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Major Article

Validation of an electronic tool for flagging surgical site infections based on clinical practice patterns for triaging surveillance: Operational successes and barriers

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Surgical site infection surveillance
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electronic SSI flagging tool
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Background: Surveillance is an effective strategy for reducing surgical site infections (SSIs); however, current identification methods are resource-intensive. Therefore, we sought to validate an electronic SSI triaging tool for detection of probable infections and identify operational barriers and challenges.

Methods: A retrospective cohort study was conducted among all Veterans Affairs Surgical Quality Improvement Program (VASQIP)–reviewed surgeries at 2 Veterans Affairs medical centers from October 1, 2011-September 30, 2014. During the postoperative period, clinical and administrative variables associated with SSI (relevant microbiology order, antibiotic order, radiology order, and administrative codes) were extracted from the electronic medical record and used to score the probability (high, intermediate, and low) that an SSI occurred. VASQIP manual chart review was used as the gold standard of comparison.

Results: VASQIP manual review identified 118 SSIs out of 3,700 surgeries (3.2%). There were 2,041, 1,428, and 231 surgeries that met criteria for low, intermediate, and high probability for SSI. The tool's area under the curve was 0.86 (95% confidence interval, 0.82-0.89). The sensitivity among low-probability surgeries was 92.4%, and the specificity among high-probability surgeries was 95.1%.

Conclusions: The electronic SSI tool has the potential to be used for triaging VASQIP surveillance toward the high-probability surgeries and to avoid manual review of surgeries with low probability of SSI.

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BACKGROUND

Surgical site infections (SSIs) are among the most common health care–associated infections,[1,2] accounting for up to 20% of all health care–associated infections in hospitalized patients.[3] SSIs increase morbidity, mortality, medical costs, and are used as a quality benchmark.[4-6]

Surveillance is an effective strategy for deploying infection prevention resources and ultimately reducing SSIs. However, currently available methods have significant limitations. Isolated clinical markers, such as microbiology results, have low sensitivity.[7-9] Complex detection algorithms are hampered by narrow generalizability and complexity.[10,11] Because SSI is a rare outcome, random sampling with manual review is low-yield, resource-intense, and impractical in many settings. An additional limitation of manual review programs is the inherent subjectivity of the method.[12-15] Automated SSI triaging tools based on readily available clinical and administrative variables are an attractive alternative because they have the potential to expand current surveillance capacity consistently and accurately across medical institutions.[16]

The Veterans Affairs Surgical Quality Improvement Program (VASQIP), which applies recent Centers for Disease Control and Prevention's National Healthcare Safety Network (NHSN) surveillance definitions to identify SSI, includes detailed manual review of a selection of surgical procedures by a trained nurse reviewer. Sampling is based on a validated method that targets major cases and limits review of minor cases, such as hernia repairs.[17] An alternative strategy for conducting SSI surveillance is the use of clinical variables—part of the usual diagnosis and treatment of SSI and other health care associated infections—to guide detection and subsequent case review. Using clinical practice patterns to guide surveillance activities has been a successful strategy for identifying other health care–associated infections, such as clinical methicillin-resistant *Staphylococcus aureus* infections.[18]

A simple and easily automated triaging tool for identifying SSI based on clinical variables associated with the diagnosis and treatment of SSI, including antimicrobial use, was previously developed at a single Veterans Affairs (VA) medical center.[19] Based on an initial case-control study, this surveillance tool demonstrated excellent operating characteristics (area under the curve [AUC], 0.87).[19] In the setting of expanding our SSI surveillance for quality assurance purposes,[20] we operationalized this tool to expand surveillance at 2 VA medical centers. The purpose of this study was to validate the tool and determine operational barriers to using a practice pattern–based approach to SSI detection.

METHODS

Medical center overview

The study cohort included 2 geographically distributed level 1 VA facilities: VA Eastern Colorado Healthcare System (Denver VA) and VA Boston Healthcare system (Boston VA). They perform approximately 4,000 and 5,000 operating room surgical procedures annually, respectively, including major cardiothoracic, abdominal, orthopedic, and vascular surgeries.

Cohort development and case definition

All surgeries that were manually reviewed for the presence of SSI by VASQIP during the period from October 1, 2011-September 30, 2014 were included. The VASQIP determination was compared with the probability score from the electronic triaging tool.

Data collection

Data were extracted from the VA Heath Information Systems electronically. Type of surgical procedure was determined based on VASQIP entry. Electronically extracted variables included demographic (age and sex), potentially relevant microbiology culture orders (examples of labels include swab, tissue, fluid, abscess fluid, connective tissue, and bone; blood, urine, sputum, and methicillin-resistant *Staphylococcus aureus* nasal surveillance swabs were specifically excluded), first antimicrobial order within the postoperative window, radiology orders, and ICD-9 or current procedural terminology codes determined a priori to be potentially indicative of SSI diagnosis. A random sample of the electronically extracted data was validated using manual chart review blinded to electronic flag to evaluate the accuracy of electronically extracted variables.

SSI triaging tool

Clinical and administrative variables included in the previously constructed electronic tool were ICD-9 or CPT code indicative of SSI, first new antibiotic order, relevant microbiology culture order, and computed tomography (CT) or magnetic resonance imaging (MRI) radiology examination during the NHSN-defined postoperative data extraction period (30 days). Antibiotic orders placed within 24 hours after a surgical procedure were excluded from the triaging tool, given the accepted time frame for perioperative prophylaxis according to former Surgical Care Improvement Project measures.[17]

Statistical analysis

SSI triaging tool

The practice pattern–based SSI detection tool was applied to all VASQIP-reviewed surgical procedures during the study period, using a weighted point system based on previously published data (antimicrobial order, 2 points; wound, tissue, or fluid specimen logged in microbiology laboratory, 1 point; CT or MRI order, 1 point; ICD-9 or CPT code, 5 points).[19] Surgeries with a score of zero were classified as low probability, 1-3 points were classified as intermediate probability, and ≥4 points were classified as high probability of SSI.[19] True SSI cases flagged in the low-probability category (false negatives) and high-probability noncases (false positives) at 1 facility were reviewed to ascertain reasons for discordance between the electronic algorithm and the gold standard manual review.

The sensitivity and specificity of each cut point were calculated and examined, and the area under the receiver operator characteristic curve was obtained. Positive likelihood ratios (LRs+) and negative likelihood ratios (LRs–) were calculated to determine the probability of SSI changes for each cut point. LR+ > 10 indicated a large increase in the likelihood of disease, and LR– < 0.1 indicated a large decrease in the likelihood of disease.

$$LR+ = \frac{sensitivity}{1 - specificity} \qquad LR- = \frac{1 - sensitivity}{specificity}$$

Receiver operator characteristic curves were calculated to assess operability of the probability score. To ensure that algorithm accuracy was not overestimated, confidence intervals for AUC values were obtained via bootstrapping with 1,000 repetitions. Multivariable logistic regression was also used to confirm the independent contribution of each of the 4 clinical variables in predicting SSI in this larger sample set.

Given that procedure-related infections typically do not occur in the first 24 hours after a surgical intervention,[21,22] and concern that microbiology orders logged during this time frame might be related to preexisting, nonprocedure-related infections, a sensitivity analysis on the window period for the microbiology order flagging

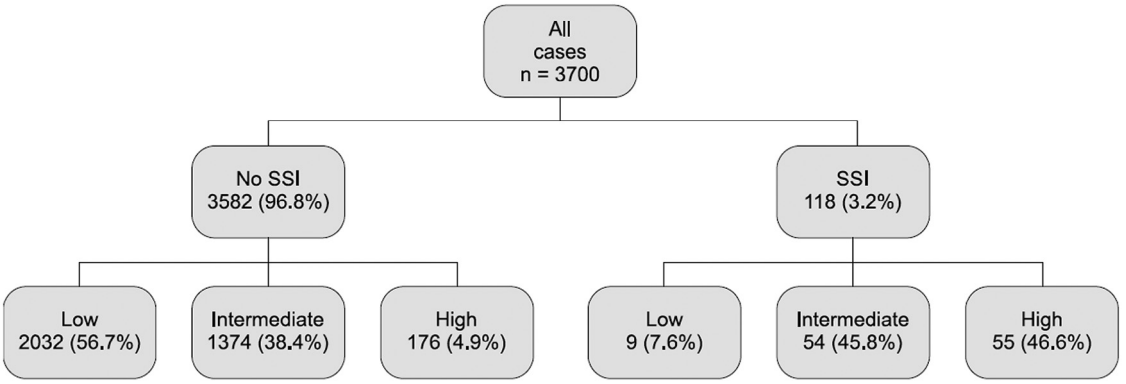

Fig 1. Surgical cases flow diagram. *SSI*, surgical site infection.

criteria was undertaken. In the sensitivity analysis, the window period for SSI detection was shifted by 1 or 2 days to evaluate if these exclusions would improve the performance of the tool.

All statistical analyses and power calculations were conducted using SAS version 9.4 (SAS Institute, Cary, NC) and STATA/IC version 13.1 (StataCorp, College Station, TX).

RESULTS

Primary analysis

There were 3,700 surgeries in unique patients evaluated by VASQIP for presence of SSI (1,372 surgeries from the Boston VA and 2,328 surgeries from the Denver VA) (Fig 1). There were 118 SSIs identified (3.2%). Most surgeries included in the study were performed on men (93%). The mean age of the cohort was 63 years. There was no difference between mean age, ratio of men to women, or percent of SSIs between VA sites.

Of the 153 charts randomly sampled for clinical variable validation, 100%, 96%, and 98% of radiology, antibiotics, and microbiology flags, respectively, were accurate. Discordance between electronic flags and blinded manual validation of variables was most often caused by transfer of records from non-VA facilities in which outside antibiotics or microbiology orders were not logged into the ordering VA system but recorded in the clinical chart.

Identification of electronic variables associated with the diagnosis and treatment of SSI

During the window period after a surgery, 1,298 (35.1%) surgeries had at least 1 new antibiotic order, 321 (8.7%) surgeries had wound, tissue, or fluid cultures ordered and logged, 741 (20%) had MRI or CT completed, and 118 (3.2%) surgeries had an ICD-9 or CPT code suggestive of infection (Table 1). In other words, there were >4-fold as many new antibiotics ordered as cultures, and >10-fold antibiotics ordered as ICD-CPT infection diagnosis codes entered into the electronic medical record. Multivariable logistic regression analysis of the 4 electronic variables demonstrated that each had independent clinical significance (Table 2).

Electronic SSI triaging tool characteristics

Of the 3,700 surgeries included in the primary analyses, 2,041 surgeries (55.2%) were categorized as low probability, 1,428 (38.6%) were categorized as intermediate probability, and 231 (6.2%) were categorized as high probability using the electronic SSI triaging tool. There were 55 of 118 (46.6%) surgeries with SSIs categorized as high probability and 2,032 of 3,582 (56.7%) surgeries without SSIs categorized as low probability. There were 54 of 118 (45.8%) surgeries with SSIs and 1,374 of 3,582 (38.4%) surgeries without SSIs categorized as intermediate probability (Fig 1). Nine of 2,041 (0.44%) surgeries categorized as low probability had an SSI based on VASQIP manual review.

Table 1
Percent utilization of clinical variables in the final cohort (N = 3,700)

	Final cohort (N = 3,700)	SSI cases (n = 118)
Antibiotics	1,298 (35.1)	100 (84.7)
Microbiology	321 (8.7)	63 (53.4)
Radiology	741 (20)	80 (67.8)
Infection code	118 (3.2)	18 (15.3)
Antibiotics and microbiology	250 (6.8)	57 (48.3)
Antibiotics and radiology	456 (12.3)	73 (61.9)
Radiology and infection code	44 (1.2)	10 (8.5)
Microbiology and radiology	151 (4.1)	48 (40.7)
Microbiology and infection code	50 (1.4)	14 (11.9)
Antibiotics and infection code	88 (2.4)	16 (13.6)
Antibiotics, microbiology, and infection code	44 (1.2)	12 (10.2)
Antibiotics, microbiology, and radiology	134 (3.6)	44 (37.3)
Infection code, microbiology, and radiology	23 (0.6)	8 (6.8)
All 4 variables	21 (0.6)	7 (5.9)

NOTE. Values are n (%).

Table 2
Multivariable regression results for the surgical site infection tool's 4 clinical variables

Clinical variable	Odds ratio	95% confidence limits	*P* value
Antibiotics	3.60	2.25-5.73	<.0001
Microbiology	5.52	3.80-8.03	<.0001
Radiology	5.13	3.50-7.51	<.0001
Infection code	2.09	1.20-3.64	.009

The SSI triaging tool had an AUC of 0.86 (bootstrapped 95% confidence interval, 0.82-0.89). The sensitivity, negative predictive value, and LR– of the test using a low-probability cut point (where a score >0 was defined as positive) were 92.4%, 99.6%, and 0.13, respectively. The specificity, positive predictive value, and LR+ of the test using a high-probability cut point (where a score >3 was defined as positive) were 95.1%, 23.8%, and 9.5, respectively (Table 3).

Using an intermediate-probability cut point to flag for SSI reduced the discriminatory abilities of the tool (Table 3). Therefore, surgeries that fell into the intermediate probability could not be reliably flagged as SSI or no SSI. The limited discriminatory ability of the practice pattern–based tool for the intermediate probability cases was driven primarily by antimicrobial orders in cases without SSI and lack of microbiology orders in cases with SSI. In surgeries without SSIs, antibiotics were ordered 76% of the time in the intermediate-probability group (1,050/1,374) compared with 0% of the time in

Table 3
Triaging tool operability characteristics by probability cut point for surgical site infection flag

Probability cut point (score)	Sensitivity (95% CI)	Specificity (95% CI)	PPV	NPV	LR+	LR–
Low probability (≥1)	92.4%	56.7%	6.57%	99.6%	2.13	0.13
	109/118	2,032/3,582	109/1,659	2,032/2,041		
	(87.6%-97.2%)	(55.1%-58,4%)	(5.4%-7.8%)	(99.3%-99.9%)		
Intermediate probability (≥2)	89.0%	65.4%	8.3%	99.4%	2.57	0.17
	105/118	2,344/3,582	105/1,343	2,344/2,357		
	(81.9%-94.0%)	(64.0%-67.0%)	(6.4%-9.2%)	(99.2%-99.8%)		
Intermediate probability (≥3)	76.3%	85.0%	15.2%	99.0%	5.09	0.28
	90/118	3,045/3,582	90/627	3,045/3,073		
	(68.6%-83.9%)	(83.8%-86.2%)	(11.6%-17.1%)	(98.8%-99.4%)		
High probability (≥4)	46.6%	95.1%	23.8%	98.2%	9.49	0.56
	55/118	3,406/3,582	55/231	3,406/3,469		
	(37.6%-55.6%)	(94.3%-95.8%)	(18.5%-29.8%)	(97.7%-98.6%)		

CI, confidence interval; *LR+*, positive likelihood ratio; *LR–*, negative likelihood ratio; *PPV*, positive predictive value; *NPV*, negative predictive value.

the low-probability group (0/2,032). In surgeries with SSIs, microbiology cultures were ordered approximately 22% of the time in the intermediate-probability group (12/54) compared with 93% of the time in the high-probability group (51/55).

The triaging tool performed differently when applied to individual facilities, with an AUC ranging from 0.81 (Denver VA) to 0.94 (Boston VA). This was driven primarily by the difference between sites in antibiotic ordering for patients without SSIs and microbiology ordering for patients with SSIs. In the Denver VA, antibiotics were ordered approximately 10% more frequently (37% compared with 27.5%) in surgeries without SSIs, but microbiology cultures were ordered approximately 42% less frequently in surgeries with SSIs (39% compared with 80.5%).

Creating a very high-probability cut point (where a score ≥5 was defined as positive) increased the specificity to 97.2%, but decreased the sensitivity to 15.3%. Creating time-from-surgery restrictions on antibiotics, microbiology, and radiology flags worsened the tool's AUC.

Manual review of false-positive cases at the Denver VA was completed; false-negative cases at both facilities were also evaluated. The most common reason for false-positive flags by the electronic algorithm was wound cellulitis that did not meet NSHN criteria for SSI (n = 5). Other reasons included sepsis of unknown etiology (n = 2) and wound dehiscence not meeting SSI criteria (n = 1) and cholangitis not meeting SSI criteria (n = 1). Nine false-negative SSI cases were identified. False-negative cases fell into 3 major categories: superficial SSI or wound dehiscence that did not require antimicrobial therapy and in which microbiology orders were not placed, SSI treated at other facilities, and ordering of antibiotics or microbiology that occurred outside of the NHSN window period, but in which symptoms started within the defined time frame. In 1 case, a limb amputation followed the initial surgery for clinical cure of infection and additional diagnostic and treatment interventions associated with SSI were not clinically indicated.

DISCUSSION

The goals of this study were to validate a simple electronic tool based on clinical practice patterns for flagging potential SSI and to identify operational challenges to using this tool to enhance current surveillance activities. In this multicenter study, the operating characteristics of the tool were similar to the results from the smaller case-control investigation,[19] which reported an AUC of 0.87. Overall, we found that absence of specific diagnostic and therapeutic variables was effective for ruling out SSI, and conversely, presence of these variables, with or without a relevant diagnosis code, was useful for flagging cases with a high probability of having an SSI.

In cases where only 1 or 2 clinical variables were present, the tool was not able to reliably distinguish SSI cases from surgeries without SSI. False positives were because of high rates of antimicrobial use, and false negatives were because of failure to order microbiology cultures, cultures ordered outside of the window period, or cultures ordered at an outside facility.

The practice pattern–based electronic tool was useful for identifying low-probability surgeries, although imperfect. Our review of these false-negative cases suggests that the SSI flagging tool is less useful for identifying less severe SSI that do not require treatment beyond wound care or simple drainage and SSI that are diagnosed and treated in outside facilities.

With these limitations in mind, this SSI triaging tool could potentially be leveraged to target limited surveillance resources toward the highest yield cases because the tool was useful for flagging high-probability cases. Assuming an SSI prevalence of 3.5%,[23] the posttest probability of SSI (prevalence × positive likelihood ratio) in the high-probability category increased approximately 10-fold, from 3.5% to 33.3%. Further, manual review of false-positive cases found that although many cases did not meet NHSN SSI criteria, all had significant postoperative complications, including wound cellulitis and dehiscence, other types of health care–associated infections, and patient safety events, such as falls. Therefore, although the electronic tool could not be used without additional manual review to measure rates of SSI, it is helpful for identifying cases with adverse events that would benefit from additional review and provides useful quality assurance data.

Operationally, surgeries categorized as low probability by this electronic tool (55.5% of surgeries in this cohort) could be excluded from additional SSI review. Surgeries categorized as high probability could be manually reviewed to measure SSI and, if present, explored further for additional clinical and institutional factors that may have contributed to SSI development. Therefore, potential benefits of the electronic tool include increased SSI case finding in the setting of tangible resource savings. Because VASQIP currently reviews only a selection of surgeries, implementation of this SSI triaging tool could change which surgeries are selected for SSI review and data collection and augment current VASQIP breadth by including fewer major surgeries and including procedures that are currently rarely reviewed, or not reviewed. This is an important consideration, given the time and personnel resources required to collect SSI data using manual chart review.[24]

Another benefit of this electronic data extraction tool is that it is based on readily accessible electronic variables that are collected by all electronic medical record systems (antimicrobial orders, microbiology results, imaging orders, and ICD-9 or CPT codes). As electronic medical record systems become the mandatory standard of care, this tool can be considered for non-VA health care systems to improve the efficiency and scope of SSI detection.

Our study also elucidates why prior investigations evaluating the utility of clinical variables, such as antibiotic orders and microbiology

orders, have limited ability to distinguish surgeries with SSI from surgeries without SSI. Although SSI is a rare outcome, antibiotic utilization during the postoperative period is common—almost 40% of the patients in our cohort received antimicrobials during the 30-day postoperative window. Therefore, although antimicrobials are a cornerstone of SSI treatment, antimicrobial prescriptions on their own are not sufficient to distinguish surgeries with SSI from surgeries without SSI. A reason the tool was more predictive in surgeries with high-probability scores is that combinations of the clinical variables, such as antimicrobial use plus relevant microbiology orders, occurred in a much smaller proportion of surgeries, and therefore had higher discriminatory abilities (Table 1).

The SSI triaging tool had varying performance across different medical centers; sensitivity analyses by facility calculated AUCs ranging from 0.81-0.94. These differences were driven by differences in clinical practice patterns between the 2 facilities, particularly in antimicrobial prescribing and collection of microbiologic cultures.

Elements of this SSI triaging tool could be refined to improve case ascertainment. We were not able to measure if the tool performance varied based on type of surgery or surgical subspecialty. We also did not link ICD-9 or CPT code to specific surgical type. However, although further refining these variables might somewhat improve algorithm performance, these alterations would cause additional programming complexity, potentially limiting its practicality and usefulness in facilities with limited information technology resources.

There were several limitations of this study. First, this was a VA study; therefore, applicability to other health care systems may be hampered by availability of electronic health records and loss to follow-up. However, the electronic tool is based on simple, readily accessible clinical variables collected as part of all electronic medical records, which increases its generalizability. We found significant differences in the tool's operating characteristics between the 2 health care systems involved in the study. Facility-specific clinical practice patterns of antimicrobial use and microbiology ordering vary considerably; therefore, the tool may be more effective in some hospital settings than in others. These practice pattern variations limit the tool's usefulness as a method for comparing interfacility rates of SSI.

CONCLUSIONS

In this validation study, we found that clinical and administrative variables associated with SSI diagnosis and treatment can be extracted reliably and with high accuracy to flag high-probability cases for further review, and low-probability cases for exclusion. Time and resource limitations have prevented complete and widespread surveillance for SSI; this electronic surveillance tool provides a mechanism to expand case ascertainment. Differences in practice patterns between different facilities limit the tool's usefulness for interfacility comparison of SSI rates.

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