

Original Investigation

Costs Associated With Surgical Site Infections in Veterans Affairs Hospitals

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IMPORTANCE Surgical site infections (SSIs) are potentially preventable complications that are associated with excess morbidity and mortality.

OBJECTIVE To determine the excess costs associated with total, deep, and superficial SSIs among all operations and for high-volume surgical specialties.


DESIGN, SETTING, AND PARTICIPANTS Surgical patients from 129 Veterans Affairs (VA) hospitals were included. The Veterans Health Administration Decision Support System and VA Surgical Quality Improvement Program databases were used to assess costs associated with SSIs among VA patients who underwent surgery in fiscal year 2010.

MAIN OUTCOMES AND MEASURES Linear mixed-effects models were used to evaluate incremental costs associated with SSIs, controlling for patient risk factors, surgical risk factors, and hospital-level variation in costs. Costs of the index hospitalization and subsequent 30-day readmissions were included. Additional analysis determined potential cost savings of quality improvement programs to reduce SSI rates at hospitals with the highest risk-adjusted SSI rates.

RESULTS Among 54 233 VA patients who underwent surgery, 1756 (3.2%) experienced an SSI. Overall, 0.8% of the cohort had a deep SSI, and 2.4% had a superficial SSI. The mean unadjusted costs were \$31 580 and \$52 620 for patients without and with an SSI, respectively. In the risk-adjusted analyses, the relative costs were 1.43 times greater for patients with an SSI than for patients without an SSI (95% CI, 1.34-1.52; difference, \$11 876). Deep SSIs were associated with 1.93 times greater costs (95% CI, 1.71-2.18; difference, \$25 721), and superficial SSIs were associated with 1.25 times greater costs (95% CI, 1.17-1.35; difference, \$7003). Among the highest-volume specialties, the greatest mean cost attributable to SSIs was \$23 755 among patients undergoing neurosurgery, followed by patients undergoing orthopedic surgery, general surgery, peripheral vascular surgery, and urologic surgery. If hospitals in the highest 10th percentile (ie, the worst hospitals) reduced their SSI rates to the rates of the hospitals in the 50th percentile, the Veterans Health Administration would save approximately \$6.7 million per year.

CONCLUSIONS AND RELEVANCE Surgical site infections are associated with significant excess costs. Among analyzed surgery types, deep SSIs and SSIs among neurosurgery patients are associated with the highest risk-adjusted costs. Large potential savings per year may be achieved by decreasing SSI rates.

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Surgical site infections (SSIs) are associated with excess morbidity and mortality.¹⁻⁴ Treatment of SSIs often includes long courses of antibiotics, months of physical therapy, readmissions to the hospital, and reoperations.^{3,5,6} The costs of SSIs have been under scrutiny ever since the Centers for Medicare and Medicaid have stopped paying for the increased costs associated with SSIs after some surgical procedures because it was determined that these types of infections are potentially preventable.⁷ Thus, knowledge of the risk-adjusted costs of SSIs can inform policy makers and create a business case for implementing specific interventions to reduce the number of SSIs.

Surgical site infections may be classified as superficial SSIs involving the skin or subcutaneous tissue only, or they may be classified as deep SSIs, which are more serious infections involving tissue under the skin, organs, or implanted devices or material. Prior estimates of the cost of hospitalizations after SSIs vary widely and range from \$24 000 to \$100 000.^{4,8,9} These prior estimates are based on a small number of complex cases and may be inaccurate for a variety of reasons. First, the portion of these costs that are directly attributable to the SSI vs other factors (such as surgical complexity, facility-level variation in costs, and patient comorbidities) is unclear. Also, the costs of SSIs may vary dramatically depending on whether the SSI is deep or superficial because deep SSIs are associated with much higher morbidity.

Using the Veterans Affairs Surgical Quality Improvement Program (VASQIP) database and the Veterans Health Administration (VHA) Decision Support System (DSS) cost database from fiscal year 2010, our study determined the excess costs associated with superficial and deep SSIs in VA hospitals nationwide for all surgery types, as well as separately for 5 high-volume surgical specialties. In addition, we estimated the potential savings from reducing the SSI rate to the median hospital rate in hospitals with the highest risk-adjusted SSI rates. The VASQIP database is ideal for investigating SSIs because it includes detailed data from a multitude of surgery types among 129 hospitals and because it uses optimal measurement methods such as the Centers for Disease Control and Prevention (CDC) National Healthcare Safety Network definitions for SSIs. The VHA DSS cost database allows for the application of advanced “microcosting” methods to determine the attributable cost of an SSI.

Methods

Data Sources

Our study was approved by the University of Iowa institutional review board and the Iowa City VA Health Care System Research and Development Committee with a waiver of informed consent. Patients did not receive financial compensation.

This was a retrospective cohort study of all patients who underwent surgery during inpatient hospitalizations in the VHA between October 1, 2009, and September 30, 2010 (fiscal year 2010), as identified in the VASQIP database. The VASQIP database includes noncardiac patients undergoing surgery un-

der general, spinal, or epidural anesthesia from all VA medical centers that perform surgery.

The data set includes patient demographics and preoperative risk factors, information about the operative procedure and anesthesia, and information about postoperative complications. The information contained in the VASQIP database is abstracted by trained surgical clinical nurse reviewers from 129 acute care VA medical centers. These reviewers use standard CDC National Healthcare Safety Network definitions to ensure data reliability. Data available from the VASQIP data set are listed in **Table 1** and include demographics, comorbid conditions, other preoperative laboratory values, wound classification (status of operative wound determined by surgeon: clean, clean/contaminated, contaminated, or dirty/infected), work relative-value unit (as a measure of surgical complexity), and specialty of the operating surgeon.

Operations performed in VA hospital inpatient settings during fiscal year 2010 were identified in VASQIP data ($n = 57\,654$). Operations were excluded if they were preceded within 30 days by a prior operation ($n = 3373$), if they had diagnosis-related group code 452 or 453 (representing complications of previous treatment; $n = 10$), or if any of the patient’s demographic or surgery-related variables were missing ($n = 38$). The final sample included 54 233 patients from 127 VA hospitals who underwent general surgery during fiscal year 2010.

The VASQIP data set also includes information about surgical complications that occur within 30 days of surgery. Surgical site infections were defined using CDC criteria, with the exception that the CDC criteria require longer follow-up for some procedures (eg, hip replacement). Surgical site infections were also classified as superficial or deep according to CDC definitions.¹⁰ Superficial SSIs involved the skin and subcutaneous tissue, whereas deep SSIs involved organs, spaces, and/or deep soft tissue.

In addition, the VHA DSS cost database was used to identify the main outcome of our study, defined as total costs associated with the index admission and all subsequent readmissions within 30 days of discharge. The DSS uses “activity-based costing,” which is similar to microcosting in that it uses automated data to assign costs based on relative resource use for each patient.¹¹ The DSS includes direct costs such as health care products and staff time, as well as indirect costs such as overhead, allocated based on specified algorithms. Thus, to determine the cost of a patient encounter, the departmental unit costs are multiplied by product quantities to derive the cost for each product (eg, chest radiography and unit of blood), and total direct costs are calculated by summing the cost of all products used during a hospitalization. These costs can vary greatly from one hospital to another. In contrast to the use of data in single-center studies, the use of data from multiple hospitals provides robust cost estimates.

Statistical Methods

First, data distributions were inspected for missing or out-of-range values. For most patient variables, the presence of missing values was minimal. As noted previously, we excluded a small number of patients ($n = 38$) with missing data on variables reflecting demographics or details of the surgical proce-

Table 1. Characteristics of the Study Population^a

Characteristic	SSI (n = 1756)	No SSI (n = 52 477)	P Value
Age, mean (SD), y	63.24 (10.76)	62.98 (12.11)	.38
Female sex, No. (%)	96 (5.47)	3208 (6.11)	.27
Surgery type, No. (%)			
General	888 (50.57)	14 576 (27.78)	<.01
Neurosurgery	61 (3.47)	4214 (8.03)	
Orthopedic	206 (11.73)	13 422 (25.58)	
Peripheral vascular	355 (20.22)	7462 (14.22)	
Urology	83 (4.73)	6192 (11.80)	
Oral surgery	2 (0.11)	108 (0.21)	
Otolaryngology	43 (2.45)	1708 (3.25)	
Plastic surgery	37 (2.11)	811 (1.55)	
Podiatry	11 (0.63)	388 (0.74)	
Thoracic surgery	44 (2.51)	2707 (5.16)	
Other	26 (1.48)	889 (1.69)	
Emergency surgery	219 (12.47)	5209 (9.93)	<.01
Preoperative conditions, No. (%)			
Alcohol use (>2 drinks/d)	170 (9.68)	4293 (8.18)	.02
History of diabetes	301 (17.14)	6228 (11.87)	<.01
History of COPD	354 (20.16)	8230 (15.68)	<.01
History of rest pain/gangrene	201 (11.45)	2773 (5.28)	<.01
History of myocardial infarction	15 (0.85)	393 (0.75)	.62
Sepsis 48 h prior to surgery	58 (3.30)	1451 (2.77)	.18
Current pneumonia	12 (0.68)	489 (0.93)	.28
Weight loss ^b	103 (5.87)	2057 (3.92)	<.01
History of angina 30 d prior to surgery	36 (2.05)	711 (1.35)	.01
Bleeding disorder	141 (8.03)	3561 (6.79)	.04
Congestive heart failure 30 d prior to surgery	33 (1.88)	603 (1.15)	<.01
Steroid use 30 d prior to surgery	44 (2.51)	1264 (2.41)	.79
Acute renal failure	12 (0.68)	364 (0.69)	.96
Dialysis 2 wk prior to surgery	32 (1.82)	1061 (2.02)	.56
Ventilator dependent 48 h prior to surgery	10 (0.57)	428 (0.82)	.25
Ascites	16 (0.91)	445 (0.85)	.78
Preoperative laboratory values, mean (SD)			
Hematocrit, %	38.66 (6.02)	39.36 (5.91)	<.01
Serum albumin, g/dL	3.68 (0.75)	3.77 (0.97)	<.01
WBC count, /μL	8.62 (3.75)	8.31 (4.35)	<.01
BUN, mg/dL	17.34 (10.60)	17.79 (10.66)	.09
Partial thromboplastin time, s	32.01 (11.14)	31.19 (8.97)	<.01
Total bilirubin, mg/dL	0.73 (0.65)	0.75 (0.93)	.34
ASA classification, No. (%)			
1-2	247 (14.07)	10 590 (20.18)	<.01
3	1180 (67.20)	34 411 (65.57)	
4-5	328 (18.68)	7470 (14.24)	
Wound classification, No. (%)			
Clean	634 (36.10)	28 888 (55.05)	<.001
Clean/contaminated	794 (45.22)	17 161 (32.70)	
Contaminated	183 (10.42)	2874 (5.48)	
Dirty/infected	145 (8.26)	3554 (6.77)	

Abbreviations: ASA, American Society of Anesthesiology; BUN, blood urea nitrogen; COPD, chronic obstructive pulmonary disease; SSI, surgical site infection; WBC, white blood cell.

SI conversion factors: To convert hematocrit to proportion of 1.0, multiply by 0.01; to convert serum albumin to grams per liter, multiply by 10; to convert WBC count to $\times 10^9$ per liter, multiply by 0.001; to convert BUN to millimoles per liter, multiply by 0.357; and to convert total bilirubin to micromoles per liter, multiply by 17.104.

^a All of the variables were assessed for inclusion in the multivariable model.

^b Loss of more than 10% of body weight in last 6 months.

ture. However, important laboratory values were missing for a significant portion of patients (eg, 27.6% of patients had missing data on bilirubin level, 5.7% of patients had missing data

on blood urea nitrogen level, 23.4% of patients had missing data on albumen level, 30% of patients had missing on partial thromboplastin time, and 3% of patients had missing data on white

blood count and hematocrit level). Therefore, multiple imputations were performed on laboratory values to provide complete laboratory data for all patients, as previously described.^{11,12} We performed 5 imputations using a Markov chain Monte Carlo method that assumed multivariate normality. All subsequent analyses were conducted on the imputed data and repeated using the original data that excluded patients with 1 or more missing laboratory values. Second, the unadjusted association between presence of SSI and cost was assessed using the Wilcoxon rank sum test.

Third, multivariable risk-adjustment models of the association between presence of SSI and cost were developed in an iterative process that incorporated multiple steps. First, previous studies^{11,13-16} based on VASQIP data were reviewed to identify important predictors of cost and modeling techniques. Second, bivariate relationships between log-transformed costs and individual patient risk factors were examined using the *t* test for risk factors measured as dichotomous variables and analysis of variance for risk factors measured as ordinal or continuous variables. Candidate variables that were significantly related ($P < .01$) to costs were considered candidate variables for inclusion in multivariable models. Third, correlation among candidate variables was evaluated using both bivariable correlation coefficients, as well as the variance inflation factor for multiple variables.¹⁷ Redundant collinear variables were eliminated by retaining the variables that maximized model fit. Fourth, candidate variables were entered into several regression models with forward, backward, or stepwise elimination. For each model, selected variables were inspected for consistency with clinical expectation and previous literature based on analyses of the VASQIP. The model fit was evaluated using the Akaike information criterion and was based on the *R*-squared values between predicted and actual costs. After several iterations, a final set of variables was identified. These were included in a final model for costs, which was generated as a generalized linear model with γ -distributed errors and a log-link function to account for the skew of costs, and incorporated fixed effects for VA hospitals to account for hospital-level variations in costs (eTable in the Supplement). The *R*-squared values for final cost models were 0.27 for the overall model and 0.32, 0.31, 0.16, 0.29, and 0.28 for models that included general surgery, orthopedic surgery, peripheral vascular surgery, urologic surgery, and neurosurgery, respectively. The SAS software MIANALYZE procedure (version 9.3; SAS Institute Inc) was used to accommodate the multiple models based on multiple data imputations.

Two sets of multivariable models were generated using the full cohort. The first evaluated the relationship between the presence of any SSI and costs, whereas the second evaluated deep SSI and superficial SSI costs separately. Subsequently, we performed separate analyses for the 5 highest-volume surgical specialties as reported by the fiscal year 2010 VASQIP data set (general, orthopedic, peripheral vascular, urology, and neurosurgery). All models included fixed effects for each VA facility to adjust for possible idiosyncratic assignment of cost across medical centers.¹¹

Finally, we generated a risk-adjustment model for the occurrence of SSI. Model development followed a procedure simi-

lar to that used for the cost-related multivariable models, except that models were estimated using logistic regression (final SSI models were estimated as a generalized linear model with logit link and binomial errors). Discrimination and fit of the logistic regression models were measured using the C statistic and the Hosmer-Lemeshow goodness-of-fit test. The C statistic was 0.78 for the overall SSI models, and it was 0.76 for general surgery, 0.78 for orthopedic surgery, 0.79 for peripheral vascular surgery, 0.91 for urologic surgery, and 0.84 for neurosurgery. The Hosmer-Lemeshow goodness-of-fit test was nonsignificant for all models, suggesting a good fit across categories of patients defined by likelihood of SSI.

Based on the SSI model, hospitals were ranked by risk-adjusted SSI rates. To make a business case for reducing SSI rates, we determined the cost savings for the entire VHA if hospitals in the worst 10th percentile in terms of the risk-adjusted SSI rates are targeted for quality improvement so that their risk-adjusted rates decrease to the median hospital rate (equal to the 50th percentile). This was also performed to evaluate the reduction in costs when hospitals moved from the worst 25th percentile or worst 50th percentile in terms of risk-adjusted SSI rates to become equal to hospitals with rates in exactly the 50th percentile.

Results

Overall, 54 233 veterans underwent surgery in fiscal year 2010 and were included in the VASQIP data set. Three percent ($n = 1756$) of these veterans received a diagnosis of SSI. Of these, 1301 (74.1%) had a superficial SSI, and 455 (25.9%) had a deep SSI.

Characteristics of the study population are displayed in Table 1. Patients who experienced an SSI were more likely to have preoperative comorbid conditions (eg, diabetes mellitus and chronic obstructive pulmonary disease) and were more likely to drink more than 2 drinks per day in the 2 weeks before the operation ($P < .05$). Patients who experienced an SSI were also more likely to have a more severe wound classification and were more likely to undergo emergency surgery ($P < .01$). Operations that resulted in an SSI had a higher mean number of work relative-value units (18.1 vs 16.4; $P < .01$) than operations that did not result in an SSI. Therefore, these characteristics were included in the multivariable model to statistically adjust the association between SSIs and cost.

The mean (SD) unadjusted 30-day postoperative cost among patients who developed an SSI was \$52 620 (\$47 730). In comparison, the mean (SD) unadjusted 30-day postoperative cost accumulated by patients without an SSI was \$31 580 (\$36 088) for an unadjusted mean difference of \$21 040 (\$36 523) ($P < .01$). As expected, the unadjusted mean (SD) cost was higher for deep SSIs (\$73 533 [\$55 751]) than for superficial SSIs (\$45 306 [\$42 231]). Table 2 presents the unadjusted mean difference in costs, comparing patients with deep or superficial SSIs with patients with no SSI.

The risk-adjusted costs for patients who experienced an SSI were 1.43 (95% CI, 1.34-1.52) times higher than those for patients without an SSI after statistically adjusting for age, sex,

Table 2. Relative Total Cost Differences of Any Surgical Site Infection (SSI) Compared With No SSI

Type of SSI	Mean Total Cost (SD), \$	Unadjusted Cost Difference (95% CI), \$	Risk-Adjusted Cost Difference, \$
Any SSI	52 620 (47 730)	21 040 (18 785-23 295)	11 876
Depth of SSI			
Superficial	45 306 (42 231)	13 726 (11 408-16 043)	7003
Deep	73 533 (55 751)	41 952 (36 807-47 098)	25 721
Surgical category			
Neurosurgery	48 429 (51 720)	17 896 (4615-31 178)	23 755
Orthopedic	48 123 (37 259)	19 499 (14 365-24 632)	15 243
General surgery	56 052 (48 502)	20 649 (17 381-23 917)	10 849
Peripheral vascular	46 976 (47 007)	15 380 (10 405-20 356)	7354
Urology	42 575 (40 583)	22 198 (13 315-31 081)	4842

preoperative laboratory values (eg, albumin level and white blood cell count), preoperative conditions (eg, diabetes and chronic obstructive pulmonary disease), wound classification, American Society of Anesthesiology Physical Status Classification, surgery type, emergency surgery, and work relative-value units associated with the surgery. This resulted in a risk-adjusted difference in relative total costs of \$11 876 for the average surgical patient (Table 2).

In the risk-adjusted analysis, the costs were 1.25 times higher for patients with superficial SSIs than for patients without an SSI (95% CI, 1.17-1.35; risk-adjusted mean difference, \$7003). The largest risk-adjusted costs were found among patients with a deep SSI. For patients with a deep SSI, the risk-adjusted costs were 1.93 times higher than for patients without an SSI (95% CI, 1.71-2.18; risk-adjusted mean difference, \$25 721) (Table 2).

The 5 highest-volume surgical specialties were general surgery, orthopedic surgery, urologic surgery, peripheral vascular surgery, and neurosurgery. Of these, the highest mean cost attributable to SSIs was among neurosurgery patients (\$23 755). This was followed by orthopedic surgery, general surgery, peripheral vascular surgery, and urologic surgery (Table 2).

Next, we assessed the cost savings to the VHA if hospitals with high risk-adjusted SSI rates improved. We ranked all included VA hospitals into percentiles according to their risk-adjusted SSI rates. If hospitals in the highest 10th percentile (eg, worst) reduced their SSI rates to the rates of the hospitals in the 50th percentile, the VHA system would save approximately \$6 742 080 in 1 year. Similarly, if hospitals in the highest 25th percentile reduced their risk-adjusted rates to the 50th percentile, the VHA system would save approximately \$11 328 832 in 1 year. Finally, if hospitals in the highest 50th percentile reduced their SSI rates to the rates of the hospitals in exactly the 50th percentile, the annual savings to the VHA system would be \$13 198 865.

Discussion

In this analysis of large multicenter data sets, we found that SSIs are associated with significantly increased costs. This was especially true for deep SSIs and SSIs after neurosurgery. The

results presented here are more conservative than some previously published estimates because they are adjusted for patient factors, surgical factors, and medical center factors that could also contribute to increased postoperative costs.

Three prior studies^{4,11,18} performed risk-adjusted analyses of postoperative complications that included SSIs. In a study of fiscal year 2006 VASQIP and DSS data, we found that wound complications (defined as SSI or wound dehiscence or disruption) were associated with a 44% increase in risk-adjusted costs after statistically adjusting for facility-level variation in costs and patient characteristics.¹¹ Dimick et al¹⁸ found that the attributable costs of postoperative infectious complications was \$1398 (95% CI, \$377-\$2418) after adjusting for procedure complexity, patient characteristics, and other complications. The present study extends this research by evaluating the risk-adjusted costs of SSIs alone and stratified by deep or superficial SSIs. Both of these prior studies underestimate the costs of SSIs because wound dehiscence was included as an outcome even though wound dehiscence is less severe and requires fewer resources than SSIs.

Poultides et al⁴ analyzed data from the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project National Inpatient Sample and found that, among patients who underwent a primary hip or knee arthroplasty, the average cost of in-hospital care was double for patients with an SSI vs those without an SSI. We also found that, among orthopedic surgery patients, the postoperative costs nearly doubled. However, our study assessed a wider variety of surgery types.

Our study had several potential limitations. First, the VASQIP data only included patients followed up for 30 days postoperatively, even though CDC guidelines suggest that patients who receive a surgical implant should be followed up for a year.¹⁰ Therefore, our results may underestimate the costs associated with SSIs, particularly for orthopedic operations. However, we do not think that this will be a large underestimate because other studies have shown that more than 75% of SSIs are detected within 30 days and that most SSIs manifest within 22 days.¹⁹⁻²³ Second, the costs and burdens of superficial SSIs are usually incurred in the outpatient setting and would not be captured in our cost analysis. Thus, our analysis is an underestimate of the costs of all SSIs. Similarly, the cost of SSIs may be greater if analyzed from the perspective of

society or a patient rather than the current hospital perspective. Third, we used VHA data sets; thus, it may be inappropriate to generalize our findings outside the VA system. The patient population in VA hospitals is generally sicker^{24,25} and much more likely to be male than the patient population in private hospitals. Finally, our data do not include information on cardiac operations because these operations are not included in the VASQIP data set.

Although neurosurgery is one of the 5 most common surgery types in this data set and is associated with the highest costs attributable to SSIs, cost-benefit analyses should be performed to determine which surgical groups should be targeted for prevention efforts. For example, 40.5% of all SSIs reported to the CDC National Healthcare Safety Network were following orthopedic surgery, whereas only 2.4% of reported SSIs were following neurological surgery.²⁶ Interventions that can be implemented across multiple types of surgery may be ideal for preventing SSIs and their associated costs.

For more than 2 decades, the VHA has been a leader in implementing strategies to reduce the rates of health care-associated infections, specifically SSIs.^{27,28} For instance, the

VHA was involved in the early development of the Surgical Care Improvement Project and the VA implemented the National Surgical Quality Improvement Program (predecessor to the VASQIP) before it became widespread in the private sector.^{28,29} The proportion of surgical patients with an SSI in our VA cohort is consistent with that among the private sector National Surgical Quality Improvement Program cohort.^{30,31} Nonetheless, our results demonstrate that the VHA could financially benefit if they continued to implement additional strategies to prevent SSIs.

Conclusions

In conclusion, SSIs are associated with a significant increase in attributable postsurgical costs, even after adjusting for patient-level, surgical-level, and facility-level factors. These increases in costs were highest among deep SSIs and SSIs among neurosurgery patients. Hospital administrators, policy makers, surgeons, and hospital epidemiologists can use these data to make a business case for quality improvement efforts focused on SSIs.

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