ORIGINAL ARTICLE

Improved Risk Adjustment in Public Reporting: Coronary Artery Bypass Graft Surgical Site Infections

Sandra I. Berríos-Torres, MD;[1] Yi Mu, PhD;[1] Jonathan R. Edwards, MStat;[1]
Teresa C. Horan, MPH;[1] Scott K. Fridkin, MD[1]

OBJECTIVE. The objective was to develop a new National Healthcare Safety Network (NHSN) risk model for sternal, deep incisional, and organ/space (complex) surgical site infections (SSIs) following coronary artery bypass graft (CABG) procedures, detected on admission and readmission, consistent with public reporting requirements.

PATIENTS AND SETTING. A total of 133,503 CABG procedures with 4,008 associated complex SSIs reported by 293 NHSN hospitals in the United States.

METHODS. CABG procedures performed from January 1, 2006, through December 31, 2008, were analyzed. Potential SSI risk factors were identified by univariate analysis. Multivariate analysis with forward stepwise logistic regression modeling was used to develop the new model. The c-index was used to compare the predictive power of the new and NHSN risk index models.

RESULTS. Multivariate analysis independent risk factors included ASA score, procedure duration, female gender, age, and medical school affiliation. The new risk model has significantly improved predictive performance over the NHSN risk index (c-index, 0.62 and 0.56, respectively).

CONCLUSIONS. Traditionally, the NHSN surveillance system has used a risk index to provide procedure-specific risk-stratified SSI rates to hospitals. A new CABG sternal, complex SSI risk model developed by multivariate analysis has improved predictive performance over the traditional NHSN risk index and is being considered for endorsement as a measure for public reporting.

Infect Control Hosp Epidemiol 2012;33(5):463-469

Approximately 440,000 coronary artery bypass graft (CABG) surgical procedures are performed annually in the United States.[1] Complex (deep incisional and organ/space)[2] sternal surgical site infections (SSIs) complicate approximately 0.5%–4.0% of CABGs,[3,4] resulting in increased morbidity,[5] mortality,[5-7] length of stay,[6] and cost of hospitalization.[7] Common risk factors include those that are modifiable (eg, postoperative hyperglycemia,[8] blood transfusion[5,6]), nonmodifiable (eg, age,[9] diabetes[9,10]), and potentially modifiable (eg, procedure duration,[11] smoking status,[3] obesity[5,6,9-11]).

Surveillance has become integral to hospital infection prevention and quality improvement programs. Feedback of rates has been an important component of SSI reduction strategies.[12] Hospitals with surgeons who treat patients with multiple nonmodifiable risk factors would expect higher SSI rates. Risk adjustment to account for differences in the patient case mix allows for more meaningful comparisons and has been used as a quality improvement performance tool.[13]

Previously, the National Healthcare Safety Network (NHSN) adjusted SSI rates using a risk index of 3 equally weighted factors: the American Society of Anesthesiologists (ASA) score,[14] wound classification, and procedure duration.[15] Because most CABG patients have similar ASA scores and a clean wound, the risk index tended to dichotomize them on procedure duration; therefore, accounting for additional patient and institutional factors is desirable.[16-18]

Since 2002, 28 states and the District of Columbia have enacted laws mandating public reporting of healthcare-associated infections.[19] In June 2009, the US Department of Health and Human Services Action Plan to Prevent Healthcare-Associated Infections proposed national 5-year SSI prevention targets and metrics to evaluate progress.[20] The target is a reduction in procedure-specific complex SSIs, detected on admission and readmission, by at least 25% from the 2009 baseline, using NHSN data. Beginning in 2012, the Healthcare and Education Affordability Reconciliation Act of 2010[21] requires all healthcare facilities participating in the Centers for Medicare and Medicaid Services Inpatient Prospective Payment System to report SSI data, as outlined in the action plan.[20] In 2012, these data will be reported to the NHSN and

Affiliation: 1. Division of Healthcare Quality Promotion, National Center for Emerging and Zoonotic Infectious Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia.

Received July 12, 2011; accepted December 5, 2011; electronically published March 20, 2012.

 0899-823X/2012/3305-0005$15.00. DOI: 10.1086/665313

publicly reported by the Centers for Medicare and Medicaid Services.

Publicly reported data should account for variability in patient case mix, adjust for all possible risk factors to the greatest extent possible, and be based on consistent case detection systems.[22] A procedure-specific, multivariate risk model incorporating additional weighted patient factors could calculate a more credible, standardized, and reliable risk-adjusted SSI metric than one limited to the traditional NHSN risk index.[23-25] Applying this new metric to public reporting could help assess quality of care, focus surveillance and prevention measures on high-risk patients, and identify programs that might benefit from special interventions.[16]

The objective of our study was to use multivariate analysis to develop a CABG complex, sternal, admission or readmission detected SSI risk model, incorporating NHSN data elements and comparing its predictive performance to that of the NHSN risk index.

METHODS

Study Population and End Point

In 2005, the NHSN—a secure, Internet-based surveillance system managed by the Centers for Disease Control and Prevention's Division of Healthcare Quality Promotion—began operation.[26] As of March 2012, more than 3,250 hospitals reported SSI data to the NHSN.[27] Infection preventionists report denominator data on patients undergoing procedures within the selected categories for each month of surveillance performed.[2,28] They investigate and report all SSIs detected during the initial admission, through postdischarge surveillance, or upon readmission to the same hospital as the index procedure.[2] SSIs are reported if they become apparent within 30 days following the index procedure for superficial incisional infections and if the procedure included an implant (sternal wires) up to 1 year for deep incisional and organ/space infections.[2]

Data were analyzed for hospitals reporting CABG procedures performed from January 1, 2006, through December 31, 2008. These included those with sternal and harvest site incisions (NHSN procedure code CBGB; *International Classification of Diseases, Ninth Revision, Clinical Modification* [ICD-9-CM] procedure codes 36.10–36.14, 36.19) and those with only sternal incisions (NHSN procedure code CBGC; ICD-9-CM procedure codes 36.15–36.17, 36.2).[2,26] Demographic and SSI characteristic data were evaluated. Only complex (deep and organ/space), sternal, admission or readmission detected SSIs were included in the model. SAS (ver. 9.1; SAS Institute) was used for analysis. This analysis did not require institutional review board review.

Selection of Candidate Predictor Variables

The NHSN risk index multivariate model contains 3 dichotomous variables: ASA score (3–5), wound classification (contaminated or dirty), and procedure duration (greater than seventy-fifth percentile or 300 minutes). Each risk factor represents 1 point; thus, the index ranges from 0 (lowest risk) to 3 (greatest risk).[15] The new predictive model incorporates the 3 NHSN risk index variables and additional data elements currently collected in the NHSN. Variables were dichotomous (general anesthesia, emergent procedure, gender, trauma, medical school affiliation), ordinal (ASA score), categorical (wound classification and number of hospital beds), or continuous (age and procedure duration).

Variables required for data entry but not included were outpatient (all CABGs are inpatient), endoscope (applies to peripheral graft harvest), implant (all yes), nonautologous transplant (all no), and multiple procedures (inconsistently classified). Continuous variables were grouped as appropriate to improve the model's performance. The procedure duration 10 variable was derived from the procedure duration variable for every 10-minute increase in procedure duration. Age 10 was derived from the age variable for every 10-year increase in age. ASA scores were regrouped according to χ^2 test results.

Five variables with 319 (0.24%) missing values among 133,503 CABGs were included: trauma (n = 215, 0.16%),

TABLE 1. Patient and Hospital Characteristics of 133,503 Coronary Artery Bypass Graft Procedures, National Healthcare Safety Network, 2006–2008

Characteristic and value	*N*	%
Sex		
Female	38,124	28.56
Male	95,379	71.44
Age, mean, years (median)	66 (66)	...
Emergent		
Yes	11,691	8.76
Trauma		
Yes	659	0.49
General anesthesia		
Yes	131,976	98.86
ASA score		
1	259	0.19
2	1,942	1.45
3	33,075	24.77
4	97,310	72.89
5	902	0.68
Wound classification		
Clean	129,677	97.13
Clean contaminated	3,526	2.64
Contaminated	196	0.15
Dirty	95	0.07
Procedure duration, mean, minutes (median)	253 (240)	...
Medical school affiliation		
Yes	185	63.14
No. of hospital beds		
<200	24,687	18.49
201–500	54,582	40.88
>500	54,234	40.62

NOTE. ASA, American Society of Anesthesiologists.

https://doi.org/10.1086/665313 Published online by Cambridge University Press

TABLE 2. Characteristics of Surgical Site Infections (SSIs) following Coronary Artery Bypass Graft Procedures (CABG) by SSI Type and Detection Method, National Healthcare Safety Network, 2006–2008

	All CABG procedures (N = 133,503)			Sternal incisions (N = 133,503)			Harvest incisions (N = 124,296)		
SSI type by detection method	N	Rate[a]	%	N	Rate[a]	%	N	Rate[a]	%
All SSIs	4,008	3.00		2,899	2.17		1,109	0.89	
Admission	1,094		27.30	794		27.39	300		27.05
Readmission	2,376		59.28	1,768		60.99	608		54.82
Total on admission/readmission	3,470	2.60	86.58	2,562	1.92	88.38	908	0.73	81.87
Postdischarge	537		13.40	336		11.59	201		18.12
Superficial SSIs	1,998	1.50		1,153	0.86		845	0.68	0.68
Admission	529		26.48	304		26.37	225		26.63
Readmission	1,056		52.85	615		53.34	441		52.19
Total on admission/readmission	1,585	1.19	79.33	919	0.69	79.71	666	0.54	78.82
Postdischarge	413		20.67	234		20.29	179		21.18
Complex SSIs	2,009	1.50		1,745	1.31		264	0.21	
Admission	565		28.12	490		28.08	75		28.41
Readmission	1,320		65.70	1,153		66.07	167		63.26
Total on admission/readmission	1,885	1.41	93.82	1,643	1.23	94.15	242	0.19	91.67
Postdischarge	124		6.17	102		5.85	22		8.33
Missing	1			1			0		

[a] Unadjusted rate per 100 procedures.

general anesthesia (n = 74, 0.06%), ASA score (n = 15, 0.01%), wound classification (n = 9, 0.01%), and emergent procedure (n = 6, 0.01%).

Univariate Analysis

The χ^2 test was used to test for each individual variable's association with SSI. Dichotomous variables were described as counts and percentages and tested for significance. Ordinal variables' scores were collapsed into 1 group if the χ^2 test showed no significant difference between them. For categorical variables, multiple categorizations were used; only the one most significantly associated with SSI risk was retained. For continuous variables, outliers were excluded; the remaining variables were divided into quartiles and compared by the χ^2 test. Continuous variables were coded as binary if a significant cut point was found. Univariate analysis variables with $P < .25$ were considered potential independent variables and designated as candidate variables for the logistic regression model.

Multivariate Analysis

Forward stepwise logistic regression analysis was used to develop the model (the referent category was the one that conferred the least risk of SSI). Variables were eligible for inclusion at likelihood ratio test (LRT) $P = .25$ and removed at $P = .05$. For variables with multiple categorical, ordinal, or dichotomous cutoff values, the one with the smallest LRT P value was included. The Hosmer-Lemeshow test was applied to assess the model goodness-of-fit (good fit indicated by $P > .05$). To confirm the appropriateness of the final model, stepwise model selection was performed including all 11 variables. Interaction terms were tested and included at LRT $P = .05$. The model was validated internally by 100-fold bootstrapping. The end point was CABG complex, sternal, admission or readmission detected SSIs.

Model Comparison

The predictive performances of the logistic regression models were assessed constructing receiver operating characteristic (ROC) curves and calculating the c-index for the separate logistic regression models. An ROC curve plots 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 is the c-index, 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. The range from least to best predictive ability is 0.5 to 1.0.[13] Differences in c-index were tested using Hanley and McNeil's method.[29]

RESULTS

Demographics

During the study period, 293 hospitals (mean number of beds, 379) reported 133,503 CABGs to the NHSN. Ninety-one percent were performed in nonprofit hospitals (n = 247, 84.30%) and 71% in medical school–affiliated hospitals (n = 185, 63.14%).

The patients' mean age was 66 years (median, 66; interquartile range, 58–74), and 71.44% were male. The majority of procedures were nonemergent (91.23%) and unrelated to trauma (99.35%). Nearly all patients had an ASA score of 3

https://doi.org/10.1086/665313 Published online by Cambridge University Press

TABLE 3. Univariate Analysis: Candidate Variables for Coronary Artery Bypass Graft Sternal, Complex Surgical Site Infection Risk Model, National Healthcare Safety Network, 2006–2008

Effect	Variable type	OR	95% CI	P
Sex (female vs male)	Binary	1.71	1.55–1.89	<.0001
ASA score (1/2, 3, 4/5)	Ordinal	1.48	1.32–1.66	<.0001
Procedure duration 10[a]	Continuous	1.03	1.02–1.03	<.0001
Medical school affiliation (yes vs no)	Binary	1.23	1.10–1.37	<.0003
Number of hospital beds (≤200 or >500 vs 201–500)	Categorical	1.19	1.08–1.32	<.0007
Wound classification (contaminated/dirty vs clean/clean contaminated)	Categorical	1.40	0.58–3.40	.45
Emergent procedure (yes vs no)	Binary	1.06	0.90–1.26	.48
Age 10[b]	Continuous	0.99	0.95–1.04	.71
General anesthesia (no vs yes)	Binary	1.07	0.68–1.68	.79
Trauma (no vs yes)	Binary	1.01	0.50–2.04	.97

NOTE. ASA, American Society of Anesthesiologists; CI, confidence interval; OR, odds ratio.

[a] For every additional 10-minute increase in procedure duration.

[b] For every additional 10-year age increment.

or greater (98.34%) and a wound classification of clean or clean contaminated (99.77%). The mean procedure duration was 253 minutes (median, 240 minutes; interquartile range, 190–300; Table 1).

SSIs

There were 4,008 SSIs (unadjusted rate per 100 procedures, 3.00). Seventy-two percent were sternal (rate, 2.17), and 60% of the sternal were complex (rate, 1.31), with 94% of them detected on admission/readmission (rate, 1.23). Of the superficial sternal infections (n = 1,153; rate, 0.86), 80% were detected on admission/readmission (rate, 0.69; Table 2).

New NHSN Risk Model

Variables significantly associated with increased risk in the univariate analysis included procedure duration (odds ratio [OR], 1.03; $P < .01$), female gender (OR, 1.71; $P < .01$), number of hospital beds (OR, 1.19; $P < .01$), ASA score (OR, 1.48; $P < .01$), and medical school affiliation (OR, 1.23; $P < .01$; Table 3).

Fifteen (0.01%) procedures with missing values were excluded from the multivariate analysis (n = 133,488 procedures in the model). Only sternal, complex SSIs detected on admission or readmission (n = 1,643) were included. Risk factors identified as independent predictors included ASA score of 4 or 5 (OR, 1.47; $P < .0001$), procedure duration (OR, 1.03 for each additional 10 minutes; $P < .0001$), medical school affiliation (OR, 1.21; $P = .0009$), and an interaction term (age in 10-year increments and gender; $P = .0044$; OR, 0.95 [male], 0.82 [female]; Table 4).

Model Performance

The new model's c-index showed significantly improved predictive performance (0.62) as compared with the risk index (0.56; $P \leq .0001$). Hosmer-Lemeshow goodness-of-fit statistic was 0.92 (Figure 1). The 100-fold bootstrapping mean c-index was 0.62 (95% confidence interval, 0.61–0.64), indicating good internal validation.

DISCUSSION

We used logistic regression modeling to develop a new risk model predicting CABG complex, sternal, admission or readmission detected SSIs and compared its performance with that of the NHSN risk index model. The new model provides a risk-adjusted SSI metric consistent with public reporting requirements and improves on the risk index in several ways. It focuses on complex, sternal, admission or readmission detected SSIs; incorporates additional factors already collected through NHSN; omits 1 factor determined not to be independently associated with increased risk (wound classification), and does not force equal weights on the factors, yielding a model with significantly improved predictive performance.

Our data add to studies that have demonstrated the ability to improve on the NHSN risk index.[23-25] There is significant variability in the types of procedures, length of the study period, number of hospitals, SSI detection method, and follow-up, number, and type of candidate variables among these studies. Most comparable is the Society of Thoracic Surgeons (STS) model, with 1,860 "deep sternal wound infections" among 464,929 CABG procedures.[23] Its higher predictive performance may result from a longer study period, surveillance at more than twice the number of hospitals, and the incorporation of more variables, though not all variables contribute equally to predicting excess risk of SSI. Most NHSN users consider the routine collection of additional variables an excessive burden. However, incorporation of select variables to improve risk adjustment may be needed.

The STS model's exclusion of SSIs detected on readmission may explain the lower unadjusted SSI rate reported (1,860/464,929; rate, 0.4) as compared with the NHSN's (1,644/133,488; rate, 1.23). In the NHSN, 66% of sternal complex SSIs were detected on readmission. If the STS's 1,860 SSIs represent the 28% that would have been reported during

TABLE 4. Multivariate Analysis: Final Variables for Coronary Artery Bypass Graft Sternal, Complex Surgical Site Infection Risk Model, National Healthcare Safety Network, 2006–2008

Effect	Variable type	OR	95% CI	*P*	C-index	Goodness-of-fit
ASA score (1/2, 3, 4/5)	Ordinal	1.47	1.31–1.65	<.0001	0.62	0.92
Procedure duration 10[a]	Continuous	1.03	1.02–1.03	<.0001		
Medical school affiliation (yes vs no)	Binary	1.21	1.08–1.36	.0009		
Age 10[b]	Interaction			.0044		
Male		0.95	0.90–0.98	...		
Female		0.82	0.79–0.86	...		

NOTE. ASA, American Society of Anesthesiologists; CI, confidence interval; OR, odds ratio.
[a] For every additional 10-minute increase in procedure duration.
[b] For every additional 10-year age increment.

admission, then there could have been 4,783 detected on readmission, or 6,643 total SSIs (unadjusted rate of 1.34, closer to the NHSN's 1.23).

The new NHSN model will be used to risk adjust facility-specific CABG SSI experiences. In as much as the model's sample is nationally representative, it is likely generalizable to other US facilities. It focuses solely on sternal SSIs, more readily identified and clinically important.[17] Because CABG SSI rates vary by incision site,[11,22] it has been suggested that for interhospital comparison, only sternal SSIs be reported, or if harvest site SSIs are reported, they be reported separately.[30]

The model focuses on complex SSIs. Approximately 50% of SSIs are superficial. Their diagnosis has decreased sensitivity as compared with the complex,[31,32] and the majority are inconsistently diagnosed through postdischarge surveillance.[33] Surgeons,[22] stakeholders in public health, and infection control committees are generally opposed to giving them the same weight as complex; therefore, it has been recommended that public reporting include only complex SSIs.[34]

The model is limited to SSIs detected on admission/readmission. To reduce potential bias introduced by variability in institutional methodology, minimize differences in SSI detection practices, and improve the likelihood of obtaining comparable data, it has been recommended that public reporting focus on SSIs detected on admission/readmission.[20,34,35] More than 90% of CABG complex SSIs were detected on admission/readmission. The impact of focusing public reporting on these SSIs becomes apparent when comparing the unadjusted SSI rate for CABG at 3.0 (all SSIs, all detection methods) to CABG complex, sternal, admission or readmission detected SSIs at 1.23.

This model will be used to calculate facility-specific standardized infection ratios (SIRs), comparing the number of observed to expected infections.[36-38] An SIR of 1.07 means 7% more infections were observed than expected (adjusted for patient case mix).

While the model improves on the NHSN risk index for surveillance and benchmarking purposes, limitations still exist. First, it is limited to currently collected data elements. Second, it is not based solely on modifiable, patient-specific, preoperative risk factors that could identify high-risk patients a priori so that risk reduction interventions could be implemented.[11,39] Third, it does not account for potential increased risk of infection in a CABG with a valve replacement. Finally, validation with external databases would be ideal.

A significant concern with focusing the new predictive risk model and public reporting on CABG complex, sternal, admission or readmission detected SSIs is that infection prevention programs may assume that they do not need to monitor harvest site incisions or superficial SSIs or perform postdischarge surveillance. Ninety-three percent of CABGs included a harvest site (n = 1,109 SSIs; rate, 0.89). Fifty-one percent of all SSIs were superficial; most were harvest site (76.11%), with both contributing to morbidity and increased cost. Postdischarge surveillance detected 11.59% of sternal and 18.12% of harvest SSIs. Because interfacility methodology and intensity of postdischarge surveillance varies, these SSIs are excluded from public reporting. Surveillance needs for internal infection control and quality improvements differ but are no less important than those for public reporting.

Public reporting can assist facilities' move toward the elimination of SSIs. Improved models will improve risk adjustment and more accurately assess individual facility perfor-

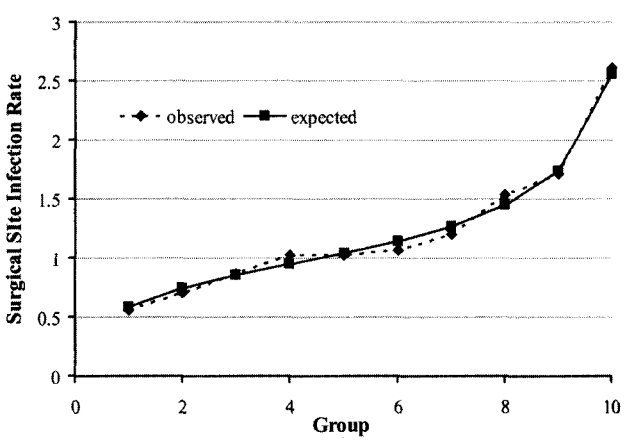

FIGURE 1. Partition for the Hosmer and Lemeshow test (goodness-of-fit).

https://doi.org/10.1086/665313 Published online by Cambridge University Press

mance (eg, interfacility comparison of SIRs or an evaluation of the facility's performance over time). As surgical techniques evolve and the prevalence of patient-level risk factors increases, the need to reevaluate these models will grow. Hospitals and surgeons will insist that risk adjustment methods adequately account for modifiable and nonmodifiable risk factors. As public reporting of CABG SSIs becomes widespread, it is imperative that risk adjustment both achieves credibility among surgeons and satisfies public reporting needs.

ACKNOWLEDGMENTS

We thank the NHSN participants for their efforts to monitor infection and improve patient safety.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article. All authors submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and the conflicts that the editors consider relevant to this article are disclosed here.

Address correspondence to Sandra I. Berríos-Torres, MD, 1600 Clifton Road NE MS A-31, Atlanta, GA 30329 (zbn6@cdc.gov).

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

REFERENCES

1. De Frances CJ, Lucas CA, Buie VC, Golosinskiy A. *2006 National Hospital Discharge Survey*. National Health Statistics Reports, no. 5, July 30, 2008. http://www.cdc.gov/nchs/data/nhsr/nhsr005.pdf. Accessed November 12, 2010.
2. Horan TC, Gaynes RP, Martone WJ, Jarvis WR, Emori TG. CDC definitions of nosocomial surgical site infections, 1992: a modification of CDC definitions of surgical wound infections. *Infect Control Hosp Epidemiol* 1992;13:606–608.
3. Abboud CS, Wey SB, Baltar VT. Risk factors for mediastinitis after cardiac surgery. *Ann Thorac Surg* 2004;77:676–683.
4. The Parisian Mediastinitis Study Group. Risk factors for deep sternal wound infections after sternotomy: a prospective, multicenter study. *J Thorac Cardiovasc Surg* 2006;111:1200–1207.
5. Risnes I, Abdelnoor M, Almdahl SM, Svennevig JL. Mediastinitis after coronary artery bypass grafting risk factors and long-term survival. *Ann Thorac Surg* 2010;89:1502–1510.
6. Olsen MA, Lock-Buckley P, Hopkins D, Polish LB, Sundt TM, Fraser VJ. The risk factors for deep and superficial chest surgical-site infections after coronary artery bypass graft surgery are different. *J Thorac Cardiovasc Surg* 2002;124:136–145.
7. Hollenbeak CS, Murphy DM, Koenig S, Woodward RS, Dunagan WC, Fraser VJ. The clinical and economic impact of deep chest surgical site infections following coronary artery bypass graft surgery. *Chest* 2000;118:397–402.
8. Zerr KJ, Furnary AP, Grunkemeier GL, Bookin S, Kanhere V, Starr A. Glucose control lowers the risk of wound infection in diabetics after open heart operations. *Ann Thorac Surg* 1997;63:356–361.
9. Harrington G, Russo P, Spelman D, et al. Surgical-site infection rates and risk factor analysis in coronary artery bypass graft surgery. *Infect Control Hosp Epidemiol* 2004;25:472–476.
10. Braxton JH, Marrin CAS, McGrath PD, et al. 10 year follow-up of patients with and without medisatinitis. *Semin Thorac Cardiovasc Surg* 2004;16:70–76.
11. Russo PL, Spelman DW. A new surgical-site infection risk index using risk factors identified by multivariate analysis for patients undergoing coronary artery bypass graft surgery. *Infect Control Hosp Epidemiol* 2002;23:372–376.
12. Haley RW, Culver DH, White JW, et al. The efficacy of infection surveillance and control programs in preventing nosocomial infections in United States hospitals. *Am J Epidemiol* 1985;121:182–205.
13. Brandt C, Hansen S, Sohr D, Daschner F, Ruden H, Gastmeier P. Finding a method for optimizing risk adjustment when comparing surgical-site infection rates. *Infect Control Hosp Epidemiol* 2004;25:313–318.
14. American Society of Anesthesiologists. New classification of physical status. *Anesthesiology* 1963;24:111.
15. Culver DH, Horan TC, Gaynes RP, et al. Surgical wound-infection rates by wound class, operative procedure, and patient risk index. *Am J Med* 1991;91:S152–S157.
16. Roy MC, Herwaldt LA, Embrey R, Kuhns K, Wenzel RP, Perl TM. Does the Centers for Disease Control's NNIS System risk index stratify patients undergoing cardiothoracic operations by their risk of surgical-site infection? *Infect Control Hosp Epidemiol* 2000;21:186–190.
17. Friedman ND, Bull AL, Russo PL, Gurrin L, Richards M. Performance of the National Nosocomial Infections Surveillance risk index in predicting surgical site infection in Australia. *Infect Control Hosp Epidemiol* 2007;28:55–59.
18. Gaynes RP. Surgical-site infections (SSI) and the NNIS SSI risk index, part II: room for improvement. *Infect Control Hosp Epidemiol* 2001;22:268–272.
19. Association for Professionals in Infection Control. *HAI Reporting Laws and Regulation 2010*. http://www.apic.org/Resource_/TinyMceFileManager/Advocacy-PDFs/HAI_map.gif. Accessed March 5, 2012.
20. US Department of Health and Human Services. *HHS Action Plan to Prevent Healthcare Associated Infections: Appendix G*. http://www.hhs.gov/ash/initiatives/hai/index.html. Accessed July 28, 2010.
21. Centers for Medicare and Medicaid Services. *42 CFR Parts 412, 413, 415, et al. Medicare Program; Hospital Inpatient Prospective Payment Systems for Acute Care Hospitals and the Long Term Care Hospital Prospective Payment System Changes and FY2011 Rates; Provider Agreements and Supplier Approvals; and Hospital Conditions of Participation for Rehabilitation and Respiratory Care Services; Medicaid Program: Accreditation for Providers of Inpatient Psychiatric Services; Final Rule*. Federal Register, Rules and Regulations. Washington, DC: Department of Health and Human Services, 2010;75(157):50041–50681. http://edocket.access.gpo.gov/2010/pdf/2010–19092.pdf. Accessed November 3, 2010.
22. Anderson DJ, Chen LF, Sexton DJ, Kaye KS. Complex surgical site infections and the devilish details of risk adjustment: important implications for public reporting. *Infect Control Hosp Epidemiol* 2008;29:941–946.
23. Shahian DM, O'Brien SM, Filardo G, et al. The Society of Tho-

racic Surgeons 2008 cardiac surgery risk models. 1. Coronary artery bypass grafting surgery. *Ann Thorac Surg* 2009;88:S2–S22.
24. Friedman ND, Bull AL, Russo PL, et al. An alternative scoring system to predict risk for surgical site infection complicating coronary artery bypass graft surgery. *Infect Control Hosp Epidemiol* 2007;28:1162–1168.
25. Paul M, Raz A, Leibovici L, Madar H, Holinger R, Rubinovitch B. Sternal wound infection after coronary artery bypass graft surgery: validation of existing risk scores. *J Thorac Cardiovasc Surg* 2007;133:397–403.
26. Edwards JR, Peterson KD, Mu Y, et al. National Healthcare Safety Network (NHSN) report: data summary for 2006 through 2008, issued December 2009. *Am J Infect Control* 2009;37: 783–805.
27. Centers for Disease Control and Prevention. *National Healthcare Safety Network.* http://www.cdc.gov/nhsn/. Accessed June 26, 2010.
28. Centers for Disease Control and Prevention. *National Healthcare Safety Network: Denominator for Procedure Form.* http://www.cdc.gov/nhsn/forms/57.121_DenomProc_BLANK.pdf. Accessed November 12, 2010.
29. Hanley JA, McNeil BJ. A method of comparing the areas under receiver operating characteristic curves derived from the same cases. *Radiology* 1983;148:839–843.
30. Friedman ND, Russo PL, Bull AL, Richards MJ, Kelly H. Validation of coronary artery bypass graft surgical site infection surveillance data from a statewide surveillance system in Australia. *Infect Control Hosp Epidemiol* 2007;28:812–817.
31. Yokoe DS, Noskin GA, Cunningham SM, et al. Enhanced identification of postoperative infections among inpatients. *Emerg Infect Dis* 2004;10:1924–1930.
32. Cardo DM, Falk PS, Mayhall CG. Validation of surgical wound surveillance. *Infect Control Hosp Epidemiol* 1993;14:211–215.
33. Petrosillo N, Drapeau CMJ, Nicastri E, et al. Surgical site infections in Italian hospitals: a prospective multicenter study. *BMC Infect Dis* 2008;8:34.
34. National Quality Forum. *National Voluntary Consensus Standards for the Reporting of Healthcare-Associated Infection Data.* http://www.qualityforum.org/Publications/2008/03/National_Voluntary_Consensus_Standards_for_the_Reporting_of_Healthcare-Associated_Infection_Data.aspx. Accessed August 9, 2010.
35. Society for Healthcare Epidemiology of America. *Essentials of Public Reporting of Healthcare-Associated Infections: A Tool Kit.* http://www.shea-online.org/Assets/files/Essentials_of_Public_Reporting_Tool_Kit.pdf. Accessed July 22, 2010.
36. Liddell FDK. Simple exact analysis of the standardized mortality ratio. *J Epidemiol Community Health* 1984;38:85–88.
37. Rioux C, Grandbastien B, Astagneau P. The standardized incidence ratio as a reliable tool for surgical site infection surveillance. *Infect Control Hosp Epidemiol* 2006;27:817–824.
38. Geubbels E, Grobbee DE, Vandenbroucke-Grauls C, Wille JC, de Boer AS. Improved risk adjustment for comparison of surgical site infection rates. *Infect Control Hosp Epidemiol* 2006;27: 1330–1339.
39. Neumayer L, Hosokawa P, Itani K, El-Tamer M, Henderson WG, Khuri SF. Multivariable predictors of postoperative surgical site infection after general and vascular surgery: results from the patient safety in surgery study. *J Am Coll Surg* 2007;204: 1178–1187.