The risk factors for deep and superficial chest surgical-site infections after coronary artery bypass graft surgery are different

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Objective: We sought to determine risk factors for deep and superficial chest wound infections after coronary artery bypass graft surgery to develop predictive models.

Methods: We retrospectively analyzed data collected on 1980 consecutive patients undergoing coronary artery bypass surgery at our institution between January 1, 1996, and June 30, 1999, by using the Society of Thoracic Surgery database. Independent risk factors for surgical-site infection were identified with multivariate logistic regression.

Results: There were 37 (1.9%) deep chest and 46 (2.3%) superficial chest surgical-site infections. Obese diabetic patients had a 7.7-fold increased risk of deep chest infections after controlling for intra-aortic balloon pump use (odds ratio, 3.1) and postoperative transfusion (odds ratio, 2.3). Independent risk factors for superficial surgical-site infections included obesity (odds ratio, 3.1), diabetes in persons 65 years of age or older (odds ratio, 2.7), and current smoking (odds ratio, 2.5). Use of antiplatelet drugs was associated with a lower risk of superficial infections (odds ratio, 0.4). Predicted operative mortality as a marker of severity of illness was not clearly predictive of deep or superficial surgical-site infection. Mortality in the year after the operation was increased in patients with deep chest infections compared with that seen in uninfected control subjects (8/37 [21.6%] vs 114/1612 [7.1%], $P = .004$) but not in patients with superficial chest infections (7/47 [15.2%] vs 114/1612 [7.1%], $P = .075$).

Conclusions: Risk factors for deep and superficial chest surgical-site infections after coronary artery bypass surgery differ, suggesting different mechanisms of pathogenesis. Appropriate risk stratification models specific to these important outcomes must be developed.

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Up to 20% of patients undergoing coronary artery bypass graft (CABG) surgery in the United States have hospital-acquired infections within 30 days of the operation.¹ Surgical-site infections (SSIs) are among the most morbid and costly. Risk factors for CABG chest SSI consistently identified in multiple studies include obesity, diabetes, female sex, perioperative blood transfusions, reexploration for bleeding, aortic crossclamp time, and use of bilateral internal thoracic artery (ITA) grafts.²⁻¹⁸ Advanced age, chronic obstructive pulmonary disease, active smoking, connective tissue disease, reoperation, nasal carriage of *Staphylococcus aureus*, operative status, postoperative inotropic support, intra-aortic balloon pump (IABP) use, postoperative renal failure, and high preoperative

serum glucose levels (≥ 200 mg/dL) have been reported as risk factors in some studies.^{2,3,5,6,8,9,11,12,19-22}

Risk factors for SSI in patients undergoing CABG must be identified to devise strategies to minimize or eliminate them. Some success has been achieved in this endeavor. Rates of mediastinitis were reduced 2-fold by the use of mechanical clippers rather than razors for hair removal.²³ Overall SSI rates in patients undergoing elective clean or clean-contaminated operations were reduced more than 2-fold when prophylactic antibiotics were administered no more than 2 hours before incision compared with perioperative administration (0-3 hours after incision).²⁴ Zerr and associates²⁵ and Furnary and colleagues²⁶ reported a reduction in the rate of deep chest SSIs in diabetic patients to the baseline rates observed in their nondiabetic patients by means of implementation of a strict glucose-control policy.

With the ultimate objective of developing a predictive risk model for deep and superficial chest SSI, we retrospectively analyzed our experience with these complications after CABG surgery over a 42-month period by comparing patients with and without SSIs to control for severity of illness. Data on all our patients undergoing CABG surgery were collected according to the guidelines of the Society of Thoracic Surgeons (STS) national database, which was established for the purpose of risk stratification for mortality after cardiac operations. Thus the variables selected for inclusion in the database are those related to the primary outcome of mortality and include a variety of underlying medical, operative, and postoperative conditions and processes of care. We sought to determine whether these same risk factors predict chest SSI in patients with CABG.

Methods

All patients ($n = 1980$) undergoing CABG surgery at Barnes-Jewish Hospital between January 1, 1996, and June 30, 1999, were included. Data were collected prospectively. Preoperative demographics, operative details, and postoperative complications were derived from our institutional STS database. All superficial and deep chest SSIs were cross-checked for accuracy by using the hospital's ongoing infection-control database, which is maintained separately from the surgical database by the infection-control department in accordance with Centers for Disease Control and Prevention guidelines. Discrepant results were reconciled with the patient's medical record. Control subjects were excluded from the study only if data for variables found to be important in the multivariate analyses were missing (no infected subjects had missing information).

Only confirmed superficial and deep chest SSIs meeting the National Nosocomial Infections Surveillance criteria and occurring within 30 days of the operation were included in the subsequent analysis.²⁷ Deep chest SSIs were defined as involving fascial and muscle layers or organ spaces plus one of the following: (1) purulent drainage from the deep incision or organ space; (2) spontaneous dehiscence of the incision or open exploration by the surgeon in patients with fever (temperature $>38^{\circ}\text{C}$), localized

pain, or tenderness; (3) abscess or other evidence of deep infection; or (4) diagnosis of deep incisional infection, osteomyelitis, or mediastinitis by a surgeon. Superficial SSIs were defined as involving only skin and subcutaneous tissue of the incision, plus one of the following: (1) purulent drainage from the superficial incision; (2) microorganisms isolated from a culture of fluid or tissue from the superficial incision; (3) pain, tenderness, swelling, redness, or heat in a superficial incision deliberately explored by the surgeon; or (4) diagnosis of superficial incisional infection by the surgeon (assumed when antibiotic therapy was instituted).

Variables analyzed by means of univariate analysis included history of diabetes (including method of treatment), chronic obstructive pulmonary disease, congestive heart failure (including severity and previous myocardial infarction), renal failure, hypertension, hypercholesterolemia, peripheral vascular disease, and cerebrovascular accident (or transient ischemic attack). Baseline characteristics tested included body mass index (BMI; ie, weight in kg/[height in m]²), smoking history, previous cardiac surgical and nonsurgical interventions, length of hospital stay before the operation, use of inotropic drugs before the operation, number of diseased vessels, and use of various preoperative medications. Operative or postoperative variables included the number and type of blood transfusions received during and after the operation, use of ITA grafts, reexploration for bleeding, use of IABP, operative status, aortic crossclamp time, time on bypass, duration of antibiotic prophylaxis before incision, and mortality after the operation. Active surveillance for mortality in the 30 days after the operation was performed, whereas mortality after 30 days was assessed actively for patients readmitted to our hospital and by means of passive surveillance for patients who did not require readmission (primarily through reporting by physician's office staff).

Because risk factors for SSI might also be risk factors for other types of infections, control patients for all the univariate and multivariate analyses were restricted to those patients with no identified infection within 30 days of the operation. Therefore patients with sepsis, pneumonia, urinary tract infection, or any SSI (chest, radial artery, leg, and IABP site) were excluded from the control population.

Statistical analyses were performed with SPSS 10.0 software (SPSS, Inc, Chicago, Ill). Univariate analyses were performed for all relevant categorical variables by using contingency tables (χ^2 or Fisher exact tests for variables with small expected cell numbers) and t tests or the Mann-Whitney U test for continuous variables. Multivariate analyses were performed by using logistic regression, in which all variables with a P value of less than .10 in the univariate analyses or that were thought to be related to infection from the literature were included in the initial full models. All 2-way interaction factors involving categorical variables that were deemed relevant were tested in the models after selection of the independent risk factors (main effects) and were included in the final models only if they were significant.²⁸ The final models were judged to be a good fit for the data by using the Hosmer and Lemeshow goodness-of-fit test.

Results

Prevalence of Deep and Superficial SSIs and Univariate Analyses

During the 42-month study interval, 1980 patients underwent CABG surgery (isolated or in combination with an-

TABLE 1. Baseline characteristics of patients who underwent CABG surgery from January 1996 through June 1999

Characteristic	No. (%) of patients with no infection (n = 1612)	No. (%) of patients with deep chest infection (n = 37)	No. (%) of patients with superficial chest infection (n = 46)
Diabetes (total)	563 (34.9)	24 (64.9)	21 (45.7)
Oral therapy	243 (15.2)	11 (29.7)	10 (21.7)
Insulin therapy	236 (14.8)	11 (29.7)	10 (21.7)
Female sex	525 (32.6)	20 (54.1)	21 (45.7)
Race-ethnicity			
White	1409 (87.4)	28 (75.7)	39 (84.8)
African American	180 (11.2)	9 (24.3)	6 (13.0)
Other	22 (1.4)	0	1 (2.2)
Surgical data			
CABG only	1344 (83.4)	32 (86.5)	38 (82.6)
CABG + valve	168 (10.4)	4 (10.8)	5 (10.9)
CABG + other*	77 (4.8)	1 (2.7)	2 (4.3)
CABG + valve + other	23 (1.4)	1 (2.7)	1 (2.2)
Previous CABG surgery	140 (8.7)	2 (5.4)	5 (10.9)
Age (y)			
<60	493 (30.6)	11 (29.7)	20 (43.5)
60-69	520 (32.3)	8 (21.6)	13 (28.3)
70-79	470 (29.2)	14 (37.8)	8 (17.4)
>80	129 (8.0)	4 (10.8)	5 (10.9)
Obesity: BMI			
30-35	318 (19.7)	16 (43.2)	13 (28.3)
35-40	128 (7.9)	3 (8.1)	7 (15.2)
>40	47 (2.9)	4 (10.8)	7 (15.2)
Smoked cigarettes			
Ever	1090 (67.6)	22 (59.5)	36 (78.3)
Current smoker	293 (18.2)	4 (10.8)	16 (34.8)
Preexisting comorbidities (other than diabetes and obesity)			
0	328 (20.4)	4 (10.8)	6 (13.3)
1	732 (45.6)	15 (40.5)	20 (44.4)
2	363 (22.6)	13 (35.1)	14 (31.1)
≥3	182 (11.4)	5 (13.5)	5 (11.1)
Severe congestive heart failure (NYHA class III or IV)	406 (25.2)	11 (29.7)	14 (30.4)
No. of diseased vessels			
None: left main only	39 (2.4)	0	2 (4.3)
Single	216 (13.4)	3 (8.1)	4 (8.7)
Double	441 (27.4)	11 (29.7)	14 (30.4)
Triple	914 (56.7)	23 (62.2)	26 (56.5)
Operative status			
Emergency	101 (6.3)	3 (8.1)	1 (2.2)
Urgent	197 (12.2)	6 (16.2)	3 (6.5)
No. of ITA grafts used			
0	255 (15.8)	5 (13.5)	6 (13.0)
1	1322 (82.2)	29 (78.4)	37 (80.4)
2	32 (2.0)	3 (8.1)	3 (6.5)
Reoperation for bleeding			
Yes	85 (5.3)	2 (5.4)	4 (8.7)
No	1527 (94.7)	35 (94.6)	42 (91.3)

NYHA, New York Heart Association.

*Other category includes any additional cardiac procedure performed at the same time as the CABG surgery.

other cardiac procedure). There were 37 (1.9%) confirmed deep chest and 46 (2.3%) confirmed superficial chest SSIs. Selected presurgical patient characteristics are shown in Table 1. The ages of patients with deep or superficial chest

SSIs were not significantly different from those of patients without a postsurgical infection (Tables 1 and 2). In contrast, the mean BMI was significantly higher in patients with deep and superficial chest SSIs (Table 2) than in control

TABLE 2. Univariate analysis of categoric risk factors for deep and superficial chest infections after CABG surgery

Variable	Deep chest infections		Superficial chest infections	
	OR (95% CI)	P value	OR (95% CI)	P value
Age ≥ 65 y	1.19 (0.61-2.31)	.613	0.47 (0.26-0.87)	.014
Female sex	2.44 (1.27-4.69)	.006	1.74 (0.97-3.14)	.063
Race (nonwhite)	2.24 (1.04-4.82)	.044	1.25 (0.55-2.84)	.590
BMI 25-30	1.18 (0.39-3.53)	.774	5.55 (1.28-24.14)	.022
BMI 30-35	4.45 (1.61-12.27)	.004	9.03 (2.03-40.31)	.004
BMI 35-40	2.07 (0.49-8.79)	.323	12.09 (2.48-58.89)	.002
BMI > 40	7.52 (1.95-28.98)	.003	32.91 (6.65-163.01)	$< .001$
BMI ≥ 30	3.73 (1.90-7.31)	$< .001$	3.23 (1.78-5.86)	$< .001$
Current smoker of cigarettes	0.54 (0.19-1.54)	.244	2.39 (1.28-4.43)	.005
Diabetes (all forms of control)	3.42 (1.73-6.77)	$< .001$	1.56 (0.86-2.81)	.138
Diabetes				
Oral control	3.63 (1.61-8.20)	.002	1.72 (0.81-3.62)	.157
Insulin control	3.74 (1.65-8.44)	.002	1.77 (0.84-3.73)	.136
Hypercholesterolemia	0.96 (0.49-1.88)	.909	1.86 (0.94-3.70)	.071
≥ 2 previous MI	2.49 (1.22-5.11)	.010	0.56 (0.20-1.58)	.267
Previous TIA	3.24 (1.32-7.95)	.019	0.37 (0.05-2.73)	.513
Antiplatelet medication before the operation	1.80 (0.70-4.64)	.221	0.44 (0.24-0.80)	.006
Previous nonsurgical cardiac intervention	1.95 (1.00-3.79)	.046	1.67 (0.91-3.08)	.094
Previous atherectomy-laser therapy	0.97 (0.23-4.08)	1.000	2.54 (1.05-6.14)	.046
Previous thrombolysis	1.78 (0.54-5.94)	.419	2.47 (0.95-6.42)	.070
IABP inserted during or after CABG surgery	3.97 (1.50-10.55)	.014	0.57 (0.08-4.17)	1.000
Intraoperative cryoprecipitate	1.76 (0.23-13.37)	.448	4.43 (1.29-15.23)	.040
Intraoperative Hespan	2.21 (1.03-4.74)	.047	1.23 (0.54-2.79)	.617
Transfusion with ≥ 4 units of RBCs postoperatively	2.55 (1.27-5.15)	.007	1.67 (0.84-3.34)	.140
Transfusion with ≥ 5 units of RBCs postoperatively	3.11 (1.44-6.71)	.007	2.35 (1.12-4.97)	.037
Transfusion with ≥ 6 units of RBCs postoperatively	4.57 (2.10-9.93)	.001	2.13 (0.88-5.14)	.123
Transfusion with ≥ 2 units of platelets postoperatively	4.81 (2.21-10.46)	$< .001$	1.04 (0.32-3.42)	.763
Transfusion with ≥ 3 units of platelets postoperatively	7.29 (3.06-17.39)	$< .001$	2.18 (0.65-7.26)	.180

MI, Myocardial infarction; TIA, transient ischemic attack.

subjects. There was a trend toward increasing numbers of comorbidities (other than diabetes and obesity, which were examined separately) in patients with deep chest SSIs ($P = .079$, χ^2 test for linear trend) but not in patients with superficial chest SSIs ($P = .269$).

Mortality in the first year after the operation was significantly higher in patients with deep chest SSIs than in control subjects (8/37 [21.6%] vs 114/1612 [7.1%]; odds ratio [OR], 3.63; 95% confidence interval [CI], 1.62-8.11; $P = .004$), although there was no difference in mortality within 30 days ($P = .438$). Five of the 8 patients with deep chest SSIs who died within a year of their operation also had sepsis in the month after the operation. Patients with superficial chest SSIs were more likely to die in the first year after the operation than control patients with no infections, although this was only marginally significant (7/46 [15.2%]

vs 114/1612; OR, 2.36; 95% CI, 1.03-5.39; $P = .075$). Three of the 7 patients with superficial chest SSIs who died within a year of the operation also were septic postoperatively. Patients with a harvest-site infection in the month after the operation were more likely to have a superficial chest SSI diagnosed than patients without harvest-site infection (6 [7.0%] patients with both a superficial chest SSI and harvest-site infection of 86 total with harvest-site infection compared with 37 [2.1%] patients with superficial chest SSI of 1791 without harvest-site infection; $P = .012$, Fisher exact test). In contrast, there was no association between harvest-site infection and deep chest SSI (1/86 [1.2%] vs 32/1791 [1.8%], $P = 1.00$).

The microbiology of deep and superficial chest SSI was very similar, although less than one half of the patients with superficial chest SSIs had wound cultures collected. *Staph-*

TABLE 3. Univariate analysis of continuous variables as risk factors for deep and superficial chest infections after CABG surgery

Variable	Patients with deep chest SSIs	Patients with superficial chest SSIs	Control subjects with no postoperative infection	P value for deep chest SSIs*	P value for superficial chest SSIs*
Age (y)	68 (56-76)	62 (55-72)	66 (57-73)	.42	.128
BMI	30.4 (26.6-33.0)	31.7 (26.5-36.3)	27.7 (24.6-30.9)	.004	<.001
Crossclamp time (min)	73 (55-87)	83 (67-108)	85 (64-109)	.015	.920
Time on CPB (min)	126 (101-147)	123 (102-156)	138 (107-168)	.075	.226
Lowest core temperature (°C)	32 (30-33)	32 (30-33)	32 (31-33)	.715	.377
Duration of antibiotic prophylaxis before incision (min)	60 (44-80)	65 (52-85)	65 (50-80)	.547	.792
Length of procedure (min)	297 (251-354)	311 (284-373)	305 (258-360)	.635	.229
Predicted mortality†	2.95 (1.41-6.06)	1.67 (1.09-2.60)	2.02 (1.07-3.92)	.082	.415
Chest tube drainage (mL)	575 (425-1100)	655 (398-1019)	771 (509-1160)	.282	.198
Days on mechanical ventilation‡	0.5 (0-0.8)	0.3 (0-0.7)	0.4 (0.2-0.7)	.340	.247

Values are given as medians (interquartile ranges) where shown.

*Compared with control patients with no infection during the 30 days after the operation (Mann-Whitney *U* test).

†Percent predicted mortality calculated with the STS software.

‡After the operation.

Staphylococcus aureus was isolated from 54% of patients with deep chest SSIs (18/33 patients) and from 41% of patients with superficial chest SSIs (9/22 patients). Gram-negative bacilli were isolated from approximately one fourth of patients (8/33 patients with deep SSIs and 5/22 patients with superficial chest SSIs), whereas coagulase-negative staphylococci were isolated slightly more frequently from patients with superficial than those with deep chest SSIs (6/22 vs 4/33 patients).

Results of the univariate analyses for categoric risk factors found to be significantly associated with deep or superficial chest SSIs are shown in Table 2, and the results for continuous variables are shown in Table 3. After correction for testing multiple variables (Bonferroni correction), only obesity (BMI ≥ 30), diabetes, and transfusion of 6 or more units of packed red blood cells (pRBCs) or 2 or more units of platelets postoperatively were significantly associated with deep chest SSI. A dose-response relationship between deep chest infection and the number of units of pRBCs or platelets is evident (Table 2). Obesity was also significantly associated with superficial chest SSI (Tables 2 and 3). A dose-response relationship was apparent between increasing categories of BMI and superficial chest SSI (χ^2 test for trend = 27.303, $P < .001$, Table 2). A significant dose-response relationship increasing categories of BMI and deep chest SSI also existed, although the increase in ORs was not as striking as that seen for superficial chest SSI (χ^2 test for trend = 13.394, $P < .001$, Table 2).

Predicted Risk of Mortality and Prevalence of Deep and Superficial SSI

Interestingly, almost no other variables representing underlying severity of illness other than diabetes and obesity were

significantly associated with deep or superficial chest SSI by means of univariate analysis. Rates of infection were compared with the predicted risk of mortality computed with the STS software to confirm this.²⁹ The rates of superficial chest SSI showed no correlation with the predicted risk of mortality (Figure 1), irrespective of whether the predicted risk categories were split into quartiles, quintiles, or traditional risk groups (Figure 1). The correlation of deep chest SSI with predicted risk of mortality was dependent on the way in which the predicted risk of mortality was categorized. If predicted risk was categorized by quintiles or more traditional risk groups (Figure 1), there was a significant trend toward increasing risk of deep chest SSI with increased predicted mortality ($P = .035$ for quintiles and $P = .049$ for grouping shown in Figure 1, χ^2 test for trend). If, however, predicted risk was categorized as quartiles, the trend was no longer statistically significant ($P = .129$, χ^2 test for trend). In contrast, significant linear trends of increasing risk of SSI with increasing predicted risk of mortality were observed for all the systemic infections recorded in the STS database, no matter how predicted risk was categorized.³⁰

Predictors of Deep SSI From the Multivariate Analyses

The results of the multivariate analyses to identify independent risk factors associated with deep chest SSI are shown in Table 4. Obesity, diabetes, transfusion of 4 or more units of pRBCs postoperatively, and IABP insertion during or after the operation were all independent risk factors for deep chest SSI. Additional multivariate models were created to assess interactions between variables. In Table 5 the interaction of obesity and diabetes was compared for deep and superficial infection after controlling for respective independent risk fac-

Figure 1. Percentage of patients with deep or superficial chest SSIs according to preoperative predicted mortality. The percentage of predicted operative mortality, calculated by using the STS software, was categorized into 4 groups: 0% to 1.99%; 2% to 4.99%; 5% to 9.99%; and 10% and greater. The percentage of patients with deep or superficial chest SSIs was determined within each category of predicted mortality.

TABLE 4. Multivariate analysis of independent risk factors for deep and superficial chest SSI

Risk factor	Deep chest infections		Superficial chest infections	
	OR (95% CI)	P value	OR (95% CI)	P value
Obesity (BMI ≥ 30)	3.36 (1.69-6.67)	.001	3.50 (1.92-6.40)	<.001
Diabetes	2.85 (1.42-5.70)	.003		
≥ 4 units pRBCs postoperatively	2.39 (1.13-5.06)	.022		
IABP	2.81 (0.98-8.03)	.054		
Current smoking			2.68 (1.43-5.03)	.002
Antiplatelets			0.39 (0.21-0.73)	.003

tors. Compared with control subjects, obese diabetic patients were at greatest risk of both superficial and deep chest SSI. Obese patients who did not have diabetes were at increased risk of superficial, but not deep, chest SSI. Nonobese diabetic patients were not at increased risk for either. Thus the relative contributions of obesity and diabetes to deep and superficial SSI appear different, with obesity alone being the primary risk factor for superficial SSI, whereas for deep SSI, the interaction of obesity and diabetes confers the greatest risk.

A second multivariate model for deep chest SSI includes the interaction of postoperative transfusion and obesity (Table 6). Among nonobese (BMI ≤ 30) patients, deep chest SSI was more likely to occur in those who received 4 or more units of pRBCs postoperatively than among those who did not. This relationship was also apparent if 2 or more

units of platelets was used to define increased rates of transfusions postoperatively (adjusted OR for deep chest SSI in nonobese persons who received 2 or more units of platelets postoperatively = 14.2; 95% CI, 4.6-44.0; $P < .001$). In contrast, obese individuals were just as likely to have a deep chest SSI, irrespective of whether they required transfusions (risk of deep chest SSI in obese patients who received ≥ 4 units of pRBC vs obese patients who received < 4 units of pRBCs, $P = .552$). The lack of a relationship between increased rates of transfusions and deep chest SSI in obese individuals was confirmed when transfusion was defined as receipt of 2 or more units of platelets postoperatively (comparison of deep chest SSI in obese patients who received ≥ 2 units of platelets postoperatively and obese patients receiving < 2 units of platelets, $P = 1.0$).

TABLE 5. Risk of superficial and deep chest infections according to coexisting obesity, diabetes, or both*

Category	Deep chest infections			Superficial chest infections		
	No. of infected patients/total in category (%)	OR† (95% CI)	P value	No. of infected patients/total in category (%)	OR‡ (95% CI)	P value
Neither diabetic nor obese	9/778 (1.2)	1.0		11/780 (1.4)	1.0	
Diabetic only	5/351 (1.4)	1.2 (0.4-3.6)	.761	8/354 (2.3)	1.7 (0.7-4.4)	.238
Obese only	4/277 (1.4)	1.3 (0.4-4.2)	.682	14/287 (4.9)	3.9 (1.7-8.8)	.001
Both diabetic and obese	19/237 (8.0)	7.7 (3.4-17.4)	<.001	13/231 (5.6)	4.7 (2.1-10.9)	.001

*Compared with 1607 control patients with no infections during the 30-day postoperative period.

†OR for deep chest infections after controlling for 4 or more units of pRBCs transfused postoperatively (adjusted OR, 2.3; 95% CI, 1.1-5.0) and IABP placed during or after the operation (adjusted OR, 3.1; 95% CI, 1.1-8.9).

‡OR for superficial chest infections after controlling for current smoking (adjusted OR, 2.8; 95% CI, 1.5-5.2) and antiplatelet use before the operation (adjusted OR, 0.4; 95% CI, 0.2-0.7).

TABLE 6. Postoperative transfusion is a risk factor for deep chest infections in nonobese patients but not in obese patients

Obesity	≥4 units of pRBCs postoperatively	No. of infected patients/total in category (%)		ORs* (95% CI)	P value
		No. of infected patients/total in category (%)	ORs* (95% CI)		
No	No	6/939 (0.6)	1.0		
No	Yes	8/194 (4.1)	5.9 (2.0-17.7)	.001	
Yes	No	19/443 (4.3)	6.0 (2.4-15.3)	<.001	
Yes	Yes	4/73 (5.5)	6.5 (1.7-24.2)	.006	

*ORs adjusted for diabetes (adjusted OR, 2.9; 95% CI, 1.4-5.8) and IABP placed during or after the operation (adjusted OR, 2.8; 95% CI, 1.0-8.0).

TABLE 7. Younger, but not older, diabetic patients have increased risk for superficial chest infection

Diabetes	Age ≥65 y	No. of infected patients/total in category (%)		ORs* (95% CI)	P value
		No. of infected patients/total in category (%)	ORs* (95% CI)		
No	No	11/474 (2.3)	1.0		
No	Yes	14/593 (2.4)	1.4 (0.6-3.3)	.413	
Yes	No	18/273 (6.6)	2.7 (1.2-6.0)	.013	
Yes	Yes	3/312 (1.0)	0.5 (0.1-2.0)	.354	

*ORs adjusted for obesity (BMI ≥30; adjusted OR, 3.1; 95% CI, 1.7-5.8), current smoking (adjusted OR, 2.5; 95% CI, 1.3-4.9), and antiplatelet use before the operation (adjusted OR, 0.4; 95% CI, 0.2-0.8).

Predictors of Superficial Chest SSI in the Multivariate Analysis

The multivariate model for superficial chest SSI included the independent risk factors of obesity, current smoking, and use of antiplatelet drugs before the operation (Table 4). In a separate model analyzing the interaction between age (<65 years) and diabetes, increased risk of superficial chest SSI was limited to younger diabetic patients, with an OR of 2.7 compared with younger patients without diabetes (after adjusting for other risk factors in the multivariate model, Table 7). Older diabetic patients were not at increased risk of superficial chest SSI and were also less likely than younger diabetic patients to be obese (31% vs 49%; $P < .001$, χ^2 test) and less likely than younger diabetic patients to be receiving insulin therapy (38% vs 47%; $P = .028$, χ^2 test). The increased risk of superficial chest SSI in younger diabetic patients remained significant after adjusting for BMI as a continuous variable, suggesting that some factor other than obesity was responsible for this increased risk in these patients.

Adjusted Risk of Infection by Surgeon

The results from the multivariate models were then used to examine the association of individual staff surgeons and residents with deep and superficial chest SSIs. The percent-

age of patients with superficial chest SSIs varied from 0% to 7.7% for the 17 individual residents with a sufficient number of procedures to analyze and from 0% to 12.5% for 12 individual attending surgeons. For deep chest SSI, rates ranged from 0% to 7.1% for individual residents and from 0% to 4.7% for individual attending surgeons. We chose to analyze the odds of SSI according to resident by creating a categorical variable, including all individual residents whose rate of infection was above the mean rate (2.3% for superficial infection and 1.9% for deep chest infection) and using all individuals at or below the mean as the single reference category. The ORs for superficial and deep SSIs were calculated for the residents and attending surgeons after adjusting for the independent risk factors identified in the multivariate analyses. Six residents had significantly elevated ORs for superficial chest SSIs by using this criteria (OR range, 3.8-10.6), and 3 of these same residents had significantly elevated ORs for deep chest SSIs (ORs of 4.5, 5.7, and 13.5, respectively). The same analyses performed for attending surgeons identified 3 surgeons with significantly elevated ORs for superficial chest SSIs (ORs of 2.2, 3.6, and 9.7, respectively), and one surgeon with a significantly elevated OR for deep chest SSIs (OR, 4.6).

During the 42-month time period of this study, one outbreak of 6 deep chest SSIs associated with one individual

resident occurred (OR, 13.5). The dates of operation for the outbreak cases were clustered in a 25-day period, and the infections were associated with a variety of different bacteria (no common organism). After exclusion of the 6 outbreak cases from analysis, the one surgeon identified above no longer had an elevated OR for deep chest SSI. In contrast, no outbreaks of superficial chest SSI were identified, and the same 3 surgeons had significantly elevated ORs for superficial chest SSI when the ORs of superficial SSI were calculated for surgeons after controlling for residents in the multivariate model.

Discussion

This analysis of risk factors for deep and superficial chest SSI after CABG surgery indicates that the risk factors for the 2 types of SSI differ. Increased risk of deep chest SSI was associated with a combination of obesity and diabetes, whereas increased risk of superficial chest SSI was associated primarily with obesity and, to a much lesser extent, diabetes. The placement of an IABP during or after the operation and postoperative transfusions were independent risk factors for deep chest SSI, whereas current smoking was a risk factor specifically for superficial chest infections, and antiplatelet use was protective of superficial chest SSI.

The risk of superficial chest SSI was significantly increased in patients with a harvest-site infection in the month after the operation in comparison with patients without a harvest-site infection. The majority of the harvest SSIs in our patient population were superficial infections, and thus the increased risk of only superficial chest, but not deep chest, SSI might be due to common risk factors for superficial infection.³¹ Mortality was significantly increased in patients with deep chest SSIs in the year after CABG surgery in comparison with that seen in uninfected control subjects. Although our assessment of mortality beyond the first month after the operation relied primarily on passive reporting, the 22% mortality rate observed in our patients with deep chest SSIs is consistent with that reported previously in other studies.^{11,32,33} Interestingly, we also found an increased risk of 1-year mortality in patients with superficial chest SSIs compared with that seen in uninfected control subjects, attesting to the clinical importance of these outcomes.

Association of Deep Chest SSI With Predicted Mortality

Consistent with the lack of association between superficial chest SSI and number of comorbidities and the results of the multivariate analysis, we did not observe an association between the predicted risk of mortality and the prevalence of superficial chest SSI. The association between predicted risk of mortality and deep chest SSI was equivocal and depended on the categorization of the predicted risk. In

contrast, we have found that the prevalences of sepsis and pneumonia in the month after CABG surgery are linearly related to increasing predicted mortality.³⁰ Hattler and colleagues³⁴ have previously reported significantly increased risks of mediastinitis and septicemia in patients with a 30% predicted risk of mortality or higher compared with that seen in patients with the lowest risk of mortality. This difference might have been due to the small number of cases during our study period. Clarification of this result will likely require a multi-institutional analysis of a larger number of patients.

Increased Risk of Deep Chest SSI in Obese Diabetic Patients

The increased risk of deep chest SSI in obese, but not in nonobese, diabetic patients might be due to poor glucose control. Increased risk of deep chest SSI after CABG surgery has been demonstrated in diabetic patients with preoperative serum glucose levels exceeding 200 mg/dL.²² Diabetic patients with serum glucose levels of less than 200 mg/dL were not at increased risk. Furthermore, implementation of a strict glucose-control regimen has been shown to reduce deep chest SSIs in diabetic patients to the baseline rate for patients without diabetes.^{25,26} Unfortunately, we do not have data on perioperative glucose levels for the study patients; however, obese diabetic patients are more likely to have high serum glucose levels than nonobese diabetic patients.³⁵

Transfusion as a Risk Factor for Deep Chest SSI

In both the stratified and multivariate analyses, nonobese patients receiving large numbers of transfusions were at increased risk of deep, but not superficial, chest SSI. This increased risk might be attributed to immunosuppressive effects of blood transfusion, the presence of a hematoma to act as a culture medium for bacterial growth, or the possibility that bleeding is indicative of compromised wound closure. Receipt of blood products after CABG surgery has previously been associated with prolonged hospital stay and an increased incidence of sepsis and pneumonia.^{18,36} Other investigators have suggested that white blood cells contaminating pRBC and platelet units might act as immunomodulators.¹⁸ Interestingly, obese patients requiring transfusion were not at increased risk of deep chest infection in this study. This could be a statistical artifact given the small number of obese patients with deep chest SSIs who required multiple transfusions.

Additional Risk Factors for Deep and Superficial Chest SSI

Active smoking was an independent risk factor for superficial chest SSI, possibly because of impaired cutaneous circulation. Conversely, use of antiplatelet medication before the operation was associated with a decreased risk of

superficial chest infections, but not deep chest infections, possibly as a result of improved circulation. Neither of these factors was associated with deep chest SSI. Placement of an IABP during or after the operation was associated with an increased risk of deep chest SSI, possibly reflecting a relationship between tissue perfusion and infection. Because the number of patients in our study who required an IABP was small (66 patients), this finding requires confirmation in larger studies.

Analysis of Surgeon and Resident Rates of Infection After Risk Adjustment

We used the results of our multivariate models to control for independent risk factors in analyzing infection rates for surgical staff. Several residents and staff surgeons had adjusted rates of superficial chest infections significantly higher than those of their peers, which was not a surprising finding given the large number of individual residents and surgeons involved. What was of interest, however, was that 3 residents were found to have significantly higher rates of both superficial and deep chest SSI than their peers. This suggests that this type of risk-adjusted comparison could be used on an ongoing basis for identification of surgical practices associated with higher than expected rates of infection and could be the basis for education and intervention.

Study Limitations and Strengths

As in most previous reports, the principle limitation of this study is the small numbers of superficial and deep chest SSIs. Resolution of this will likely require a multi-institutional approach because of the low prevalence of these infections in most centers. Despite this, the numbers of superficial and deep SSIs in this study are still larger than those in most other published reports. Furthermore, our study benefits from the rigor of the data set, with confirmation of SSI by using National Nosocomial Infections Surveillance criteria to verify the identification of deep and superficial infections. The STS database includes a large quantity of information on potential risk factors, although admittedly some potential predictor variables are not available, such as oxygen saturation. Our database does, however, include information concerning the number of units of transfused blood products, duration of antibiotic prophylaxis, and other data added at the request of our infection-control program. Because our database included information on a variety of other infectious outcomes, we were also able to exclude patients with other infections as control subjects.

Our multivariate analysis of risk factors for deep and superficial chest SSIs included all potentially relevant 2-way interaction factors. We were interested in the interaction of obesity and other factors in this patient population

to determine whether there are unique groups of patients undergoing CABG who are at increased risk of infection because of their combination of different risk factors. We identified obese diabetic and nonobese individuals with excessive bleeding postoperatively as being at higher risk of deep chest infections. There was no interaction between diabetes and receipt of bilateral ITA grafts because the number of patients who received bilateral ITA grafts during the interval of this study was very small. To our knowledge, only 2 previous studies^{22,37} have included an analysis of interactions between variables to determine whether particular subsets of patients are at increased risk of infection, although only one of these studies analyzed specifically the risk of deep chest SSI.²²

The major strength of this study was the construction of separate models to discriminate between risk factors for deep versus superficial chest SSI. Of the many previous studies of chest wound infections in patients undergoing CABG, most have analyzed risk factors for superficial and deep chest SSIs together (ie, reported risks for chest infections^{2,3,5,7,14}) or have analyzed deep chest infections or mediastinitis only.^{6,11,16,17,19,22} In addition, some studies have pooled the analyses to include patients with any SSI, obscuring the delineation of risk factors specific to chest or harvest-site infections.^{9,12,13,15,37} Our analysis of deep and superficial chest SSI separately has allowed for the discrimination of risk factors unique to each infection, emphasizing the difference in the 2 types of infection.

Relevance to Infection Control

The goal of this analysis was to use the knowledge of risk factors to develop strategies to reduce the incidence of SSI in patients undergoing CABG. The most obvious strategy to reduce the incidence of deep chest SSI supported by the findings of this study is the implementation of a diabetic protocol^{25,26} to maintain adequate serum glucose levels in obese diabetic patients. Another potential method to reduce the risk of deep chest SSI is the use of antibiotic prophylaxis in patients at increased risk because of transfusion with very large amounts of blood products postoperatively. Prophylaxis of multiply transfused patients cannot be recommended on the basis of this study alone because the time after the operation that transfusions were given is not known. A further method to reduce the risk of deep chest SSI in multiply transfused patients involves the use of white blood cell-depleted blood products, although it is not clear from the results of randomized clinical trials that this reduces the risk of SSI.¹⁸ Development of interventions to reduce the risk of superficial chest SSI are more difficult to envision because the risk factors for these infections cannot be directly modified by physicians or infection-control personnel. Clearly more work needs to be done in the area of infection control to develop new interventions to reduce the risk of SSI in patients undergoing CABG surgery.

Summary

Deep chest SSI continues to be a serious complication of CABG surgery, carrying with it the prospect of substantial morbidity, increased mortality, and high costs. Superficial chest SSI results in additional, albeit less profound, morbidity and increased costs. We have demonstrated different independent risk factors for the 2 infections, suggesting different mechanisms of pathogenesis. We have also identified specific combinations of risk factors that place patients at particularly high risk. These results further suggest that risk stratification can be used to adjust rates of infection associated with individual surgeons for the purpose of quality-improvement programs.

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