An evaluation of differences in risk factors for individual types of surgical site infections after colon surgery

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Background. *Most studies and national programs aggregate the different types of surgical site infections (SSIs) potentially masking and misattributing risk. Determining that risk factors for superficial, deep, and organ space SSIs are unique is essential to improve SSI rates.*
Methods. *This cohort study utilized data of 59,365 patients who underwent colon resection at hospitals participating in the American College of Surgeons National Surgical Quality Improvement Program from 2007 to 2009. Four independent, multivariable, predictive models were developed to assess the unique associations between risk factors and each SSI group: Superficial, deep, organ space, and an aggregate of all 3 types of SSIs.*
Results. *Overall, 13% of colon cases developed SSIs: Superficial (8%), deep (1.4%), and organ space (3.8%). Each model was different. Morbidly obese patients were more likely to develop SSIs than normal weight patients across all models; however, risk factors common to all models (eg, body mass index [BMI], duration of operation, wound class, laparoscopic approach) had very different levels of risk. Unique risks for superficial SSIs include diabetes, chronic obstructive pulmonary disease, and dyspnea. Deep SSIs had the greatest magnitude of association with BMI and the greatest incidence of wound disruption (19.8%). Organ space SSIs were often owing to anastomotic leaks and were uniquely associated with disseminated cancer, preoperative dialysis, preoperative radiation treatment, and a bleeding disorder, suggesting a physically frail or compromised patient may put the anastomosis at risk.*
Conclusion. *Risk factors for superficial, deep, and organ space SSI differ. More effective prevention strategies may be developed by reporting and examining each type of SSI separately. (Surgery 2014;156:1253-60.)*

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Surgical site infections (SSIs) related to abdominal operations are estimated to account for 26% of all reported SSIs.[1] The Centers for Disease Control and Prevention has identified 3 specific types of SSIs: Superficial incisional (the skin), deep incisional (deep soft tissue and/or muscle), and organ space (within the abdomen).[2,3] Despite this classification of different SSIs, researchers and quality improvement initiatives aggregate frequently the different types of SSIs into a single outcome for analysis.[4,5]

Recently, this approach has been criticized, because these individual types of SSIs may be owing to different risk factors.[6-11] Historically, superficial SSIs have been considered relatively minor and not life threatening because they are often discovered after hospital discharge and treated in the outpatient clinic.[12,13] Thus, some groups have suggested reporting only the aggregate deep and organ space SSIs, which are fewer in number, require more complex treatment, and are easier to track than the superficial SSIs. Deep and organ space SSIs are known to be related to longer duration of stay, greater rates of readmission, and greater health care costs.[14]

SSIs have become a national health care focus and have been studied extensively; however, there may be an opportunity to identify more granular and modifiable risk factors if the individual types of SSIs are modeled separately. The objectives of this study were to determine whether the risk factors associated with the individual types of SSI are different in patients who underwent colon surgery.

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METHODS

Data source. Data from the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) were obtained for January 1, 2007, through December 31, 2009. During this period, 235 participating ACS NSQIP hospitals contributed detailed data on 818,965 major operations.

The data collection procedures of the ACS NSQIP have been described previously.[15-17] Briefly, at each participating hospital, eligible cases are reviewed by a specially trained nurse using data definitions that are standardized across all participating hospitals. The data collected includes >50 preoperative and 30 intraoperative patient characteristics, comorbidities, and laboratory values. In addition, 42 postoperative 30-day outcomes are reported. Data abstractors follow patients 30 days postoperatively. The database is compliant with the Health Insurance Portability and Accountability Act and contains no patient, health care provider, hospital, or regional identifiers. This study was reviewed and approved by The University of Texas Health Science Center at Houston committee for the Protection of Human Subjects.

Patients. Patients that had major colon resections were identified using Current Procedural Terminology codes, including 44140, 44141, 44143–44147, 44160, 44204–44208, 44150, 44151, and 44210. Patients <18 years old at the time of operation or who had a principal Current Procedural Terminology code indicating a rectal procedure were not included. The 357 patients reported to have ≥2 types of postoperative SSIs were excluded.

Risk factors with >10% missing values were not included, leading to the exclusion of the majority of preoperative laboratory values. The patients' race/ethnicity and their body mass index (BMI) immediately before operation had relatively high proportions of missing data (8.3% and 2.7%, respectively). Age was modeled as a continuous variable and rescaled so that the odds ratios represented the association between an increase in age of 5 years and the occurrence of a SSI. Operative time was converted from minutes to hours and modeled as a continuous variable. Using the patient's weight and height, BMI was calculated and categorized using the categories of the World Health Organization: Underweight (<18.50 kg/m^2), normal (18.50–24.99 kg/m^2), overweight (25–29.99 kg/m^2), obese (30–34.55 kg/m^2), and morbidly obese (>35 kg/m^2). Postoperative diagnosis codes were categorized into neoplasm, enteritis/colitis, diverticulitis, bowel obstruction/perforation, other colon diagnosis, or other diagnosis. The physical classification score of the American Society of Anesthesiologists, which describes overall physical status of the patient at the time of operation, was dichotomized into those with a score of <3 representing those with normal health or mild systemic disease and those with a score of ≥3.

Several variables were transformed into dichotomous variables. Traditionally, wound class has 4 categories: 1 (clean), 2 (clean/contaminated), 3 (contaminated), and 4 (dirty/infected).[2,18] Colon surgery by definition is clean/contaminated. Thus, wound class was dichotomized into 2 (clean/contaminated) and those with wound classes of ≥3. Diabetes was grouped into nondiabetic and diabetic requiring medication combining those taking oral medications and/or insulin. Two variables addressing patient's functional status before current illness and before operation originally had 3 categories: Independent, partial dependence, and dependent, which were recategorized into independent or not independent.

Outcome measures. There were 4 outcomes examined in this study: Superficial SSIs, deep SSIs, organ space SSIs, and the aggregate of all single SSIs. NSQIP follows rigorous definitions established by the Centers for Disease Control and Prevention for categorizing types of SSIs.[2,3] Infections of the skin or subcutaneous tissue are classified as superficial, whereas infections of the fascia and muscle layers are classified as deep SSIs. Infections of the surgical area that do not extend through to the incision site are classified as organ space SSIs. Documentation of specific symptoms, conditions, or events that must accompany the designation of a SSI have been documented previously.[3]

Statistical analysis. The distribution of patient risk factors was compared across 5 outcomes: The referent group without SSIs and the 4 groups of SSIs (superficial, deep, organ space, and the aggregate of all single SSIs). Fifty-three preoperative and intraoperative factors were assessed individually using logistic regression to establish their univariate relationship to each SSI outcome. The comparison group for each analysis was the population of colon operations that did not develop SSIs within 30 days of operation (eg, modeling the outcome of deep SSI versus no SSI). The factors that were associated with the particular SSI outcome with a *P*-value of <.25 were included in the preliminary multivariable logistic model. Age, sex, race/ethnicity, and BMI were included initially in all 4 preliminary models, regardless of the level of significance of their univariate associations. A backward selection method was used to eliminate variables in the preliminary

models. The variable with the greatest *P*-value determined the order of variable evaluation. If a categorical variable had a single significantly associated subcategory, all the subcategories would remain in the model. Each variable was tested using the likelihood ratio test to compare the full model including the variable with the reduced model without the variable. If the likelihood ratio test comparing the 2 models was significant with a *P*-value of $<.05$, the variable would remain in the model. If the likelihood ratio was not significant, a new full model would be established without that variable. The overall effect of each categorical variable that remained in the final models was also tested individually using likelihood ratio. The models for each of the 4 outcome groups were built using the same potential risk variables and methodology. Each model was examined with area under the receiver operating characteristic curve (c statistic), which exhibits sensitivity to one minus the specificity. The level of statistical significance was set at .05 and all tests were two sided. All analyses were performed using STATA 11 (StataCorp LP, College Station, TX).

RESULTS

There were 59,365 colon cases eligible for this study. The patients were predominately female (53%) and had an overall mean age of 62 years. Approximately 77% of patients were recorded as non-Hispanic white followed by 9% African-American black and 2.5% white Hispanic. Neoplasm was the most common postoperative diagnosis at 48%, with diverticulitis ranking second at 18%. The average duration of operation was 2 hours 40 minutes. Approximately 38% of the cases were performed laparoscopically. Overall, 13.2% of the colon cases developed a single type of SSI; 8% of these were superficial, 1.4% were deep, and 3.8% were organ space.

Several patient outcomes differed between the groups that did and did not develop SSIs. Only 1.1% of the patients who did not develop a SSI had a wound disruption; the percent of wound disruptions varied significantly between those that developed a superficial, deep, or organ space SSI (3.7%, 19.8%, and 7.4%, respectively). The overall 30-day mortality rate among the 51,644 patients who did not develop a SSI was 4.4%. Notably, the 4,634 patients who developed a superficial SSI had a lesser 30-day mortality rate of 2.1% compared with those patients who experienced a deep or organ space SSIs (4.7% and 5.7%, respectively). The median duration of hospitalization for patients with no SSIs was 6 days. For the patients who developed a superficial, deep, or organ space SSIs, the median duration of stay was greater (8, 11, and 16 days, respectively).

Tables I and II describe the demographics and selected patient characteristics stratified by 5 groups; no SSIs, superficial SSIs, deep SSIs, organ space SSIs, and the composite of these SSIs. The percentage of patients without SSIs was greater among patients who were older, had a shorter duration of operation, or had a laparoscopic approach. The percentage of patients was higher in those who developed a SSI who had the following clinical characteristics: Male sex, non-Hispanic blacks, obesity, alcohol consumption, smoker, diabetes, chronic pulmonary obstructive disease, disseminated cancer, a wound class >2, or a postoperative diagnosis of bowel obstruction or perforation.

Four SSI models were examined to evaluate the association between risk factors and the individual SSI outcomes among patients who had undergone colon surgery. Table III summarizes the adjusted odds ratios of risk factors independently associated with the aggregate of all SSIs. Table IV displays the adjusted odds ratios of significant risk factors associated with the individual superficial, deep, and organ space SSIs. Race/ethnicity was not associated with any of the 4 SSI outcomes. Increased age was mildly protective against developing a SSI in 3 out of 4 models. A BMI of >30 was significantly associated with developing a SSI in all models. The level of risk for BMI of >30 differed notably across the SSI models. As BMI increased, the strength of the association with SSIs increased in all models. Each additional hour of operative time increased the likelihood of developing SSIs in all models (eg, for 1 additional hour of operation, a patient was 24% more likely to develop a deep SSI). Only the postoperative diagnosis of bowel obstruction or perforation was significantly associated with all types of SSIs when compared with patients with a postoperative diagnosis of neoplasm. Wound class of >2 was significantly associated with all types of SSIs. Having laparoscopic surgery versus an open procedure was protective for developing all types of SSIs. Although these variables were significant in all of the SSI models, the magnitude of their effect differed. The association with preoperative sepsis differed between the SSI models. All categories of preoperative sepsis were associated with developing an organ space SSI. Preoperative sepsis had a protective association with the development of a superficial SSI and no association with deep SSIs. Smoking was associated with all but the superficial SSI model. The unique cluster of risk factors identified for individual types of SSIs will be explored further in the Discussion.

Table I. Demographics of patients who underwent colon surgery by type of surgical site infection (SSI), ACS NSQIP data 2007–2009

Variable	*No SSI*	*All single*	*Superficial*	*Deep*	*Organ space*
n	51,644	7,721	4,634	855	2,232
Male (%)	24,215 (47)	3,839 (50)	2,263 (49)	419 (49)	1,157 (52)
Age, mean (SD), y	63 (15.5)	61 (15.1)	62 (14.8)	62 (14.7)	60 (15.9)
Race/ethnicity					
Non-Hispanic white (ref)	39,956 (77)	5,874 (76)	3,529 (76)	645 (75)	1,700 (76)
Non-Hispanic black	4,748 (9)	750 (10)	444 (10)	95 (11)	211 (10)
Hispanic	1,322 (3)	178 (2)	112 (2)	21 (2)	45 (2)
Other/unknown	5,618 (11)	919 (12)	549 (12)	94 (11)	276 (12)

ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; *ref*, referent; *SD*, standard deviation.

Table II. Clinical characteristics of patients who underwent colon surgery by type of surgical site infection (SSIs), ACS NSQIP data 2007–2009

Characteristic	*No SSI*	*All single*	*Superficial*	*Deep*	*Organ space*
n	51,644	7,721	4,634	855	2,232
BMI category (kg/m^2)					
Underweight <18.50	1,830 (4)	227 (3)	103 (2)	26 (3)	98 (4)
Normal (ref) (18.50–24.99)	16,283 (32)	1,900 (25)	1,060 (23)	182 (21)	658 (30)
Overweight (25–29.99)	16,785 (33)	2,365 (31)	1,443 (31)	255 (30)	667 (30)
Obese (30–34.99)	9,141 (18)	1,551 (20)	945 (20)	182 (21)	424 (19)
Morbidly obese (≥ 35)	6,193 (12)	1,473 (19)	963 (21)	189 (22)	321 (14)
Missing	1,412 (3)	205 (0.4)	120 (0.2)	21 (0.04)	64 (0.1)
Duration of operation, mean (SD), h	2.1 (1.4)	2.6 (1.8)	2.5 (1.6)	2.7 (2)	2.7 (1.9)
Wound class >2	13,631 (26)	2,635 (34)	1,396 (30)	331 (39)	908 (41)
Laparoscopic	18,537 (36)	1,929 (25)	1,264 (27)	176 (21)	489 (22)
ASA class >2	27,008 (52)	4,616 (60)	2,646 (57)	578 (68)	1,392 (62)
Postoperative diagnosis					
Neoplasm (ref)	24,867 (48)	3,273 (42)	2,097 (45)	316 (37)	860 (39)
Enteritis/colitis	2,637 (5)	464 (6)	219 (5)	51 (6)	194 (9)
Diverticulitis	9,127 (18)	1,353 (18)	907 (20)	141 (17)	305 (14)
Obstruction/perforation	3,135 (6)	657 (9)	328 (7)	95 (11)	234 (11)
Other colon	3,351 (7)	460 (6)	259 (6)	58 (7)	143 (6)
Other postoperative diagnosis	8,527 (17)	1,514 (20)	824 (18)	194 (23)	496 (22)
Preoperative sepsis category					
No sepsis (ref)	43,733 (85)	6,271 (81)	3,963 (86)	664 (78)	1,644 (74)
SIRS	4,005 (8)	795 (10)	427 (10)	99 (12)	269 (12)
Sepsis	2,296 (4)	431 (6)	177 (4)	59 (7)	195 (9)
Septic shock	1,610 (3)	224 (3)	67 (1)	33 (4)	124 (6)
Smoker within 1 year of operation	9,678 (19)	1,721 (22)	958 (21)	206 (24)	557 (25)
Alcohol >2 drinks/d	1,868 (4)	354 (5)	197 (4)	42 (5)	115 (5)
COPD	3,391 (7)	615 (8)	355 (8)	85 (10)	175 (8)
Dependent functional status preoperative	6,008 (12)	1,043 (16)	514 (11)	146 (17)	383 (17)
Diabetes*	7,631 (15)	1,345 (17)	835 (18)	158 (19)	352 (16)
Chronic steroid use within 30 days	3,297 (6)	635 (8)	296 (6)	83 (10)	256 (12)
Weight loss >10% within 6 months	2,925 (6)	528 (7)	270 (6)	46 (5)	212 (10)
Disseminated cancer	2,410 (5)	485 (6)	247 (5)	60 (7)	178 (8)
Radiation therapy within 90 days	1,134 (2)	208 (3)	107 (2)	16 (2)	85 (4)
Preoperative dialysis	788 (2)	140 (2)	53 (1)	18 (2)	69 (3)

*Diabetes requiring medication.
ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; *ASA*, American Society of Anesthesiologist; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease; *CPT*, Current Procedural Terminology; *ref*, referent; *SD*, standard deviation; *SIRS*, systemic inflammatory response syndrome.

Table III. Factors significantly associated with the aggregate of all surgical site infections (SSI), ACS NSQIP data 2007–2009

Factor	*Adjusted odds ratios (95% CI)*	P > |z|
Total no. of observations	54,915	
Male	1.08 (1.02–1.14)	.01
Age in 5-y increments	0.97 (0.96–0.98)	.00
BMI (kg/m^2) category		
Normal (ref) (18.50–24.99)	1	
Overweight (25–29.99)	1.24 (1.16–1.32)	.00
Obese (30–34.99)	1.45 (1.34–1.57)	.00
Morbidly obese (≥35)	1.86 (1.72–2.01)	.00
Duration of surgery (h)	1.17 (1.16–1.19)	.00
Wound class >2	1.23 (1.15–1.31)	.00
Laparoscopic	0.66 (0.62–0.70)	.00
ASA class >2	1.25 (1.18–1.33)	.00
Postoperative diagnosis		
Neoplasm (ref)	1	
Enteritis/colitis	1.14 (1.00–1.29)	.05
Obstruction/perforation	1.28 (1.15–1.42)	.00
Preoperative sepsis category		
No sepsis (ref)	1	
Septic shock	0.65 (0.55–0.77)	.00
Smoker within 1 year of surgery	1.10 (1.03–1.17)	.01
Alcohol >2 drinks/d	1.23 (1.08–1.40)	.00
COPD	1.12 (1.01–1.23)	.03
Dependent functional status	1.12 (1.03–1.22)	.01
Chronic steroid use within 30 d	1.13 (1.02–1.25)	.02
Weight loss >10% within 6 mo	1.14 (1.03–1.27)	.01
Preoperative platelets 100	1.04 (1.02–1.06)	.00

ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; *ASA*, American Society of Anesthesiologist; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease; *CPT*, Current Procedural Terminology; *ref*, referent.

Post analysis diagnostic tests were performed to compare the aggregate SSI model to the 3 individual SSI models. The area under the receiver operating characteristic curve for the aggregate SSI model and the superficial SSI model were similar (0.6440 and 0.6400, respectively). The deep and organ/space SSI models appeared to improve with respect to the area under the receiver operating characteristic curve (0.6892 and 0.6907, respectively).

DISCUSSION

Aggregate SSI outcomes are utilized commonly by researchers and quality programs to predict patient risk and compare hospital quality. Recent studies suggest that risk profiles may differ by type of SSIs.[7,19,20] Our results indicate that SSI risk factors are different for the 3 types of SSIs for patients undergoing colon surgery. Each model had a different number and constellation of significant risk; thus, it seems that each model suggests a different at-risk population. These findings imply that superficial, deep, and organ space SSIs should be examined separately. Hospitals and national initiatives may enhance their efforts to decrease SSI rates by targeting modifiable comorbidities or particular at-risk populations associated with the specific type of SSI.

The risk factors significantly associated with superficial SSIs (BMI > 25, diabetes, alcohol, dyspnea, and chronic pulmonary obstructive disease) have also been associated with changes in vascularization or decreases in oxygenation of the skin and wound healing.[21-23] The effect of preoperative antibiotics as a SSI reduction strategy has been discussed in many studies; positive results have been observed in the superficial SSIs. Berenguer et al[24] reported a decrease in their superficial SSI rates with their improved compliance to the National Surgical Care Improvement Project, which focuses on preoperative antibiotic timing, antibiotic selection, antibiotic duration, use of hair clippers, and normothermia. Recently Cannon et al[25] discussed the effects of preoperative oral antibiotics and mechanical bowel preparation on SSIs; among their patients who received only oral antibiotics, they observed a 67% decrease in their aggregate SSIs. Other studies have reported a lack of correlation when hospital rates of compliance were compared with rates of SSIs.[9,11,24,26,27] Perhaps the National Surgical Care Improvement Project measures would have more consistent outcomes if they were associated with the individual SSI types. Our study had the small subset of patients with preoperative sepsis that most likely all received antibiotic treatment before operation. The impact of preoperative sepsis was significantly protective for the superficial SSIs, which represent 60% of the overall SSIs. The effect of preoperative sepsis in the aggregate SSI model was protective despite the strong association with organ space SSIs. Aggregate outcomes may misattribute risk and lead to wrong assumptions.

Patients who developed a deep SSI in our study had fewer risk factors, but a strong associations with BMI of >25, duration of operation, smoking, wound class of >2, American Society of Anesthesiologist score of >2, and the indications for operation involving intestinal obstruction, perforation, enteritis, or colitis. Of note, patients with deep SSIs had the greatest incidence of wound

Table IV. Comparison of significant factors associated with the individual types of surgical site infection (SSI), ACS NSQIP data 2007–2009

Factor	*Superficial SSIs*	*Deep SSIs*	*Organ space SSIs*
Total no. of observations	52,650	49,115	49,803
Male			1.11 (1.01–1.22)
Age in 5 y increments	0.98 (0.97–0.99)		0.94 (0.93–0.96)
BMI (kg/m^2) category			
Normal (ref) (18.50–24.99)	1	1	1
Overweight (25–29.99)	1.30 (1.20–1.42)	1.41 (1.19–1.71)	
Obese (30–34.99)	1.51 (1.37–1.66)	1.78 (1.44–2.20)	1.15 (1.01–1.32)
Morbidly obese (≥35)	2.08 (1.88–2.30)	2.37 (1.92–2.93)	1.17 (1.01–1.35)
Duration of surgery (h)	1.14 (1.11–1.16)	1.24 (1.20–1.29)	1.20 (1.17–1.24)
Laparoscopic	0.66 (0.61–0.71)	0.60 (0.50–0.72)	0.67 (0.59–0.75)
Wound class >2	1.17 (1.08–1.27)	1.31 (1.12–1.54)	1.35 (1.21–1.51)
ASA class >2	1.18 (1.09–1.27)	1.46 (1.24–1.71)	1.32 (1.86–1.47)
Postoperative diagnosis			
Neoplasm (ref)	1	1	1
Enteritis/colitis		1.45 (1.05–1.20)	1.26 (1.03–1.54)
Diverticulitis	1.13 (1.03–1.24)		0.83 (0.71–0.97)
Obstruction/perforation	1.21 (1.06–1.39)	1.75 (1.35–2.27)	1.25 (1.05–1.49)
Other postoperative diagnosis		1.37 (1.13–1.67)	
Diabetes*	1.11 (1.02–1.21)		
Alcohol >2 drinks/d	1.22 (1.04–1.42)		1.33 (1.09–1.64)
COPD	1.14 (1.00–1.29)		
Preoperative dyspnea	1.13 (1.03–1.25)		
Preoperative altered mental status	0.60 (0.42–0.87)		
Smoker within 1 year of surgery		1.28 (1.09–1.52)	1.15 (1.03–1.28)
Preoperative sepsis category			
No sepsis (ref)	1	1	1
SIRS			1.26 (1.08–1.47)
Sepsis	0.72 (0.60–0.86)		1.49 (1.24–1.79)
Septic shock	0.37 (0.27–0.50)		1.27 (1.01–1.60)
Chronic steroid use within 30 d			1.35 (1.15–1.57)
Weight loss >10% within 6 mo			1.30 (1.11–1.53)
Disseminated cancer			1.21 (1.02–1.44)
Radiation therapy within 90 d			1.44 (1.3–1.82)
Preoperative dialysis			1.39 (1.05–1.83)

*Diabetes requiring medication.
Data are presented as adjusted odds ratios (95% CI).
ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; *ASA*, American Society of Anesthesiologist; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease; *ref*, referent; *SD*, standard deviation; *SIRS*, systemic inflammatory response syndrome.

disruption (approximately 20%). It is not clear which occurs first, the wound disruption or the deep SSI; however, strategies to decrease SSI might include establishing special wound closure techniques for patients who are obese or have compromised tissue owing to smoking, infection, or steroid use.

The unique group of risk factors associated only with organ space SSIs were preoperative chronic steroid use, preoperative dialysis, preoperative radiation treatment, weight loss >10%, disseminated cancer, and previous surgery within 30 days. Because most organ space infections after colectomy are owing to clinically significant and nonsignificant anastomotic leaks, these factors suggest a physically compromised patient may put the anastomosis at risk. Frailty as a risk factor for postoperative complications has been explored recently with no consensus on the definition especially as it relates to surgery patients.[28-34] Strategies that focus on patient selection, preoperative medical evaluation, and clinical optimization before operation in the patients who are physically compromised would potentially decrease postoperative complications associated with organ space SSIs.

Finally, several risk factors were significant across all 4 SSI models (eg, obesity, duration of operation, wound class of >2, and laparoscopic approach); however, these risk factors conferred a different magnitude of risk for each of the SSI

models examined. Duration of operation is a significant factor for all types of operative procedures and often a surrogate for the complexity of a procedure. Although it is not specifically a modifiable factor, intraoperative initiatives should be focused and implemented to minimize SSIs related to the duration of time. Processes should ensure antibiotics are dosed and re-dosed correctly. Because the patient and the surgical team have been identified as sources of bacterial contamination in the surgical wound, periodic changes of surgical masks, gloves, and gowns might be explored.

Currently, national quality programs aggregate categories of SSIs to provide hospitals with risk-adjusted comparisons of a hospital's SSI rate in comparison to the other participating hospitals. The national surveillance program for health care associated infections of the Centers for Disease Control and Prevention, known as the National Healthcare Safety Network, aggregated traditionally all SSIs to develop their risk model which consisted of only 3 factors: Wound class, duration of operation, and American Society of Anesthesiologist score of >2. The accuracy of these models to predict SSIs within different populations has been challenged recently.[4,14,35-38] In 2011, the National Healthcare Safety Network responded by developing new, procedure-specific risk models that utilize all factors collected currently. A secondary model is consistent with the 2008 recommendations from the National Quality Forum and meets requirements for public reporting aggregating deep and organ space SSIs of cases identified during hospitalization or rehospitalization.[10] The American College of Surgeons' NSQIP also aggregates all types of SSIs when estimating risk for postoperative complications.[8] The results from our study suggest that different types of SSIs have different risk factors and that aggregate measures of SSIs may inappropriately attribute or mask risk.

There were several limitations in our study. First, selection bias may exist, because contributing hospitals must be members of the ACS NSQIP, which requires a considerable financial investment to participate. Second, several variables related to operative practices are not collected by ACS NSQIP, such as preoperative antibiotics, preoperative skin preparation, bowel preparation, supplemental oxygen, glucose control, patient temperatures, wound protectors, normothermia, and other procedure-specific details. Third, several risk factors are significant in all the SSI models; however, the level of risk differs by type of SSI. The heterogeneity across these factors may be substantial, but owing to the design of this study, no significance can be concluded, because they were not simultaneously compared with those patients who did not develop a SSI. Future research is necessary to evaluate the association of these factors concurrently across the different types of SSIs using more complex modeling techniques.

Our study indicates that there are unique sets of risk factors associated with the individual types of SSI among patients undergoing colon cancer surgery and that aggregated SSI outcomes may misrepresent and mask important associations which are modifiable and can be leveraged in an attempt to decrease SSI rates. This study supports exploring targeted solutions for each type of SSI.[39] Additionally, national risk models should consider the 3 types of SSI separately in future models.

ACS NSQIP Disclaimer: The ACS NSQIP and the hospitals participating in the ACS NSQIP are the source of the data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

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