original article

Improving Risk-Adjusted Measures of Surgical Site Infection for the National Healthcare Safety Network

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(See the commentary by Moehring et al, on pages 987–989.)

background. The National Healthcare Safety Network (NHSN) has provided simple risk adjustment of surgical site infection (SSI) rates to participating hospitals to facilitate quality improvement activities; improved risk models were developed and evaluated.

methods. Data reported to the NHSN for all operative procedures performed from January 1, 2006, through December 31, 2008, were analyzed. Only SSIs related to the primary incision site were included. A common set of patient- and hospital-specific variables were evaluated as potential SSI risk factors by univariate analysis. Some ific variables were available for inclusion. Stepwise logistic regression was used to develop the specific risk models by procedure category. Bootstrap resampling was used to validate the models, and the c-index was used to compare the predictive power of new procedure-specific risk models with that of the models with the NHSN risk index as the only variable (NHSN risk index model).

results. From January 1, 2006, through December 31, 2008, 847 hospitals in 43 states reported a total of 849,659 procedures and 16,147 primary incisional SSIs (risk, 1.90%) among 39 operative procedure categories. Overall, the median c-index of the new procedure-specific risk was greater (0.67 [range, 0.59–0.85]) than the median c-index of the NHSN risk index models (0.60 [range, 0.51–0.77]); for 33 of 39 procedures, the new procedure-specific models yielded a higher c-index than did the NHSN risk index models.

conclusions. A set of new risk models developed using existing data elements collected through the NHSN improves predictive performance, compared with the traditional NHSN risk index stratification.

Infect Control Hosp Epidemiol 2011;32(10):970-986

Surgical site infection (SSI) is one of the most common healthcare-associated infections (HAIs) and is a major cause of increased length of hospital stay and mortality.[1-3] SSI surveillance is integral to hospital infection control and quality improvement programs, with feedback of SSI rates being an important component of SSI reduction strategies.[4,5] However, hospitals with surgeons who treat patients with multiple nonmodifiable risk factors would expect higher SSI rates. Therefore, risk adjustment that accounts for differences in patient case mix is critical to allow for more meaningful comparisons between surgeons or between hospitals, especially when using SSI summary data as a quality improvement performance metric.[6,7]

Controversies exist regarding several aspects of such risk adjustment. One is the inclusion of intraoperative or postoperative variables in any risk adjustment strategy, because these variables may reflect surgical technique more than patient case mix, and adjustment for surgical technique may inappropriately allow for adjusting rates down among surgeons with poor technique. Another is the inclusion of SSIs detected through SSI surveillance after discharge from the hospital, which is a setting with great variation in case-finding intensity. In addition, including more procedure-specific variables to generate improved procedure-specific models adds to the data collection burden.

These controversies are relevant to the National Healthcare Safety Network (NHSN), a secure Web-based system used by the Centers for Disease Control and Prevention (CDC) and its healthcare and public health partners for surveillance of HAIs, other adverse events in health care, and adherence to prevention practices in hospitals and other reporting facilities. Traditionally, SSI rates calculated by the CDC and other NHSN data users from data reported to the NHSN have been risk stratified using a risk index of 3 equally weighted factors: the American Society of Anesthesiologists (ASA) score, wound classification, and procedure duration.[8,9] However, for some procedures, these variables are not associated with SSI risk, are not equally important in the risk they confer, and

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Received May 10, 2011; accepted July 12, 2011; electronically published September 1, 2011.

 0899-823X/2011/3210-0002$15.00. DOI: 10.1086/662016

are candidates for replacement by other, more important risk factor variables that should be taken into account. Second, beginning in 2012, hospitals participating in the Center for Medicare and Medicaid Services (CMS) Inpatient Prospective Payment System (IPPS) will be required to report SSI data through NHSN, and these data will be included in the Inpatient Quality Reporting data that are publicly reported by CMS at the Hospital Compare Web site.[10] Publicly reported SSI data should account for variability in patient case mix, adjust for all possible risk factors, and be based on consistent case detection systems.[7,11] Procedure-specific, multivariate risk models that incorporate additional weighted patient factors could calculate more credible, standardized, and reliable risk-adjusted SSI metrics than stratified SSI rates that are limited to the traditional NHSN risk index.[12-15]

The objectives of our evaluation were to develop procedure-specific risk models for each of the procedure categories reported to the NHSN, incorporating existing NHSN data elements, and to compare their predictive performance with procedure category–specific models composed of only the variable of the traditional NHSN risk index. A secondary objective was to utilize similar methodology to develop models for proposed public reporting metrics (ie, using only deep incisional and organ/space SSIs detected during hospitalization or rehospitalization at the same hospital).

The resulting procedure-specific risk models can be used as a reference of how risk adjustment is currently performed in the NHSN application, and this article will essentially replace the historical annual report containing risk stratification tables.[16]

METHODS

Study Population, Endpoints, and Statistical Approach

As of September 2010, more than 1,900 hospitals reported SSI data to the NHSN. Reporting has been predominately voluntary and confidential; however, during 2008–2009, several states enacted laws mandating SSI reporting to the NHSN for specific procedures at hospitals in their jurisdiction.[17] The methodology of SSI surveillance has been described elsewhere.[18] In brief, infection preventionists (IPs) choose a procedure category to follow for an entire month and report data on all patients undergoing all procedures within the procedure category for each month of surveillance performed. IPs also are required to identify and report all SSIs detected during the initial hospitalization, through surveillance after hospital discharge, or upon rehospitalization at the same hospital at which the initial procedure was performed. SSIs are classified using standard definitions as superficial incisional, deep incisional (involving the fascia or muscle), or organ/space. SSIs reported to the NHSN are limited to those detected within 30 days after the initial procedure (superficial incisional) or up to 1 year for deep incisional and organ/space if the procedure included an implant (eg, sternal wires or prosthesis).[18]

SSI data were analyzed for all reported procedures performed from January 1, 2006, through December 31, 2008, including data for all 40 NHSN procedure categories. For this analysis, the NHSN procedure code CBGB (with both sternal and harvest site incisions) and CBGC (with sternal site incision only) were grouped into a single procedure category, CABG, for a total of 39 procedures. In addition, only primary incisional SSIs were analyzed, because no patient- or procedure-specific variables were collected for secondary incision sites; therefore, any SSIs related to secondary incision sites for the NHSN codes CBGB, FUSN, and RFUSN were excluded. All SSIs (superficial incisional, deep incisional, and organ/space) detected through all methods of surveillance (hospitalization, rehospitalization, and surveillance after hospital discharge) for both inpatient and outpatient surgical procedures were included.

Procedures containing outlier values were excluded according to rules described in Appendix A. As a result, a total of 6,432 (0.75%) procedures were excluded from the analysis; the final number of procedures eligible for further analysis was 849,659.

First, patient and hospital characteristic data were evaluated. Second, NHSN risk index models were created for all 39 NHSN procedures. Third, new procedure-specific predictive risk models were created for the same set of procedures through an interactive process that included univariate analysis of all available patient- and hospital-level variables, multivariate modeling, and model validation. SAS, version 9.2 (SAS Institute), was used for data analysis. After completion of the primary analysis, endpoints were altered to include only complex (deep incisional and organ/space) SSIs detected at hospitalization and rehospitalization to develop models appropriate for public reporting, consistent with the 2008 National Quality Forum (NQF) recommendation to exclude superficial SSIs and those detected through surveillance after discharge from the hospital.[19]

NHSN Risk Index Model

The NHSN risk index comprises 3 dichotomous variables: ASA score (3, 4, or 5), wound classification (contaminated or dirty), and procedure duration in minutes (>75th percentile). Each risk factor represents 1 point; thus, the NHSN SSI risk index ranges from 0 (lowest risk) to 3 (greatest risk).[8] Logistic regression of SSIs against the NHSN risk index was used to build the NHSN risk index models by procedure category.

New Procedure-Specific Risk Model

The new model incorporates the 3 NHSN risk index variables and additional data elements currently collected in the NHSN. These are variables of convenience in that they are routinely reported to the NHSN as part of the existing SSI surveillance methodology. Variables were dichotomous (general anesthesia, emergency procedure, gender, trauma association, and table 1. List of Variables Collected and Available for Entry in the Models for All and Selected Procedures

Procedure code	Variable
All	Gender, age, emergency, trauma, general anesthesia, ASA score, wound classification, duration, medical school affiliation, no. of hospital beds, endoscope, outpatient
HPRO	Type of surgery (total primary, partial primary, partial revision, total revision)
KPRO	Type of surgery (revision, primary)
CSEC	Labor, blood loss, body mass index
FUSN/RFUSN	Approach, spinal level, diabetes

note. Procedure codes are National Healthcare Safety Network procedure codes.[18] ASA, American Society of Anesthesiologists.

medical school affiliation), ordinal (ASA score), categorical (wound classification and number of hospital beds), or continuous (age and procedure duration; Table 1).

Procedure-specific supplemental variables include primary versus revision arthroplasty for HPRO and KPRO; total or partial hip arthroplasty for HPRO; body mass index (BMI), history of labor, and estimated blood loss for CSEC; and diagnosis of diabetes, spinal level, and surgical approach for FUSN and RFUSN (Table 1).

Among the variables common to all 849,659 procedures, 7 variables had missing values in 1,304 (0.15%) of the procedures. Variables with missing values were medical school affiliation (931 [0.11%]), trauma (219 [0.03%]), general anesthesia (89 [0.01%]), ASA score (23 [<0.01%]), endoscope (20 [<0.01%]), wound classification (12 [<0.01%]), and emergency (10 [<0.01%]). Among procedure-specific variables, missing values included the following: for CSEC, BMI (242 [0.78%]) and history of labor (5 [0.02%]); for HPRO, type of surgery (16 [0.01%]); for KPRO, type of surgery (15 [0.01%]); and for spine procedures, diabetes (157 [0.37%]), spinal level (3 [0.01%]), and surgical approach (3 [0.01%]; Table 2).

Univariate Analysis

The χ^2 test was used to test for each individual variable's association with SSI. Ordinal variables were collapsed into a single group if the χ^2 test showed no significant difference between them. For categorical variables, multiple categorizations were used, and only the category most significantly associated with SSI risk was presented as the result of univariate analysis. Continuous variables were divided into quartiles and were compared by means of the χ^2 test; continuous variables were coded as binary variables if a significant cutoff point was found. Otherwise, the continuous variable "duration" was coded as "duration10" for every 10-minute increase in duration, and "age" was coded as "age10" for every 10-year increase in age. Variables from the univariate

table 2. Patient and Procedure Characteristics for Selected Procedures, National Healthcare Safety Network, 2006–2008

Procedure code, characteristic	No. (%) of procedures
HPRO, type of surgery	
Total primary	99,046 (75.09)
Partial primary	19,658 (14.90)
Total revision	10,518 (7.97)
Partial revision	2,661 (2.02)
Missing	16 (0.01)
KPRO, type of surgery	
Revision	11,673 (6.78)
Primary	160,382 (92.75)
Missing	15 (0.05)
CSEC, labor	
Y	12,519 (40.53)
N	18,365 (59.45)
Missing	5 (0.02)
CSEC, blood loss	
≤400 mL	2,310 (7.48)
401–800 mL	23,854 (77.22)
>800 mL	4,725 (15.30)
CSEC, BMI	
≤20	323 (1.05)
21–30	11,736 (37.99)
>30	18,588 (60.18)
Missing	242 (0.78)
FUSN/RFUSN, approach	
Anterior	16,955 (40.08)
Anterior and posterior	1,229 (2.90)
Lateral transverse	1,004 (2.37)
Posterior	16,493 (38.98)
Not specified[a]	6,623 (15.65)
Missing	3 (0.01)
FUSN/RFUSN, spinal level	
Atlas-axis	284 (0.67)
Atlas-axis/cervical	66 (0.16)
Cervical	16,225 (38.35)
Cervical/dorsal/dorsolumbar	120 (0.28)
Dorsal/dorsolumbar	1,909 (4.51)
Lumbar/lumbosacral	17,923 (42.36)
Not specified[a]	5,777 (13.65)
Missing	3 (0.01)
FUSN/RFUSN, diabetes	
Y	4,517 (10.68)
N	37,633 (88.95)
Missing	157 (0.37)

note. Procedure codes are National Healthcare Safety Network procedure codes.[18] BMI, body mass index, defined as the weight in kilograms divided by the square of height in meters.

[a] Not specified was a possible choice on the case report form and was imputed on the basis of known distribution values of the variable.

TABLE 3. List of Variables That Are Significant on Univariate Analysis for 39 Procedures, National Healthcare Safety Network, 2006–2008

Procedure code	Description	List of variables
AAA	Abdominal aortic aneurysm	Emergency, wound class, ASA score, duration
AMP	Limb amputation	Bed size, duration
APPY	Appendectomy	Emergency, endoscope, gender, ASA score, wound class
AVSD	Arteriovenous shunt for dialysis	Age, duration
BILI	Bile duct, liver or pancreatic surgery	Emergency, endoscope, ASA score, wound class, bed size, duration
BRST	Breast surgery	ASA score, bed size, duration
CABG	Coronary artery bypass graft	Anesthesia, gender, medical school affiliation, ASA score, bed size, age, duration
CARD	Cardiac surgery	ASA score, wound class, age, duration
CEA	Carotid endarterectomy	
CHOL	Cholecystectomy	Emergency, endoscope, ASA score, wound class, age, duration
COLO	Colon surgery	Anesthesia, endoscope, gender, ASA score, wound class, bed size, age, duration
CRAN	Craniotomy	Trauma, bed size, age, duration
CSEC	Cesarean delivery	Body mass index, age, anesthesia, ASA, duration, labor, bed size, wound class, emergency
FUSN	Spinal fusion	Anesthesia, gender, medical school affiliation, trauma, wound class, diabetes, approach, spinal level, duration, ASA score
FX	Open reduction of long bone fracture	ASA score, age, duration, outpatient
GAST	Gastric surgery	Emergency, endoscope, gender, ASA score, wound class, age, duration
HER	Herniorrhaphy	Anesthesia, emergency, endoscope, gender, medical school affiliation, trauma, ASA score, wound class, duration, outpatient
HPRO	Hip arthroplasty	Anesthesia, emergency, gender, trauma, ASA score, wound class, bed size, age, duration, total/primary/partial/revision
HTP	Heart transplant	
HYST	Abdominal hysterectomy	Anesthesia, endoscope, ASA score, wound class, duration
KPRO	Knee arthroplasty	Anesthesia, gender, trauma, ASA score, wound class, age, duration, primary/revision
KTP	Kidney transplant	Bed size, age, duration
LAM	Laminectomy	Anesthesia, endoscope, gender, ASA score, age, duration
LTP	Liver transplant	Anesthesia, emergency, trauma, age, duration
NECK	Neck surgery	Wound class, duration
NEPH	Kidney surgery	Duration
OVRY	Ovarian surgery	ASA score, wound class
PACE	Pacemaker surgery	
PRST	Prostate surgery	ASA score
PVBY	Peripheral vascular bypass surgery	Gender, ASA score, age, duration
REC	Rectal surgery	Endoscope, gender, trauma, wound class, bed size, duration
RFUSN	Refusion of spine	Trauma, duration, diabetes, spinal level, approach
SB	Small-bowel surgery	Bed size, duration
SPLE	Spleen surgery	
THOR	Thoracic surgery	Duration
THYR	Thyroid and/or parathyroid surgery	Age
VHYS	Vaginal hysterectomy	Medical school affiliation, bed size, age, duration
VSHN	Ventricular shunt	Emergency, wound class, bed size, age
XLAP	Exploratory abdominal surgery	Bed size, duration

NOTE. Procedure codes are National Healthcare Safety Network procedure codes.[18] Statistical significance was defined as $P < .05$. ASA, American Society of Anesthesiologists.

analysis with $P < .25$ were considered potential independent variables and entered into the logistic regression model as candidate variables for inclusion.

Multivariate Analysis

Stepwise logistic regression was used to develop the model. For all regression analyses, the referent category was the one that conferred the least risk of SSI. Variables were eligible for inclusion if the likelihood ratio test (LRT) $P = .25$ and removed at LRT $P = .05$ significance. For variables with multiple categorical, ordinal, or dichotomous cutoff values, the one with the smallest LRT P value was included.

Final Model Variable Selection Procedure

To confirm the appropriateness of the final models, we performed the same stepwise model selection with all variables included regardless of their significance levels in univariate analysis. The interaction terms were tested and kept at LRT $P = .05$ significance.

Training and Validation Samples

The models were validated using a bootstrap sample following the steps described in Appendix B.

Model Comparison

The predictive performances of the new and existing NHSN risk index models were assessed by constructing receiver-operating characteristic (ROC) curves and calculating the c-index for the separate logistic regression models. An ROC curve is constructed by plotting the sensitivity (y-axis) versus 1 minus specificity (x-axis) over the range of scores for a given index. The area under the ROC curve (AUC) is the c-index. The c-index is a measure of predictive performance and represents the proportion of instances in which a patient who acquires an SSI is assigned a higher probability of SSI than a patient who does not acquire an SSI. Values for the c-index range from 0.5 (null) to 1.0 (perfect predictive ability).[20] The difference in c-index was tested using the method described by Hanley and McNeil.[21]

Prediction Models for Possible Public Reporting

To be consistent with proposed measures submitted to the NQF regarding public reporting of SSI, we also evaluated the performance characteristics of procedure-specific models for the subset of SSIs classified as deep or organ/space and detected only during the hospitalization during which the surgical procedure was performed or upon rehospitalization at the same facility. To perform this task, we repeated all of the methodologies described for all incisional SSIs for the subset of SSIs classified as complex (deep incisional or organ/space) detected during hospitalization or after rehospitalization at the same hospital. These models are referred to as predictive of complex SSI for public reporting.

RESULTS

Demographic Characteristics

From January 1, 2006, through December 31, 2008, 847 hospitals reported to the NHSN a total of 849,659 procedures and 16,147 SSIs at the primary incision site. The overall risk of SSI was 1.90 per 100 procedures, ranging from 0.26 (THYR) to 13.83 (LTP). The variability in patient and hospital characteristics for some of the main procedure-specific variables is summarized in Table 2.

Univariate Analysis

A list of the significant variables for each of the 39 procedures is summarized in Table 3. As an example, univariate analysis results are shown for hip prostheses (HPRO), for which there were 10 potential independent variables identified for inclusion in the multivariate modeling (Table 4).

Procedure-Specific Risk Prediction Model

Table 5 shows the results for models of all SSIs identified at primary incision sites for the 39 procedure categories. Multivariate modeling strategies defined new procedure-specific models for each of the 39 procedure categories. The 3 most common variables included were procedure duration, ASA score, and age (30, 21, and 20 models, respectively). Other common variables were the number of hospital beds (16 models), wound class (8), general anesthesia (6), endoscope (5), medical school affiliation (5), emergency (4), and trauma (4). All procedure-specific supplemental variables, except estimated blood loss, were selected for inclusion into the final model. No variables were selected at the $P \leq .05$ level for 4 procedures (ie, intercept-only models): carotid endarterectomy (CEA), heart transplant (HTP), pacemaker placement (PACE), and splenectomy (SPLE). The observed number of SSIs for these 4 procedures during the study period was small, ranging from 6 to 15 (Table 5).

Model Performance

For the NHSN risk index models, the c-index ranged from 0.51 (VSHN) to 0.77 (NECK), compared with 0.59 (COLO) to 0.85 (THYR) for the new procedure-specific risk models (resultant increase in the c-index from 0 to 0.2). For 33 procedures, the new models yielded a higher c-index than did the NHSN index models, and for 28 of these, the improvement was statistically significant ($[\Pr > t] < .05$; Table 5).

The subset analysis of only complex (deep incisional and organ/space) SSIs that occurred during hospitalization or rehospitalization at the same hospital resulted in prediction models that, overall, had a c-index similar to or higher than that for all SSIs, but 9 procedures had intercept-only models, which was more than what was observed in all SSIs models (Table 6).

DISCUSSION

Risk models based on the NHSN risk index, although simple in design, showed poor predictive performance for many procedures. New procedure-specific predictive models developed with currently collected NHSN data elements significantly improved the predictive performance for most procedures, including all of the most common procedures reported to the NHSN.

This study represents a large and robust data set of almost 850,000 surgical procedures among 39 procedure categories

TABLE 4. Predictors of Incisional Surgical Site Infection (SSI) by Univariate Analysis among Hip Arthroplasty (HPRO) Procedures Reported to the National Healthcare Safety Network, 2006–2008

Variable, class	No. of procedures	No. of SSIs	Risk	*P*
Age10	131,899	1,855	1.41	.0057
Anesthesia				<.0001
N	38,249	456	1.19	
Y	93,646	1,399	1.49	
ASA[a]				<.0001
1/2	66,945	565	0.84	
3	56,884	1,086	1.91	
4/5	8,069	204	2.53	
Duration10	131,899	1,855	1.41	<.0001
Emergency				.0004
N	123,829	1,704	1.38	
Y	8,070	151	1.87	
Endoscope				.6686
N	130,999	1,841	1.41	
Y	900	14	1.56	
Gender				.6022
F	76,634	1,089	1.42	
M	55,265	766	1.39	
Type of surgery[b]				<.0001
Total primary	99,046	1,134	1.14	
Partial primary	19,658	388	1.97	
Total revision	10,518	251	2.39	
Partial revision	2,661	82	3.08	
Medical school affiliation				.1784
N	50,708	685	1.35	
Y	81,138	1,170	1.44	
Bed size				<.0001
≤500	100,654	1,342	1.33	
>500	31,245	513	1.64	
Wound class				<.0001
C	128,897	1,784	1.38	
CC/CO/D	3,001	71	2.37	
Trauma				<.0001
N	121,110	1,608	1.33	
Y	10,789	247	2.29	

NOTE. Age10, 10-year increase in age; ASA, American Society of Anesthesiologists; C, clean; CC, clean contaminated; CO, contaminated; D, dirty; Duration10, 10-minute increase in duration.

[a] ASA scores of 1/2, 3, and 4/5 were coded as 0, 1, and 2, respectively.

[b] Total primary was coded as 0, partial primary was coded as 1, and total revision and partial revision were coded as 2.

reported since 2006 by 847 hospitals in 43 states. Most of the potential predictive factors included have been previously identified as risk factors in other studies.[6,22-32] The c-indices also approximate what has been reported in other studies,[6,25,32] which suggests some reproducibility in these findings.

We found that the procedure duration was the most common of the 3 traditional NHSN risk index parameters selected by 30 of the 39 models; ASA score was the next most common (21 models). Age, which is not a component of the traditional NHSN risk index, was the third most commonly selected factor (included in 18 models). Because patient-specific variables available for analysis were limited, we also included hospital-level variables. These likely serve as proxy indicators for patient case mix or possibly for surgical programs. We incorporated hospital-specific information, including the number of hospital beds (16 models) and medical school affiliation (5). Including these latter variables as well as procedure duration could introduce some risk adjustment for surgical performance (ie, surgical residents performing at teaching facilities) and/or for patient case mix (higher risk patients cared for at teaching facilities). Until further patient- (eg, BMI and diabetes) and procedure-specific data are avail-

TABLE 5. Models to Predict All Surgical Site Infections (SSIs) at Primary Incision Site for 39 Procedures, National Healthcare Safety Network (NHSN), 2006–2008

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index PSM	c-index RIM	c-index Pr>|*t*|
AAA	1,950	63					.66	.64	.1749
			Intercept	−4.20		<.0001			
			Duration10	0.04	1.04 (1.02–1.06)	<.0001			
AMP	1,413	31					.74	.62	.0007
			Intercept	−6.74		<.0001			
			Duration, >82 vs ≤82	1.09	2.97 (1.43–6.18)	.0036			
			Bed size, >200 vs ≤200	3.04	20.96 (2.83–154.99)	.0029			
APPY	6,122	85					.70	.60	.0037
			Intercept	−5.54		<.0001			
			Emergency, Y vs N	0.61	1.84 (1.14–2.99)	.0135			
			Gender, M vs F	0.53	1.70 (1.07–2.68)	.024			
			Bed size, >500 vs ≤500	0.77	2.15 (1.38–3.34)	.0007			
			Wound class, CO vs C/CC	0.63	1.89 (1.07–3.33)	.0294			
			Wound class, D vs C/CC	1.26	3.53 (2.04–6.09)	<.0001			
AVSD	864	11					.77	.61	.1521
			Intercept	−1.73		.0618			
			Age10	−0.46	0.63 (0.45–0.89)	.0082			
BILI	894	89					.75	.59	<.0001
			Intercept	−4.15		<.0001			
			ASA, ≤3 vs >3	1.02	2.76 (1.29–5.89)	.0087			
			Duration10	0.03	1.03 (1.02–1.05)	<.0001			
			Bed size, 201–500 vs ≤200/>500	0.93	2.54 (1.51–4.29)	.0005			
BRST	4,768	75					.76	.71	.0147
			Intercept	−6.22		<.0001			
			ASA, >2 vs ≤2	0.92	2.50 (1.57–4.00)	.0001			
			Duration10	0.06	1.06 (1.05–1.08)	<.0001			
			Bed size, ≤200/>500 vs 201–500	0.93	2.54 (1.29–4.98)	.0068			
CABG	133,488	2,899					.62	.54	<.0001
			Intercept	−5.10		<.0001			
			Age10	−0.02		.4978			
			Age10 : gender (interaction)	−0.24		<.0001			
			ASA (1/2, 3, 4/5)	0.28	1.33 (1.22–1.44)	<.0001			
			Duration10	0.02	1.02 (1.02–1.03)	<.0001			
			Gender, F vs M	2.16		<.0001			
			Bed size, ≤200/>500 vs 201–500	0.15	1.16 (1.08–1.26)	.0001			
CARD	29,758	381					.60	.55	.0011
			Intercept	−4.57		<.0001			
			Age10	−0.11	0.90 (0.86–0.93)	<.0001			
			ASA, >3 vs ≤3	0.49	1.63 (1.28–2.07)	<.0001			
			Duration10	0.02	1.02 (1.01–1.03)	<.0001			
CEA	4,548	15					.50	.52	.5626
			Intercept	−5.71		<.0001			
CHOL	24,810	138					.75	.71	.0001
			Intercept	−7.16		<.0001			
			Age, >52 vs ≤52	0.44	1.55 (1.05–2.29)	.0272			
			ASA (1, 2, 3/4/5)	0.60	1.82 (1.30–2.56)	.0005			
			Duration10	0.08	1.08 (1.06–1.11)	<.0001			
			Endoscope, N vs Y	0.43	1.54 (1.07–2.20)	.0191			
			Wound class, CO/D vs C/CC	0.68	1.97 (1.18–3.27)	.0093			
COLO	62,777	3,647					.59	.56	<.0001
			Intercept	−3.89		<.0001			
			Age10	−0.02	0.98 (0.96–1.00)	.0389			

TABLE 5. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index PSM	c-index RIM	c-index Pr>|*t*|
			Anesthesia, Y vs N	0.38	1.47 (1.02–2.12)	.0405			
			ASA, >2 vs ≤2	0.30	1.35 (1.26–1.46)	<.0001			
			Duration10	0.03	1.03 (1.02–1.03)	<.0001			
			Endoscope, N vs Y	0.13	1.14 (1.04–1.25)	.0063			
			Medical school affiliation, N vs Y	0.14	1.15 (1.06–1.25)	.0008			
			Bed size, >500 vs ≤500	0.26	1.30 (1.19–1.41)	<.0001			
			Wound class, CO/D vs C/CC	0.09	1.10 (1.01–1.19)	.0369			
CRAN	9,918	262					.65	.56	<.0001
			Intercept	−4.05		<.0001			
			Age10	−0.14	0.87 (0.82–0.92)	<.0001			
			ASA, >2 vs ≤2	0.32	1.38 (1.04–1.82)	.0243			
			Duration10	0.03	1.03 (1.02–1.04)	<.0001			
			Bed size, >500 vs ≤500	0.45	1.57 (1.18–2.09)	.0022			
			Trauma, Y vs N	0.54	1.72 (1.12–2.65)	.0141			
CSEC	30,645	574					.66	.58	<.0001
			Intercept	−6.56		<.0001			
			BMI	0.04	1.04 (1.03–1.05)	<.0001			
			Age, ≤26 vs >26	0.27	1.31 (1.11–1.55)	.0017			
			Anesthesia, Y vs N	0.42	1.52 (1.15–2.00)	.0032			
			ASA (1, 2, 3/4/5)	0.28	1.32 (1.10–1.59)	.0026			
			Duration10	0.13	1.14 (1.09–1.18)	<.0001			
			Emergency, Y vs N	0.21	1.23 (1.03–1.47)	.0214			
			Labor, Y vs N	0.41	1.51 (1.27–1.80)	<.0001			
			Wound class, CO/D vs C/CC	0.74	2.09 (1.39–3.15)	.0004			
FUSN	41,160	618					.75	.67	<.0001
			Intercept	−6.40		<.0001			
			Approach, B/L/P vs A	0.93	2.52 (1.96–3.25)	<.0001			
			ASA (1/2, 3, 4/5)	0.61	1.83 (1.60–2.10)	<.0001			
			Diabetes, Y vs N	0.42	1.52 (1.23–1.87)	.0001			
			Duration10	0.03	1.03 (1.02–1.03)	<.0001			
			Medical school affiliation, Y vs N	0.32	1.38 (1.14–1.68)	.0011			
			Spinal level, CD or DL vs AX, AC, or CV	0.67	1.96 (1.41–2.72)	<.0001			
			Spinal level, LL vs AX, AC, or CV	0.52	1.68 (1.32–2.14)	<.0001			
			Wound class, CO/D vs C/CC	0.84	2.31 (1.06–5.03)	.035			
			Trauma, Y vs N	0.60	1.83 (1.23–2.71)	.0026			
FX	11,361	187					.65	.60	.0003
			Intercept	−6.91		<.0001			
			Age, >25 vs ≤25	0.72	2.05 (1.29–3.28)	.0026			
			ASA (1, 2, 3/4/5)	0.29	1.34 (1.07–1.68)	.0119			
			Duration, >138 vs ≤138	0.77	2.16 (1.58–2.95)	<.0001			
			Bed size, 201–500 vs ≤200/>500	0.37	1.45 (1.07–1.95)	.0153			
			Outpatient, N vs Y	1.51	4.52 (1.11–18.36)	.0349			
GAST	8,223	183					.68	.62	<.0001
			Intercept	−5.16		<.0001			
			ASA, >2 vs ≤2	0.47	1.60 (1.06–2.40)	.0245			
			Duration10	0.06	1.07 (1.05–1.08)	<.0001			
			Emergency, Y vs N	0.64	1.90 (1.19–3.04)	.0074			
HER	18,451	227					.78	.71	<.0001
			Intercept	−7.25		<.0001			
			Age, ≤71 vs >71	0.74	2.09 (1.42–3.07)	.0002			
			ASA (1, 2, 3/4/5)	0.76	2.15 (1.68–2.74)	<.0001			
			Duration10	0.05	1.06 (1.04–1.07)	<.0001			

TABLE 5. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index PSM	c-index RIM	c-index Pr>|*t*|
			Gender, F vs M	0.83	2.30 (1.73–3.04)	<.0001			
			Outpatient, N vs Y	0.59	1.80 (1.28–2.53)	.0008			
HPRO	131,879	1,855					.66	.61	<.0001
			Intercept	−5.00		<.0001			
			Age10	−0.07	0.94 (0.90–0.97)	.0002			
			Anesthesia, Y vs N	0.11	1.12 (1.01–1.25)	.0383			
			ASA, 3 vs 1/2	0.80	2.23 (2.01–2.49)	<.0001			
			ASA, 4/5 vs 1/2	1.07	2.91 (2.45–3.46)	<.0001			
			Duration10	0.04	1.04 (1.03–1.05)	<.0001			
			Type of surgery[a]	0.26	1.29 (1.22–1.38)	<.0001			
			Bed size, >500 vs ≤500	0.19	1.21 (1.09–1.34)	.0004			
			Trauma, Y vs N	0.36	1.43 (1.24–1.65)	<.0001			
HTP	364	12					.50	.54	.5898
			Intercept	−3.38		<.0001			
HYST	54,877	975					.66	.62	<.0001
			Intercept	−6.09		<.0001			
			Age10	−0.13	0.88 (0.83–0.93)	<.0001			
			Anesthesia, Y vs N	0.68	1.97 (1.26–3.07)	.003			
			ASA (1, 2, 3/4/5)	0.86	2.37 (2.10–2.67)	<.0001			
			Duration10	0.04	1.04 (1.03–1.05)	<.0001			
			Endoscope, N vs Y	0.35	1.43 (1.17–1.74)	.0005			
			Bed size, ≤500 vs >500	0.22	1.25 (1.06–1.47)	.0065			
KPRO	172,055	1,723					.64	.60	<.0001
			Intercept	−5.77		<.0001			
			Age, ≤58 vs >58	0.30	1.34 (1.21–1.49)	<.0001			
			Anesthesia, Y vs N	0.11	1.12 (1.01–1.24)	.0383			
			ASA (1/2, 3, 4/5)	0.48	1.62 (1.49–1.76)	<.0001			
			Duration10	0.05	1.05 (1.04–1.06)	<.0001			
			Gender, M vs F	0.20	1.22 (1.11–1.34)	<.0001			
			Revision vs primary	0.63	1.89 (1.64–2.17)	<.0001			
			Bed size, >200 vs ≤200	0.11	1.12 (1.01–1.25)	.039			
			Trauma, Y vs N	0.69	1.99 (1.31–3.03)	.0013			
KTP	1,625	75					.75	.60	<.0001
			Intercept	−5.09		<.0001			
			Age, >59 vs ≤59	0.77	2.16 (1.32–3.54)	.0021			
			ASA, >3 vs ≤3	0.51	1.67 (1.01–2.75)	.0452			
			Duration10	0.05	1.05 (1.03–1.07)	<.0001			
			Bed size, ≤500 vs >500	1.30	3.65 (2.19–6.09)	<.0001			
LAM	41,414	428					.62	.60	.0003
			Intercept	−6.33		<.0001			
			Anesthesia, Y vs N	0.71	2.03 (1.04–3.94)	.0371			
			ASA (1, 2, 3/4/5)	0.50	1.64 (1.43–1.89)	<.0001			
			Duration10	0.03	1.03 (1.02–1.04)	<.0001			
			Endoscope, Y vs N	1.35	3.85 (1.57–9.49)	.0033			
LTP	824	114					.71	.56	<.0001
			Intercept	−3.30		<.0001			
			Age, ≤43 vs 44–58	1.07	2.92 (1.81–4.71)	<.0001			
			Age, >58 vs 44–58	0.62	1.86 (1.10–3.15)	.0215			
			Duration, >320 vs ≤320	1.01	2.74 (1.75–4.30)	<.0001			
			Emergency, Y vs N	0.64	1.90 (1.22–2.93)	.0042			
NECK	602	21					.81	.77	.2464
			Intercept	−4.67		<.0001			
			Duration10	0.04	1.04 (1.02–1.06)	<.0001			

TABLE 5. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index PSM	c-index RIM	c-index Pr>|*t*|
NEPH	691	10					.72	.73	.9887
			Intercept	−5.26		<.0001			
			Duration10	0.05	1.05 (1.01–1.09)	.0263			
OVRY	3,016	17					.67	.68	.7069
			Intercept	−5.84		<.0001			
			ASA, >2 vs ≤2	1.38	3.99 (1.47–10.82)	.0065			
PACE	3,438	13					.50	.53	.5148
			Intercept	−5.57		<.0001			
PRST	1,033	12					.67	.65	.7248
			Intercept	−5.55		<.0001			
			Duration, >178 vs ≤178	1.62	5.07 (1.11–23.25)	.0367			
PVBY	6,210	412					.60	.53	<.0001
			Intercept	−2.70		<.0001			
			Age10	−0.16	0.85 (0.79–0.92)	<.0001			
			ASA, >2 vs ≤2	0.57	1.77 (1.16–2.69)	.0076			
			Duration10	0.02	1.02 (1.01–1.03)	<.0001			
			Gender, F vs M	0.32	1.38 (1.12–1.69)	.0021			
			Medical school affiliation, N vs Y	0.23	1.26 (1.02–1.56)	.0338			
REC	1,215	83					.72	.62	<.0001
			Intercept	−4.14		<.0001			
			Duration10	0.04	1.04 (1.02–1.06)	<.0001			
			Endoscope, Y vs N	0.58	1.78 (1.08–2.95)	.0242			
			Gender, M vs F	0.48	1.61 (1.01–2.58)	.0464			
			Wound class, CO/D vs C/CC	0.82	2.26 (1.42–3.61)	.0006			
RFUSN	987	29					.73	.66	.1405
			Intercept	−6.34		<.0001			
			Approach, B/L/P vs A	2.12	8.35 (1.12–62.16)	.038			
			Diabetes, Y vs N	1.09	2.98 (1.16–7.69)	.024			
			Duration, >209 vs ≤209	1.25	3.48 (1.39–8.69)	.008			
SB	4,200	252					.65	.56	<.0001
			Intercept	−4.07		<.0001			
			Duration, >125 vs ≤125	0.90	2.46 (1.87–3.24)	<.0001			
			Bed size, >200 vs ≤200	0.96	2.60 (1.76–3.84)	<.0001			
SPLE	257	6					.50	.70	.0172
			Intercept	−3.73		<.0001			
THOR	1,979	22					.72	.63	.0244
			Intercept	−5.52		<.0001			
			Duration, >187 vs ≤187	1.40	4.04 (1.72–9.46)	.0013			
			Bed size, >500 vs ≤500	1.03	2.79 (1.18–6.60)	.0198			
THYR	1,168	3					.85	.63	.032
			Intercept	−3.11		.0033			
			Age10	−0.71	0.49 (0.27–0.91)	.0244			
VHYS	19,056	185					.65	.56	<.0001
			Intercept	−5.89		<.0001			
			Age, ≤44 vs >44	0.66	1.94 (1.43-2.64)	<.0001			
			ASA, >2 vs ≤2	0.42	1.51 (1.03–2.23)	.0363			
			Duration, >100 vs ≤100	0.50	1.65 (1.22–2.23)	.0011			
			Medical school affiliation, Y vs N	0.89	2.42 (1.76–3.34)	<.0001			
VSHN	5,379	288					.67	.51	<.0001
			Intercept	−6.13		<.0001			

table 5. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index PSM	c-index RIM	c-index Pr>|*t*|
			Age, ≤1 vs >1	0.77	2.16 (1.69–2.75)	<.0001			
			Medical school affiliation, Y vs N	0.69	2.00 (1.23–3.23)	.005			
			Bed size, ≤200/>500 vs 201–500	1.66	5.24 (2.92–9.40)	<.0001			
			Wound class, C vs CC/CO/D	0.82	2.27 (1.29–4.01)	.0045			
XLAP	5,115	100					.63	.60	.3044
			Intercept	−3.95		<.0001			
			Age10	−0.09	0.91 (0.84–1.00)	.0434			
			Duration, >197 vs ≤197	0.66	1.93 (1.28–2.92)	.0017			
			Bed size, >500 vs ≤500	0.53	1.71 (1.13–2.57)	.0104			

note. Procedure codes are NHSN procedure codes.[18] A, anterior; AC, atlas-axis/cervical; Age10, 10-year increase in age at procedure; ASA, American Society of Anesthesiologists score; AX, atlas-axis; B, anterior and posterior; BMI, body mass index; C, clean; CC, clean contaminated; CD, cervical/dorsal/dorsolumbar; CI, confidence interval; CO, contaminated; CV, cervical; D, dirty; Duration10, 10-minute increase in procedure duration; L, lateral transverse; Labor, if patient was in labor during hospitalization, then Labor = Y; LL, lumbar/lumbosacral; OR, odds ratio; P, posterior; Pr>|*t*|, *P* value for comparison of the predictive powers of the procedure specific model versus the risk index model; PSM, procedure-specific model; RIM, NHSN risk index model.

[a] For type of surgery, total primary was coded 0, partial primary was coded 1, and total revision/partial revision was coded 2.

able to allow comparable risk adjustment without including such proxy indicators or intermediate outcomes (like duration), we decided to maximize risk adjustment using all of the information available.

Although SSI prediction improved considerably with our models, the resulting c-indices still remained relatively low. This may result from the characteristics of the NHSN surveillance data in which, for most procedures, there are no procedure-specific risk factors. For the 5 procedures for which procedure-specific data elements were collected, improvement was noted. For example, in addition to those factors collected across all procedures, our CSEC model included BMI and whether the patient was in labor. This resulted in a model with significant improvement in predictive performance, compared with that reported by Brandt et al[6] (0.66 vs 0.55), which included only ASA score, procedure duration, age, and wound class. Further improvement can be expected with additional patient- and procedure-specific factors, such as diabetes, duration of preoperative hospital stay, indication for surgery, and the number of discharge diagnoses.[33] Beginning in January 2013, the NHSN will require submission of BMI and diabetes information for all procedures.

Our findings indicate that, with use of the currently available NHSN data, the new procedure-specific risk models significantly improved SSI prediction. This justifies their use in facility-specific performance comparisons with an external benchmark, which serve as guides for internal quality improvement efforts. To enable NHSN users to take advantage of the new procedure-specific risk models, the CDC has incorporated them into the NHSN application. The new models supersede the NHSN risk index for procedures in which the traditional NHSN risk index has little discriminatory power. Improved risk adjustment may provide SSI data that are more convincing to clinicians and thus more effective in guiding changes in infection-prevention practices. In addition, separate models for predicting the subset of SSIs classified as complex (deep incisional or organ/space infections) detected during initial hospitalization or upon rehospitalization at the same hospital were developed (Table 6). These models may be more acceptable for public reporting, because there may be less variability to detect this subset between facilities when excluding those infections detected by surveillance after hospital discharge and superficial infections. In addition, the model fit, as measured by the c-index, was improved for a number of the procedures, which indicates that perhaps the identified risk factors are better at predicting this subset of SSIs. However, any models developed for public reporting will need frequent reevaluation as more information becomes available and the quality measure environment changes.[19] Likewise, even for the overall SSI models, caution should also be exercised when evaluating some of these models. Specifically, 9 procedure categories (AVSD, CEA, HTP, NEPH, OVRY, PACE, PRST, SPLE, and THYR) had fewer than 20 SSI events, and for 4 of these (CEA, HTP, PACE, and SPLE), we were able to construct intercept-only models. The intercept-only models produce essentially unadjusted infection rates for comparison, and for the other models, the risk estimates might not be stable because of an insufficient number of SSI cases. These models can and should be modified as additional information on methods to improve risk adjustment (eg, the addition of specific patient-level variables) for specific procedures and the ability to reliably and effortlessly acquire these variables from surgical or facility information systems as part of routine SSI surveillance improve. This is an ongoing, deliberate, and iterative process. The NHSN is committed to pursue additional efforts to present

TABLE 6. Multivariate Models Predicting Deep Incisional and Organ/space Surgical Site Infections (SSIs) Detected During Initial Hospitalization or Rehospitalization at the Same Hospital for 39 Procedures Reported to the National Healthcare Safety Network, 2006–2008

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index
AAA	1,950	30					.70
			Intercept	−5.15		<.0001	
			Duration10	0.04	1.04 (1.02–1.07)	.0004	
			Wound class, CO/D vs C/CC	2.37	10.72 (3.19–36.07)	.0001	
AMP	1,413	9					.50
			Intercept	−5.05		<.0001	
APPY	5,889	50					.74
			Intercept	−6.62		<.0001	
			Emergency, Y vs N	0.87	2.38 (1.21–4.67)	.0116	
			Gender, M vs F	0.84	2.31 (1.22–4.38)	.0099	
			Bed size, >500 vs ≤500	0.94	2.56 (1.44–4.54)	.0013	
			Wound class, CO/D vs C/CC	1.07	2.90 (1.64–5.15)	.0003	
AVSD	864	8					.77
			Intercept	−1.89		.0761	
			Age10	−0.50	0.61 (0.41–0.91)	.0152	
BILI	894	63					.76
			Intercept	−4.88		<.0001	
			ASA, ≤3 vs >3	1.34	3.83 (1.36–10.82)	.0113	
			Duration10	0.03	1.03 (1.02–1.05)	<.0001	
			Bed size, 201–500 vs ≤200/>500	1.25	3.49 (1.97–6.20)	<.0001	
BRST	3,167	25					.81
			Intercept	−7.91		<.0001	
			ASA, >2 vs ≤2	1.45	4.25 (1.84–9.79)	.0007	
			Duration10	0.06	1.06 (1.04–1.08)	<.0001	
			Bed size, ≤200/>500 vs 201–500	1.51	4.51 (1.05–19.32)	.0422	
CABG	133,488	1,644					.62
			Intercept	−6.55		<.0001	
			Age10	0.07		.0187	
			Age10 : gender (interaction)	−0.26		<.0001	
			ASA (1/2, 3, 4/5)	0.38	1.47 (1.31–1.65)	<.0001	
			Duration10	0.03	1.03 (1.02–1.03)	<.0001	
			Gender, F vs M	2.29		<.0001	
			Medical school affiliation, Y vs N	0.19	1.21 (1.08–1.36)	.0009	
CARD	29,757	229					.59
			Intercept	−5.23		<.0001	
			Age, ≤56 vs >56 years	0.35	1.42 (1.09–1.85)	.0093	
			Duration, >306 vs ≤306	0.61	1.83 (1.40–2.40)	<.0001	
			Emergency, Y vs N	0.48	1.61 (1.07–2.41)	.0215	
CEA	4,548	5					.50
			Intercept	−6.81		<.0001	
CHOL	14,726	63					.77
			Intercept	−7.65		<.0001	
			Age, >52 vs ≤52	0.79	2.21 (1.18–4.13)	.0131	
			ASA, >2 vs ≤2	0.62	1.86 (1.03–3.35)	.0382	
			Duration10	0.07	1.08 (1.04–1.11)	<.0001	
			Bed size, >200 vs ≤200	0.96	2.61 (1.41–4.82)	.0022	
COLO	62,782	1,825					.61
			Intercept	−4.72		<.0001	
			Age, ≤75 vs >75	0.15	1.16 (1.03–1.30)	.0137	
			ASA, >2 vs ≤2	0.33	1.39 (1.26–1.54)	<.0001	
			Duration10	0.03	1.03 (1.03–1.04)	<.0001	
			Endoscope, N vs Y	0.18	1.19 (1.05–1.36)	.0088	
			Medical school affiliation, N vs Y	0.16	1.18 (1.06–1.31)	.0028	
			Bed size, >200 vs ≤200	0.21	1.23 (1.10–1.37)	.0004	
			Wound class, CO/D vs C/CC	0.19	1.21 (1.08–1.36)	.0013	

TABLE 6. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index
CRAN	9,918	198					.65
			Intercept	−4.02		<.0001	
			Age10	−0.15	0.86 (0.81–0.92)	<.0001	
			Duration10	0.02	1.02 (1.01–1.03)	<.0001	
			Bed size, >500 vs ≤500	0.56	1.75 (1.24–2.46)	.0013	
CSEC	30,645	160					.75
			Intercept	−7.63		<.0001	
			BMI	0.03	1.03 (1.01–1.05)	.0078	
			Age10	−0.48	0.62 (0.47–0.81)	.0004	
			Anesthesia, Y vs N	0.55	1.74 (1.09–2.78)	.0209	
			ASA (1, 2, 3/4/5)	0.53	1.69 (1.21–2.37)	.0023	
			Duration10	0.22	1.25 (1.17–1.33)	<.0001	
			Labor, Y vs N	0.83	2.29 (1.65–3.18)	<.0001	
			Bed size, >200 vs ≤200	0.84	2.32 (1.53–3.52)	<.0001	
			Wound class, CO/D vs C/CC	1.07	2.91 (1.50–5.65)	.0015	
FUSN	41,161	383					.75
			Intercept	−6.90		<.0001	
			Approach, B/L/P vs A	0.94	2.56 (1.85–3.55)	<.0001	
			ASA (1/2, 3, 4/5)	0.60	1.82 (1.54–2.16)	<.0001	
			Diabetes, Y vs N	0.39	1.48 (1.13–1.93)	.0045	
			Duration10	0.03	1.03 (1.02–1.04)	<.0001	
			Medical school affiliation, Y vs N	0.34	1.41 (1.10–1.80)	.0067	
			Spinal level, CD/DL vs AX/AC/CV	0.82	2.26 (1.51–3.40)	<.0001	
			Spinal level, LL vs AX/AC/CV	0.49	1.63 (1.20–2.22)	.002	
FX	10,646	117					.64
			Intercept	−5.80		<.0001	
			Age, >25 vs ≤25	0.83	2.29 (1.36–3.86)	.0018	
			Duration, >138 vs ≤138	0.92	2.52 (1.72–3.69)	<.0001	
			Bed size, >200 vs ≤200	0.55	1.73 (1.17–2.56)	.0064	
GAST	8,223	104					.66
			Intercept	−6.18		<.0001	
			Age10	0.21	1.24 (1.08–1.41)	.0017	
			Duration10	0.06	1.06 (1.04–1.08)	<.0001	
HER	7,487	92					.77
			Intercept	−8.11		<.0001	
			Age, ≤71 vs >71	0.93	2.53 (1.36–4.71)	.0035	
			ASA (1, 2, 3/4/5)	0.75	2.12 (1.39–3.22)	.0005	
			Duration10	0.06	1.06 (1.04–1.08)	<.0001	
			Gender, F vs M	0.85	2.35 (1.50–3.69)	.0002	
			Bed size, >200 vs ≤200	0.83	2.30 (1.31–4.01)	.0035	
HPRO	131,826	1,183					.67
			Intercept	−5.69		<.0001	
			Age10	−0.09	0.92 (0.88–0.96)	<.0001	
			Anesthesia, Y vs N	0.17	1.19 (1.03–1.36)	.016	
			ASA, 3 vs 1/2	0.82	2.27 (1.98–2.59)	<.0001	
			ASA, 4/5 vs 1/2	1.07	2.91 (2.34–3.61)	<.0001	
			Duration10	0.04	1.04 (1.03–1.05)	<.0001	
			Type of surgery[a]	0.35	1.43 (1.32–1.54)	<.0001	
			Medical school affiliation, Y vs N	0.19	1.21 (1.07–1.37)	.003	
			Bed size, >200 vs ≤200	0.31	1.37 (1.20–1.56)	<.0001	
			Trauma, Y vs N	0.24	1.27 (1.05–1.53)	.0126	
HTP	364	11					.50
			Intercept	−3.47		<.0001	
HYST	54,877	389					.64
			Intercept	−5.82		<.0001	
			Age10	−0.17	0.85 (0.77–0.93)	.0003	
			ASA (1, 2, 3/4/5)	0.73	2.08 (1.73–2.50)	<.0001	

TABLE 6. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index
			Duration10	0.04	1.04 (1.03–1.06)	<.0001	
			Bed size, ≤500 vs >500	0.33	1.39 (1.07–1.80)	.0137	
KPRO	172,039	1,108					.65
			Intercept	−6.39		<.0001	
			Age, ≤58 vs >58	0.34	1.41 (1.24–1.61)	<.0001	
			ASA (1/2, 3, 4/5)	0.49	1.64 (1.47–1.82)	<.0001	
			Duration10	0.05	1.05 (1.04–1.06)	<.0001	
			Gender, M vs F	0.35	1.42 (1.26–1.60)	<.0001	
			Revision vs primary	0.78	2.18 (1.85–2.58)	<.0001	
			Medical school affiliation, Y vs N	0.16	1.18 (1.04–1.33)	.0096	
			Bed size, >200 vs ≤200	0.18	1.20 (1.04–1.38)	.01	
			Trauma, Y vs N	0.68	1.97 (1.18–3.31)	.0099	
KTP	1,625	33					.67
			Intercept	−5.38		<.0001	
			ASA, >3 vs ≤3	0.87	2.39 (1.09–5.22)	.0292	
			Duration10	0.04	1.05 (1.02–1.07)	.0012	
LAM	40,513	218					.64
			Intercept	−6.89		<.0001	
			ASA (1, 2, 3, 4/5)	0.52	1.68 (1.38–2.03)	<.0001	
			Duration10	0.03	1.03 (1.02–1.05)	<.0001	
			Medical school affiliation, N vs Y	0.66	1.94 (1.37–2.76)	.0002	
			Bed size, >500 vs ≤500	0.61	1.84 (1.32–2.56)	.0003	
LTP	824	96					.72
			Intercept	−3.34		<.0001	
			Age, ≤43 vs 44–58	1.30	3.66 (2.18–6.16)	<.0001	
			Age, >58 vs 44–58	0.78	2.18 (1.23–3.86)	.0074	
			Duration, >320 vs ≤320	1.14	3.12 (1.92–5.06)	<.0001	
NECK	602	12					.85
			Intercept	−5.43		<.0001	
			Duration10	0.04	1.04 (1.02–1.06)	<.0001	
NEPH	691	9					.50
			Intercept	−4.33		<.0001	
OVRY	3,016	2					.50
			Intercept	−7.32		<.0001	
PACE	3,438	7					.50
			Intercept	−6.20		<.0001	
PRST	1,033	5					.50
			Intercept	−5.33		<.0001	
PVBY	6,210	176					.63
			Intercept	−4.50		<.0001	
			Age, ≤58 vs >58	0.56	1.75 (1.27–2.39)	.0005	
			ASA, >3 vs ≤3	0.39	1.47 (1.07–2.02)	.0173	
			Duration10	0.02	1.02 (1.01–1.04)	.0013	
			Medical school affiliation, N vs Y	0.62	1.86 (1.36–2.55)	.0001	
REC	1,215	38					.77
			Intercept	−5.90		<.0001	
			Duration10	0.04	1.04 (1.02–1.06)	<.0001	
			Gender, M vs F	1.06	2.87 (1.39–5.92)	.0043	
			Bed size, >500 vs ≤500	1.24	3.46 (1.43–8.40)	.006	
RFUSN	991	24					.65
			Intercept	−4.59		<.0001	
			Duration, >209 vs ≤209	1.37	3.94 (1.46–10.63)	.0069	
SB	4,200	141					.65
			Intercept	−4.79		<.0001	
			Duration, >125 vs ≤125	0.92	2.51 (1.73–3.64)	<.0001	
			Bed size, 201–500 vs ≤200	0.99	2.8 (1.40–5.12)	.0028	
			Bed size, >500 vs ≤200	1.08	2.96 (1.71–5.12)	.0001	

table 6. (*Continued*)

Procedure code	No. of procedures	No. of SSIs	Effect	Estimate	OR (95% CI)	*P*	c-index
SPLE	257	4					.50
			Intercept	−4.15		<.0001	
THOR	1,979	13					.72
			Intercept	−5.91		<.0001	
			Duration, >187 vs ≤187	1.93	6.85 (2.10–22.35)	.0014	
THYR	1,168	1					.50
			Intercept	−7.06		<.0001	
VHYS	19,009	122					.67
			Intercept	−3.96		<.0001	
			Age10	−0.46	0.63 (0.53–0.76)	<.0001	
			Duration10	0.03	1.03 (1.00–1.07)	.0366	
			Medical school affiliation, Y vs N	0.87	2.38 (1.61–3.53)	<.0001	
VSHN	5,379	270					.66
			Intercept	−6.17		<.0001	
			Age, ≤1 vs >1	0.76	2.14 (1.67–2.75)	<.0001	
			Medical school affiliation, Y vs N	0.62	1.86 (1.15–3.02)	.012	
			Bed size, ≤200/>500 vs 201–500	1.77	5.87 (3.11–11.11)	<.0001	
			Wound class, C vs CC/CO/D	0.75	2.12 (1.20–3.74)	.0094	
XLAP	5,115	39					.59
			Intercept	−5.48		<.0001	
			Duration10	0.04	1.04 (1.01–1.06)	.001	

note. Procedure codes are National Healthcare Safety Network procedure codes.[18] A, anterior; AC, atlas-axis/cervical; Age10, 10-year increase in age at procedure; ASA, American Society of Anesthesiologists score; AX, atlas-axis; B, anterior and posterior; BMI, body mass index; C, clean; CC, clean contaminated; CD, cervical/dorsal/dorsolumbar; CI, confidence interval; CO, contaminated; CV, cervical; D, dirty; DL, dorsal/dorsolumbar; Duration10, 10-minute increase in procedure duration; L, lateral transverse; Labor, number of hours that the patient underwent labor in the hospital before the operative procedure; LL, lumbar/lumbosacral; OR, odds ratio; P, posterior.

[a] For type of surgery, total primary was coded 0, partial primary was coded 1, and total revision/partial revision was coded 2.

the best available risk-adjusted SSI data to reporting facilities and to make accurate overall assessments of the status of SSI prevention efforts in the United States.

ACKNOWLEDGMENTS

We thank the NHSN participants for their ongoing efforts to monitor health-care-associated infections and improve patient safety and our colleagues in the Division of Healthcare Quality Promotion for their tireless support of this unique public health network.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of Centers for Disease Control and Prevention.

APPENDIX A

Outlier exclusion rules:

(1) Exclude all procedures where duration in minutes = 0 (n = 1,265);

(2) Exclude all procedures where patient was less than 1 day old or greater than 109 years old (n = 2,216);

(3) Exclude all procedures where wound class was undefined (n = 1,169);

(4) Exclude all procedures with duration between 0 and 5 minutes or more than 5 times the interquartile range (n = 1,782).

APPENDIX B

Bootstrap resampling steps:

(1) For each procedure category, 100 independent samples of the same size as the original sample were obtained, each of which was a simple random sample with replacement;

(2) Logistic regression was applied to each sample using selected risk factors;

(3) The 95% confidence intervals based on 100 independent samples for the estimated effects (of the risk factors) were calculated;

(4) If the effects at the 2.5th percentile and the 97.5th percentile were both positive (being risk factors) or negative (being protective factors), the effects were deemed to be significant; if the lower and the upper bound of the effects pointed to different directions (one being positive and the

other being negative), the effect was deemed to be nonsignificant;

(5) Nonsignificant effect was removed from the models, and the stepwise model selection was run to see whether other new effects could enter the models with this effect absent. The above bootstrapping process was repeated to validate the new models.

(6) If several effects were found to be nonsignificant through bootstrapping, we removed the least significant effect in step 5.

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