reduction bundle

MAIN OUTCOME MEASURES: Surgical site infection rates were compared among patients by adherence with each bundle element using Chi-squared tests and multivariable logistic regression. Principal component analysis identified composites of correlated bundle elements. Coincidence analysis identified combinations of bundle elements or principal component composites associated with the absence of surgical site infection.

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Financial Disclosures: None reported.

These data were selected as a podium presentation and electronically presented as part of the American Society of Colon and Rectal Surgeons 2020 Annual Meeting, originally scheduled for June 6–10, 2020 in Boston, MA.

RESULTS: Among 2,722 patients, 192 (7.1%) developed a surgical site infection. Infections were less likely when oral antibiotics (OR 0.63 [95% CI 0.41–0.97]), wound protectors (OR 0.55 [95% CI 0.37–0.81]), and occlusive dressings (OR 0.71 [95% CI 0.51–1.00]) were used. Bundle elements were reduced into 5 principal component composites. Adherence with the combination of (1) oral antibiotics, (2) wound protector, or (3) redosing intravenous antibiotic prophylaxis plus chlorhexidine-alcohol intraoperative skin preparation were associated with the absence of infection (consistency=0.94, coverage=0.96). Four of the five principal component composites in various combinations were associated with the absence of surgical site infection, while the composite consisting of occlusive dressing placement, postoperative dressing removal, and daily postoperative chlorhexidine incisional cleansing had no association with the outcome.

LIMITATIONS: The inclusion of hospitals engaged in quality improvement initiatives may limit the generalizability of these data.

CONCLUSION: Bundle elements had varying association with infection reduction. Implementation of colorectal surgical site infection reduction bundles should focus on the specific elements associated with low surgical site infections. See **Video Abstract** at http://links.lww.com/DCR/Bxxx.

Abstract

Los paquetes de reducción de infecciones del sitio quirúrgico son efectivos pero pueden ser complejos y requieren muchos recursos. Comprender qué elementos del paquete están asociados con la reducción de las infecciones del sitio quirúrgico puede guiar la implementación concisa del paquete.

Evaluar la asociación de los elementos individuales del paquete de reducción de infecciones del sitio quirúrgico con las tasas de infección.

Análisis post-hoc de un estudio de cohorte prospectivo.

Hospitales colaborativos para la mejora de la calidad quirúrgica de Illinois

Resecciones colorrectales electivas en los hospitales participantes entre 2016 y 2017.

Paquete de reducción de infección del sitio quirúrgico colorrectal de 16 elementos

Se compararon las tasas de infección del sitio quirúrgico entre los pacientes según la adherencia con cada elemento del paquete mediante pruebas de Chi cuadrado y regresión logística multivariable. El análisis de componentes principales identificó compuestos de elementos de paquete correlacionados. El análisis de coincidencia identificó combinaciones de elementos del haz o compuestos de componentes principales asociados con la ausencia de infección del sitio quirúrgico.

Entre 2,722 pacientes, 192 (7.1%) desarrollaron una infección del sitio quirúrgico. Las infecciones fueron menos probables cuando se administraron antibióticos orales (OR 0.63 [IC 95% 0.41–0.97]), protectores de heridas (OR 0.55 [IC 95% 0.37–0.81]) y vendajes oclusivos (OR 0.71 [IC 95% 0.51–1.00]) fueron usados. Los elementos del paquete se redujeron a 5 grupos de componentes principales. La adherencia a la combinación de (1) antibióticos orales, (2) protector de heridas o (3) redosificación de profilaxis antibiótica intravenosa más preparación de la piel intraoperatoria con clorhexidina-alcohol se asoció con la ausencia de infección (consistencia = 0.94, cobertura = 0.96). Cuatro de los cinco grupos de componentes principales en varias

combinaciones se asociaron con la ausencia de infección del sitio quirúrgico, mientras que el grupo que consiste en la colocación del apósito oclusivo, la remosión del apósito en posoperatorio y la limpieza incisional posoperatoria diaria con clorhexidina no tuvo asociación con el resultado.

La inclusión de hospitales que participan en iniciativas de mejora de la calidad puede limitar la generalización de estos datos.

Los elementos del paquete tuvieron una asociación variable con la reducción de la infección. La implementación de paquetes de reducción de infecciones del sitio quirúrgico colorrectal debe centrarse en los elementos específicos asociados con pocas infecciones del sitio quirúrgico. Consulte **Video Resumen** en http://links.lww.com/DCR/Bxxx. *(Traducción—Juan Carlos Reyes)*

Keywords

Colorectal surgery; Infection reduction bundle; Surgical site infection; Wound closure; Wound infection

INTRODUCTION

Surgical site infection (SSI) is among the most common complications following colorectal surgery, with historical rates approaching 20%.[1,2] Colorectal SSIs are associated with an average $18,000 increase in healthcare costs, equating to over $315 million in United States healthcare spending annually.[3,4] SSIs drive postoperative readmissions, are publicly reported, and fiscally penalized via pay-for-performance reimbursement programs.[5–8] Accordingly, various quality improvement efforts have focused on SSI reduction, particularly following colorectal surgery.[9–11]

SSI reduction bundles, composed of standardized perioperative processes, have effectively reduced SSIs, and have been endorsed by multiple societies and organizations.[12–18] The Illinois Surgical Quality Improvement Collaborative (ISQIC) implemented an 18-element SSI reduction bundle across the 53-hospital learning collaborative in 2016, which decreased superficial SSI rates by approximately 30% at participating institutions.[19]

Although SSI bundles are effective, they can be complex, lengthy, and difficult to implement.[20] Understanding specific bundle elements that are associated with SSI reduction may allow for focused implementation on a more concise set of bundle elements. Thus, we sought to evaluate the association of individual bundle elements on SSI rates for elective colorectal resections in ISQIC.

MATERIALS AND METHODS

Study Setting

ISQIC is a quality improvement collaborative of 53 hospitals across Illinois.[21] The goal of ISQIC is to catalyze surgical quality improvement by providing education, training, structure, and expertise for rapid and substantial improvement in healthcare quality.[22] Participating institutions receive a broad range of resources to facilitate quality improvement, such as formal mentorship, quality improvement curricula, team training,

and ready-to-implement quality improvement initiatives.[23–25] Using a learning collaborative approach, surgical quality teams at participating hospitals voluntarily participate in annual coordinated statewide Collaborative Quality Improvement Projects (CQIPs) that align with their individualized quality initiatives. ISQIC institutions utilize the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) data platform and a collaborative-specific data platform to abstract data and receive best practices feedback.[26]

SSI Reduction Bundle

The ISQIC colorectal SSI reduction bundle was offered as a voluntary CQIP in 2016. The bundle was based on a modified version of a bundle from Mantyh, *et al.* and was supplemented with best practice measures identified through a review of the literature, as previously described.[12,19] The bundle consisted of 18 elements. Two bundle elements only applicable to diabetic patients (pre-operative and intra-operative blood sugars <200 mg/dl) were not evaluated in this study based on the utilization of statistical techniques that disallow missing data. The remaining 16 colorectal SSI reduction bundle elements are listed in Table 1.

Data Collection and Patient Population

Adherence with SSI reduction bundle elements was abstracted locally by Surgical Clinical Reviewers using the ISQIC data platform and provided adherence definitions. Adherence with each SSI reduction bundle element was categorized in a binary fashion. The primary outcome was SSI per ACS NSQIP definitions, inclusive of superficial, deep, and organ space infections. ISQIC hospitals with continuous SSI reduction bundle data abstraction were eligible for inclusion in the study. Patients who underwent elective, non-emergent colorectal resection from the initiation of colorectal SSI reduction bundle abstraction in 2016 through December 2017 at participating ISQIC hospitals were identified, and patients with missing data were excluded.

Statistical Analysis

SSI rates were compared by adherence with individual SSI reduction bundle elements via separate Chi-square tests. The association between element adherence and SSI after adjusting for adherence with other bundle elements was evaluated via multivariable logistic regression accounting for hospital-level clustering. Principal component analysis (PCA), a statistical method wherein a large number of variables are evaluated for correlation and interrelated variables are grouped into a smaller number of variable composites, was performed to reduce the SSI reduction bundle elements into composites with correlated adherence.[27] Principal component scores with eigenvalues greater than 1.0 were accepted and orthogonally rotated component loadings were reported for each SSI reduction bundle element.

Coincidence analysis (CNA), a causal modelling method based on Boolean algebra, was used to identify unique combinations of SSI reduction bundle elements (configurations) that explain the presence or absence of SSI.[28] In CNA, causal pathways are built by iteratively combining individual variables with logical conditions like ‘and’ or ‘or’ to yield complex solutions that are both minimally sufficient and necessary for the outcome. Solutions are

evaluated by two model fitting criteria. Consistency is measured by the proportion of cases with the specified configuration that manifest the desired outcome, and coverage is measured by the proportion of all cases with the desired outcome who fit the specified configuration.[29] Both criteria have values from 0 to 1 indicating the degree of sufficiency or necessity in the causal relationship between the solution and the outcome.

A crisp-set strict CNA was performed using binary adherence with all 16 SSI reduction bundle elements and a specified outcome of the absence of SSI. Beginning with configurations with perfect causal relationships with the outcome (consistency=1 and coverage=1), the criteria were relaxed incrementally by 0.05 until solutions were identified. When multiple solutions resulted, those with the greatest model fit, calculated as the product of consistency and coverage, were selected. The lowest threshold for either consistency or coverage was set to 0.75, indicating that all solutions were necessary and sufficient to explain at least 75% of the SSI cases.[30] Subsequently, PCA loadings were calibrated on a 0 to 1 scale and a fuzzy-set CNA was performed on PCA composites following similar methodology.[31,32] Solution formulae were reported per standard CNA language.

All statistical analyses were performed using Stata version 14.2 (Stata Corp., College Station, Texas), R version 3.6.0 (R Foundation, Wien, Austria), and the R CNA package.[33] The pre-determined two-sided significance level was set at $P<0.05$. This study was determined to be non-human subjects research by the Northwestern University Institutional Review Board based upon the utilization of deidentified patient data.

RESULTS

Patient Population and SSI Reduction Bundle Adherence

Of the 53 ISQIC hospitals, 14 elected against participation in the SSI reduction CQIP, 3 lacked baseline colorectal SSI data, 2 had no eligible colorectal cases, 1 did not meet the minimum abstraction threshold, and 1 hospital was excluded based upon discontinuous data abstraction. Thus, 32 hospitals were included in the study and bundle adherence data were abstracted on a total of 2,747 patients. Six patients were excluded due to incomplete SSI reduction bundle data abstraction and 19 due to missing SSI outcome data. Among 2,722 analyzed patients, 1,377 (50.6%) were female, 1,026 (37.7%) had an obese body mass index, and 2,527 (92.8%) underwent a colectomy (Table 2). The overall SSI rate was 7.1% (n=192). The SSI reduction bundle elements with the highest adherence were chlorhexidine-alcohol intraoperative skin preparation (96.2%), intravenous (IV) antibiotic duration <24 hours (94.2%), PACU normothermia (93.1%), and timely initial IV antibiotic prophylaxis (92.8%). Daily chlorhexidine incision cleansing had the lowest adherence at 10.8%. Adherence with all colorectal SSI reduction bundle elements is listed in Table 1.

SSI Reduction Bundle Elements Associated with Absence of SSI

SSIs were less frequently diagnosed in patients who were adherent with 8 of the 16 SSI reduction bundle elements on unadjusted bivariate analysis, including mechanical bowel preparation (6.4% in adherent vs. 8.8% in non-adherent patients, p=0.035), redosing IV antibiotic prophylaxis (6.5% vs. 9.5%, p=0.019), clean wound closure tray/instruments

(6.1% vs. 8.2%, p=0.027), gown and glove change (5.9% vs. 8.2%, p=0.021), and re-draping (5.8% vs. 7.8%, p=0.050; Table 3). Three elements remained associated with decreased SSI rates after adjusting for adherence with other elements and hospital-level clustering: oral antibiotics (6.0% vs. 10.1%, OR 0.63 [95% CI 0.41–0.97]), wound protector utilization (5.4% vs. 10.3%, OR 0.55 [95% CI 0.37–0.81]), and occlusive dressing placement (5.7% vs. 8.4%, OR 0.71 [95% CI 0.51–1.00]). Individual and combined adherence with oral antibiotics and mechanical bowel preparation with associated SSI rates are listed in Supplemental Table 1.

SSI Reduction Bundle Composites

The Bartlett test for sphericity (P<0.001) and Kaiser-Meyer-Olkin (KMO) test of sampling adequacy (KMO=0.788) confirmed the SSI reduction bundle elements were correlated and appropriate for PCA analysis. Five principal components were accepted, which together captured 55.1% of the variation in SSI reduction bundle element adherence. Component 1 (“*Wound Closure”*) was derived from (1) gown and glove change, (2) clean wound closure tray/instruments, (3) re-draping and (4) wound protector utilization. Component 2 (*“Combined Bowel Preparation”*) was derived from (1) mechanical bowel preparation and (2) oral antibiotics while component 3 (*“Skin Preparation”*) was derived from (1) chlorhexidine skin cleansing the day of surgery, (2) chlorhexidine skin cleansing the day before surgery, and (3) chlorhexidine-alcohol intraoperative skin preparation. The fourth component (*“Dressing and Wound Care”*) was derived from (1) removal of occlusive dressing on postoperative day two, (2) daily chlorhexidine incision cleansing, and (3) occlusive dressing placement, while component 5 (*“Parenteral Antibiotics and Normothermia”*) was derived from (1) initial IV antibiotic prophylaxis, (2) IV antibiotic duration < 24 hours, (3) PACU normothermia, and (4) redosing IV antibiotic prophylaxis. Component loadings are listed in Table 4.

Coincidence Analysis (CNA)

Based on binary adherence with individual SSI reduction bundle elements, CNA suggested a solution with high consistency (≥0.935) and coverage (≥0.955): the absence of SSI was associated with one of three conditions: (1) oral antibiotics (OA), (2) wound protector (WP) utilization, or (3) the conjunction of redosing IV antibiotic prophylaxis (RA) and chlorhexidine-alcohol intraoperative skin preparation (CIO; Solution 1, Table 5). In our dataset, 93.5% of patients meeting those criteria did not have an SSI (consistency=0.935), while adherence with this combination of items was seen in 95.5% of all patients who did not develop an SSI (coverage=0.955). When lowering the coverage threshold to ≥0.93, CNA suggested another 9 solutions (Solutions 2–10, Table 5). Across these 10 solutions, the following SSI reduction bundle elements, in various combinations, were associated with the absence of SSI: (1) oral antibiotics, (2) mechanical bowel preparation, (3) chlorhexidine skin cleansing the day of surgery, (4) initial IV antibiotic prophylaxis, (5) re-dosing IV antibiotic prophylaxis, (6) PACU normothermia, (7) chlorhexidine-alcohol intraoperative skin preparation, (8) wound protector utilization, (9) gown and glove change, and (10) occlusive dressing placement. In particular, the simultaneous adherence with redosing IV antibiotic prophylaxis and chlorhexidine-alcohol intraoperative skin preparation (RA*CIO)

repeatedly appeared in 8 of the 10 solutions, and this configuration alone was identified in many patients who did not develop an SSI (consistency=0.937, coverage=0.793).

Of the five principal component composites, adherence with four was associated with the absence of SSI as shown by three CNA solutions summarized in Table 6. A pattern common to all three solutions was adherence to the *"Parenteral Antibiotics and Normothermia"* (PAN) composite. Adherence with this composite had a strong association with the absence of SSI (consistency=0.929, coverage=0.999). No evidence was found associating the *"Dressing and Wound Care"* composite with the outcome.

Cumulative Results

SSI reduction bundle elements were variably associated with the absence of SSI in each of the analytic types, which are cumulatively depicted in Table 7. Oral antibiotics and wound protector utilization were associated with the absence of SSI in all four analytic modalities. Four additional elements were associated with the outcome in three of the four analytic techniques: mechanical bowel preparation, redosing IV antibiotic prophylaxis, gown and glove change, and occlusive dressing placement. Removal of occlusive dressing on postoperative day two and daily chlorhexidine incision cleansing were not associated with reduced SSI rates in any analytic type.

DISCUSSION

SSI reduction bundles decrease SSIs following colorectal resections, but bundles can be complex.[12–17,19] Previous work has shown a stepwise decrease in colorectal SSI rates as adherence with individual bundle elements increased, but bundle elements most associated with SSI reduction remain unknown.[19] Comparisons of individual bundle elements may allow for focused efforts to maximize adherence with a limited set of bundle elements associated with SSI reduction. Thus, we evaluated the association of individual SSI reduction bundle elements with SSI rates using multiple analytic methods in a large statewide collaborative. Some bundle elements were universally associated with SSI reduction in all analyses (e.g. oral antibiotics and wound protector utilization), while other elements were not associated with SSI reduction in any analyses (e.g. removal of occlusive dressings on the second postoperative day and daily postoperative chlorhexidine cleansing). Many elements showed mixed results, which we were unable to clearly associate with reduced SSI rates.

SSI Reduction Bundle Element Adherence

Adherence with individual bundle elements was varied, potentially related to difficulties with implementation, documentation, or unaccounted factors. SSI diagnoses were less frequent in patients who were adherent with certain SSI reduction bundle elements on bivariate analysis, but not all. These findings are interesting considering the body of evidence that supports each of the elements that were included in the ISQIC SSI reduction bundle. For example, combination oral antibiotics and mechanical bowel preparation are associated with reduced SSI rates in prior studies.[34,35] Although SSI rates were lower in patients who were adherent with oral antibiotics and mechanical bowel preparation in

this study, oral antibiotics were associated with decreased SSI rates on adjusted analysis while mechanical bowel preparation was not. Additionally, a randomized controlled trial has demonstrated that two standardized preoperative chlorhexidine showers cause skin surface concentrations of chlorhexidine that are sufficient to inhibit surgical wound pathogens.[36] However, no study has demonstrated a resultant decrease in SSIs, which is consistent with our finding that adherence with preoperative chlorhexidine skin cleansing was not independently associated with decreased SSI rates.

Principal Component Analysis (PCA)

Five composites of correlated bundle elements were identified via PCA analysis. These findings make intuitive sense when considering the phase of care and providers responsible for implementing elements within composites. For example, the "*Wound Closure"* composite included items that a surgeon would control within the operating room, such as wound protector utilization and wound closure processes, while the *"Parenteral Antibiotics and Normothermia*" composite was dominated by items that would be within an anesthesiologist's purview, such as appropriate dosing and redosing of antibiotics and maintaining normothermia. Although prior evaluations of SSI reduction bundles have reported adherence rates to SSI reduction bundles as a whole, no prior study, to our knowledge, has identified clusters of elements that are commonly performed together.[16] It may be helpful to focus implementation efforts on SSI reduction bundle elements in aggregates such as these, by targeting and engaging responsible stakeholders.

Coincidence Analysis (CNA)

Through CNA, we identified combinations of elements, both individually and in principal component composites, that were both necessary and sufficient to lead to the absence of SSI. Several similar solutions were identified, and bundle element conjunctions that repeatedly appeared in solutions may be particularly important for SSI prevention. Although CNA has become an established analytic method in the social sciences, its previous use in health services research has been limited.[37,38] However, two assumptions inherent to CNA make it attractive to health services research: first, the effect of a condition may depend upon the presence or absence of other conditions, and second there can be multiple pathways leading to the same outcome.[30,32,38] Thus, CNA lends itself well to this study, wherein we sought to evaluate the benefit of individual elements within a complex intervention.

Limitations

This study should be interpreted within the context of its limitations. First, despite the large study size of over 2,700 patients, the cohort is under-powered to evaluate all 2^{16} possible bundle element combinations. While the study clearly identified associations with SSI reduction for some elements, most bundle elements were equivocal. Second, patient characteristics, such as comorbid conditions and wound contamination categories, are associated with SSIs. However, the analytic approaches used do not allow for adjustment based on these individual characteristics. Furthermore, it is unclear why particular bundle elements were completed in specific cases but not others, which could be related to patient characteristics or risk of infection (e.g., contaminated cases wherein the wound was not closed). Third, these data were derived from patients treated at hospitals within a quality

improvement learning collaborative. The characteristics of those hospitals, in combination with their quality improvement experience as part of the collaborative, may have impacted the implementation of this SSI reduction bundle. These element adherence rates may not be reproducible in other settings, however, the associations with SSI rates are unlikely to vary based on adherence rates. Additionally, the voluntary nature of offered quality improvement initiatives across ISQIC hospitals may be a source of bias, as the potential for SSI reduction is unknown at non-participating hospitals. Fourth, although CNA is a powerful method to identify causal relationships, its utility is best achieved when the number of conditions is small relative to the theoretical number of possible combinations of conditions. Our data were not heterogenous enough to cover the 2^{16} possible combinations of bundle elements, and the outcome was relatively rare, leaving a small amount of outcome variation. Thus, CNA yielded numerous solutions that fit the data well, however the other statistical methodologies utilizes in this study were not subject to this limitation. Fifth, there are limitations to the PCA methodology as a data reduction technique. Although the SSI reduction bundle elements could be reduced into 5 composites, these composites did not capture all the variance in the data. Evaluating SSIs through adherence with these composites via CNA has not been previously validated, although we believe this is a helpful way to consider the elements that were commonly performed together. Finally, it is unknown whether a truncated SSI reduction bundle would be effective in reducing colorectal SSIs, which future studies will address.

CONCLUSION

Individual SSI reduction bundle elements had varying associations with SSI rates following elective colorectal surgery across ISQIC hospitals. Oral antibiotics and wound protector utilization were associated with the absence of SSI in all analyses, while dressing removal on postoperative day two and chlorhexidine incisional cleansing were not associated with SSI reduction in any analytic approach. Based on these findings, institutions should focus on maximizing adherence to wound protector and oral antibiotic use to best reduce SSI, followed by those components associated with SSI reduction in three of the four described analytic approaches. Occlusive dressing removal and daily postoperative chlorhexidine cleansing should be omitted from the SSI bundle. Future work will prospectively evaluate the comparable utility of a limited SSI bundle that omits postoperative elements and targets interventions to maximize adherence with wound protector and oral antibiotic usage.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENTS

The authors would like to thank the quality improvement teams at the ISQIC hospitals for their participation and commitment to improving the quality and safety of surgical care in Illinois.

Funding/Support:

This work was funded by Agency for Healthcare Research and Quality (AHRQ) R01 [5R01HS024516-04] (PI: Bilimoria) and by Blue Cross/Blue Shield of Illinois (PI: Bilimoria). ADY's research is supported by the National Heart Lung and Blood Institute of the National Institutes of Health (K08HL145139).

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Table 1:

SSI Reduction Bundle Element Adherence

SSI Reduction Bundle Elements **Total** **N=2,722 patients**	**Component Adherence N (%)**
Preoperative (outpatient)	
Oral antibiotics	2,006 (73.7)
Mechanical bowel preparation	2,005 (73.7)
Chlorhexidine skin cleansing day before surgery	1,813 (66.6)
Chlorhexidine skin cleansing day of surgery	2,214 (81.3)
Preoperative (inpatient)	
Timely initial administration of appropriate intravenous SSI antibiotic prophylaxis[a]	2,527 (92.8)
Intraoperative (surgery)	
Timely intraoperative re-dosing of appropriate SSI antibiotic prophylaxis	2,227 (81.8)
First measured temperature on arrival to PACU is ≥36.0°C	2,535 (93.1)
Intraoperative skin preparation with chlorhexidine and alcohol-based solution(s)	2,618 (96.2)
Impermeable wound protector utilization for all incisions	1,820 (66.9)
Utilization of a dedicated clean wound closure tray/instruments	1,470 (54.0)
Gown and glove change for all scrubbed personnel prior to wound closure	1,339 (49.2)
Re-draping prior to wound closure	1,045 (38.4)
Sterile occlusive incisional wound dressing placed in operating room	1,344 (49.4)
Postoperative (inpatient)	
Duration of intravenous antibiotic prophylaxis is less than 24 hours	2,565 (94.2)
Removal of original operating room incisional dressing on postoperative day 2	895 (32.9)
Daily chlorhexidine incision cleansing after dressing removal until discharge (but not to exceed postoperative day 7)	294 (10.8)

SSI = Surgical site infection

PACU = Post-anesthesia care unit

[a]Acceptable intravenous antibiotics were adapted from the 2013 clinical practice guidelines from the American Society of Health System Pharmacists, Infections Diseases Society of America, Surgical Infection Society, and Society for Healthcare Epidemiology and included:

1. Cefazolin + metronidazole

2. Cefoxitin

3. Cefotetan

4. Ampicillin-sulbactam

5. Ceftriaxone + metronidazole

6. Ertapenem

7. Clindamycin + gentamicin

8. Clindamycin + tobramycin
9. Clindamycin + aztreonam
10. Clindamycin + ciprofloxacin
11. Clindamycin + levofloxacin
12. Metronidazole + gentamicin
13. Metronidazole + tobramycin
14. Metronidazole + ciprofloxacin
15. Metronidazole + levofloxacin

Table 2:

Demographic Characteristics of Analyzed Cohort

Patient Characteristics Total N=2,722 patients	**N (%)**
Age – mean (SD)	59.9 (15.0)
Sex	
Female	1,377 (50.6)
Male	1,345 (49.4)
American Society of Anesthesiology Classification	
1–2	1,350 (49.6)
3	1,304 (47.9)
4–5	68 (2.5)
Body Mass Index Classification	
Underweight (<18.5)	78 (2.9)
Normal (18.5–24.9)	746 (27.4)
Overweight (25.0–29.9)	872 (32.0)
Obese (30.0+)	1,026 (37.7)
Wound Classification	
Clean	62 (2.3)
Clean/Contaminated	2,078 (76.3)
Contaminated	433 (15.9)
Dirty or Infected	149 (5.5)
Index Procedure	
Colectomy	2,527 (92.8)
Proctectomy	195 (7.2)

SD = Standard deviation

Table 3:

Association of Colorectal SSI Reduction Bundle Element Adherence and SSIs

SSI Reduction Bundle Elements N=2,722	SSI Rates		p-value	Adjusted Odds Ratio (95% Confidence Interval)	p-value
	Adherent Patients N (%)	Non-Adherent Patients N (%)			
Preoperative (outpatient)					
Oral antibiotics	120 (6.0)	72 (10.1)	<0.001	0.63 (0.41–0.97)	0.037
Mechanical bowel preparation	129 (6.4)	63 (8.8)	0.035	1.06 (0.68–1.65)	0.805
Chlorhexidine skin cleansing day before surgery	117 (6.5)	75 (8.3)	0.084	0.86 (0.54–1.35)	0.509
Chlorhexidine skin cleansing day of surgery	151 (6.8)	41 (8.1)	0.321	0.96 (0.59–1.57)	0.882
Preoperative (inpatient)					
Timely initial administration of appropriate intravenous SSI antibiotic prophylaxis	179 (7.1)	13 (6.7)	0.827	1.20 (0.72–2.00)	0.477
Intraoperative (surgery)					
Timely intraoperative re-dosing of appropriate SSI antibiotic prophylaxis	145 (6.5)	47 (9.5)	0.019	0.86 (0.55–1.35)	0.516
First measured temperature on arrival to PACU ≥36.0°C	177 (7.0)	15 (8.0)	0.592	1.13 (0.75–1.73)	0.555
Intraoperative skin preparation with chlorhexidine and alcohol-based solution(s)	182 (7.0)	10 (9.6)	0.298	0.86 (0.37–1.98)	0.723
Impermeable wound protector utilization for all incisions	99 (5.4)	93 (10.3)	<0.001	0.55 (0.37–0.81)	0.002
Utilization of a dedicated clean wound closure tray/instruments	89 (6.1)	103 (8.2)	0.027	1.02 (0.64–1.63)	0.943
Gown and glove change for all scrubbed personnel prior to wound closure	79 (5.9)	113 (8.2)	0.021	1.00 (0.61–1.64)	0.997
Re-draping prior to wound closure	61 (5.8)	131 (7.8)	0.050	1.09 (0.70–1.68)	0.710
Sterile occlusive incisional wound dressing placed in operating room	77 (5.7)	115 (8.4)	0.008	0.71 (0.51–1.00)	0.047
Postoperative (inpatient)					
Duration of intravenous antibiotic prophylaxis <24 hours	180 (7.0)	12 (7.6)	0.766	1.01 (0.48–2.12)	0.989
Removal of original operating room incisional dressing on postoperative day 2	70 (7.8)	122 (6.7)	0.274	1.44 (1.04–2.00)	0.028
Daily chlorhexidine incision cleansing after dressing removal until discharge (but not to exceed postoperative day 7)	19 (6.5)	173 (7.1)	0.675	0.97 (0.68–1.40)	0.888

SSI = Surgical site infection,

PACU = Post anesthesia care unit

Table 4:

Principal Components Analysis (PCA) Component Loading of SSI Reduction Bundle Elements

SSI Reduction Bundle Element	Wound Closure	Combined Bowel Preparation	Skin Preparation	Dressing and Wound Care	Parenteral Antibiotics and Normothermia
Preoperative (outpatient)					
Oral antibiotics	−0.011	**0.660**	0.032	−0.026	−0.009
Mechanical bowel preparation	0.003	**0.669**	0.019	−0.010	−0.001
Chlorhexidine skin cleansing day before surgery	0.026	0.169	**0.553**	0.054	−0.020
Chlorhexidine skin cleansing day of surgery	0.016	−0.024	**0.603**	0.075	0.032
Preoperative (inpatient)					
Timely initial administration of appropriate intravenous SSI antibiotic prophylaxis	−0.034	−0.002	−0.043	−0.025	**0.716**
Intraoperative (surgery)					
Timely intraoperative re-dosing of appropriate SSI antibiotic prophylaxis	0.184	0.203	−0.200	0.056	**0.222**
First measured temperature on arrival to PACU is ≥36.0°C	0.104	0.124	−0.310	0.091	**0.253**
Intraoperative skin preparation with chlorhexidine and alcohol-based solution(s)	0.188	−0.084	**0.302**	−0.415	0.106
Impermeable wound protector utilization for all incisions	**0.369**	−0.088	−0.043	−0.089	0.101
Utilization of a dedicated clean wound closure tray/instruments	**0.500**	0.018	0.027	−0.018	−0.054
Gown and glove change for all scrubbed personnel prior to wound closure	**0.511**	0.026	0.011	−0.023	−0.077
Re-draping prior to wound closure	**0.472**	−0.022	0.039	0.072	−0.080
Sterile occlusive incisional wound dressing placed in operating room	0.197	−0.066	−0.054	**0.366**	0.237
Postoperative (inpatient)					
Duration of intravenous antibiotic prophylaxis is less than 24 hours	−0.094	−0.024	0.273	0.017	**0.483**
Removal of original operating room incisional dressing on postoperative day 2	0.014	−0.083	0.133	**0.628**	0.074
Daily chlorhexidine incision cleansing after dressing removal until discharge (but not to exceed postoperative day 7)	−0.010	0.059	0.029	**0.514**	−0.204
PCA component variance	3.051	1.682	1.524	1.395	1.170
Proportion of variance explained by PCA component	0.191	0.105	0.095	0.087	0.073

[a]Component loadings presented as values between −1.0 and +1.0, with higher absolute values indicating higher influence on the principal component

Bolded values indicate loadings primarily contributing to each component

SSI = Surgical site infection

Table 5:

Coincidence Analysis Solutions of SSI Reduction Bundle Elements Associated with the Absence of SSI

Solution[a]	Consistency[b]	Coverage[c]	Fit[d]
1. OA+WP+RA*CIO<->ssi	0.935	0.955	0.893
2. OA+WP+RA*rd<->ssi	0.937	0.947	0.887
3. WP+RA*CIO+CDOS*IA*rd<->ssi	0.935	0.944	0.883
4. OD+RA*CIO+IA*N*rd<->ssi	0.936	0.940	0.879
5. CDOS*n+RA*CIO+IA*N*rd<->ssi	0.935	0.938	0.877
6. OD+RA*CIO+CDOS*IA*rd<->ssi	0.936	0.936	0.876
7. BP+WP+bp*RA*od<->ssi	0.935	0.935	0.875
8. RA*CIO+IA*N*rd+n*ggc*rd<->ssi	0.935	0.933	0.873
9. RA*CIO+IA*N*rd+n*CIO*rd<->ssi	0.936	0.932	0.872
10. GGC+RA*CIO+IA*N*rd<->ssi	0.935	0.931	0.871

[a] Capitalization indicates presence of SSI reduction bundle element, lower case abbreviation indicates component absence. + indicates “OR,” * indicates “AND,” and <-> indicates a configuration causally linked to the outcome

[b] Consistency is the proportion of cases with a configuration as specified by the listed solution that manifests the desired outcome

[c] Coverage is the proportion of all cases with the desired outcome who fit the specified solution configuration

[d] Fit is the product of consistency and coverage

Listed abbreviations are as follows:

SSI = Surgical site infection

OA = Oral antibiotics

WP = Wound protector utilization

RA = Redosing intravenous antibiotic prophylaxis

CIO = Chlorhexidine intra-operative skin preparation

RD = Removal of occlusive dressing on POD2

CDOS = Chlorhexidine skin preparation the day of surgery

IA = Initial intravenous prophylactic antibiotics

OD = Occlusive dressing placement

N = PACU normothermia

BP= Mechanical bowel preparation

GGC = Gown and glove change

Table 6:

Coincidence Analysis Solutions of SSI Reduction Bundle Principal Components Associated with the Absence of SSI

Solution[a]	Consistency[b]	Coverage[c]	Fit[d]
1. wc+CBP+PAN<->ssi	0.930	0.816	0.759
2. WC+cbp+PAN<->ssi	0.931	0.806	0.750
3. WC+SP+AN<->ssi	0.932	0.795	0.741

[a]Capitalization indicates presence of SSI reduction bundle component, lower case indicates component absence. + indicates “OR,” * indicates “AND,” and <-> indicates a configuration causally linked to the outcome

[b]Consistency is the proportion of cases with a configuration as specified by the listed solution that manifests the

desired outcome

[c]Coverage is the proportion of all cases with the desired outcome who fit the specified solution configuration

[d]Fit is the product of consistency and coverage

Listed abbreviations refer to standard abbreviations and principal components as follows:

SSI = Surgical site infection

WC = Wound Closure Composite

CBP = Combined Bowel Preparation Composite

SP = Skin Preparation Composite

PAN = Parenteral Antibiotics and Normothermia Composite

Table 7:

SSI Reduction Bundle Elements Associated with the Absence of SSI by Analytic Approach

SSI Reduction Bundle Element	Bivariate Analysis	Logistic Regression	Bundle Element CNA	Principal Component CNA
Preoperative (outpatient)				
Oral antibiotics	X	X	X	X
Mechanical bowel preparation	X		X	X
Chlorhexidine skin cleansing day before surgery				X
Chlorhexidine skin cleansing day of surgery			X	X
Preoperative (inpatient)				
Timely initial administration of appropriate intravenous SSI antibiotic prophylaxis			X	X
Intraoperative (surgery)				
Timely intraoperative re-dosing of appropriate SSI antibiotic prophylaxis	X		X	X
First measured temperature on arrival to PACU is ≥36.0°C			X	X
Intraoperative skin preparation with chlorhexidine and alcohol-based solution(s)			X	X
Impermeable wound protector utilization for all incisions	X	X	X	X
Utilization of a dedicated clean wound closure tray/instruments	X			X
Gown and glove change for all scrubbed personnel prior to wound closure	X		X	X
Re-draping prior to wound closure				X
Sterile occlusive incisional wound dressing placed in operating room	X	X	X	
Postoperative (inpatient)				
Duration of intravenous antibiotic prophylaxis is less than 24 hours				X
Removal of original operating room incisional dressing on postoperative day 2				
Daily chlorhexidine incision cleansing after dressing removal until discharge (but not to exceed postoperative day 7)				

SSI = Surgical site infection

X = Association with Decreased/Absence of SSI