The Clinical and Economic Impact of Deep Chest Surgical Site Infections Following Coronary Artery Bypass Graft Surgery*

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Study objectives: **To examine how deep chest surgical site infections following coronary artery bypass graft (CABG) surgery impact hospital inpatient length of stay (LOS), costs, and mortality.**
Setting: **A large, Midwestern community medical center.**
Design: **All CABG patients who developed deep chest infection (n = 41) were compared to a set of control subjects (n = 160) systematically selected as every tenth uninfected CABG patient. Clinical data were abstracted from patient records, and cost information was obtained from the cost accounting database of the hospital.**
Results: **Variables that significantly increased the risk of deep chest surgical site infection included obesity (odds ratio [OR], 11; p = 0.0001), renal insufficiency (OR, 8.9; p = 0.0001), connective tissue disease (OR, 25.4; p = 0.0003), reexploration for bleeding (OR, 8.2; p = 0.0015), and the timing of antibiotic prophylaxis (> 60 min before incision; OR, 5.3; p = 0.0128). Within 1 year postoperatively, patients with deep chest surgical site infection had a mortality rate of 22%, vs 0.6% for uninfected patients (p = 0.0001). Infected patients also incurred an average of 20 additional hospital days (p = 0.0001). Univariate analysis indicated that patients who developed deep chest surgical site infection incurred $20,012 in additional costs in the first year (p = 0.0001). Infected patients who died incurred on average $60,547 more than infected patients who survived (p = 0.034). Multivariate analysis confirmed the magnitude of the estimate of the cost for deep chest surgical site infection ($18,938; p = 0.0001).**
Conclusions: **Deep chest surgical site infections following CABG surgery are associated with significant increases in LOS, hospitalization costs, and mortality. These results suggest the need for improved infection control measures to reduce deep chest surgical site infection rates.**
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Key words: coronary artery bypass graft; hospital costs; surgical site infection

Abbreviations: CABG = coronary artery bypass surgery; NNIS = National Nosocomial Infection Surveillance; OR = odds ratio; RCC = ratio of cost to charges

There are approximately 470,000 coronary artery bypass graft (CABG) procedures performed annually in the United States.[1] Surgical site infections complicating CABG procedures are significant in terms of morbidity, mortality, and economic impact.[2–6] Host risk factors contributing to the risk of chest surgical site infections have been described extensively in the literature and include obesity, diabetes mellitus, use of internal mammary artery grafts (especially when bilateral), advanced age, male gender, COPD, smoking, prolonged mechanical ventilation, steroids, and preoperative hospital stay > 5 days. Surgical risk factors include duration of surgery and perfusion time, use of an intra-aortic balloon pump, postoperative bleeding, reoperation, sternal rewiring, extensive electrocautery, shaving with razors, and use of bone wax.[1,5,7] Readmission, prolonged treatment with antibiotics, sternal debridement, flap closure of the chest, and death are consequences of deep chest surgical site infections.[2,5,8]

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The National Nosocomial Infection Surveillance (NNIS) system of the Centers for Disease Control and Prevention uses a composite index for predicting risk of surgical site infection based on three risk factors: duration of surgery, wound class, and American Society of Anesthesiology score. According to the latest NNIS report, surgical site infection rates for procedures that include both a chest and donor site (leg, arm, or other chest vessel) range from 0.84% for patients with no risk factors to 17.7% in patients with all three risk factors.[3] In 1997, NNIS hospitals reported, for chest incision only, surgical site infection rates across all risk categories to be 3.7% (n = 4,343).[3] For these procedures, deep chest incisional infection rates were 0.5, 0.7, and 3.6% for patients with one, two, or three risk factors, respectively.[3]

Deep chest infections also carry a greater risk for mortality than superficial infections, and are associated with longer hospitalizations and higher excess costs.[4–7,9–12] Previous studies of the cost of surgical site infections have produced varying estimates.[6,9,13–15] The cost of surgical site infection following CABG surgery was estimated to be $886 in 1975 dollars by Pinner and colleagues,[15] and to be $5845 in 1982 dollars by Nelson and Dries.[13] More recently, the cost of surgical site infection was estimated by Haley to range from $2,734 to $26,019 in 1985 dollars,[16] to be $13,160 in 1986 dollars by Boyce and colleagues,[9] and to be $3,937 in 1991 dollars by Zoutman and colleagues.[6] Few recent studies have focused specifically on the economic impact of CABG-related surgical site infections.

Adjusted for health-care inflation, these cost estimates today would be higher, but these estimates still might not capture the true economic impact of infections. All of the previous studies included the cost of superficial chest, and deep and superficial leg infections in their estimates. Furthermore, their costs estimates were obtained by different methodologies, including implicit physician assessment,[15] appropriateness-evaluation protocol,[6] case-control,[9] and case-cohort studies.[13,14] Most of these studies were conducted in university medical centers, and there are few data on costs from private or community medical centers.[14]

In addition to risk factors contributing to surgical site infections, this study examines the additional burden imposed by deep chest surgical site infections following CABG procedures in terms of mortality, length of hospitalization, and excess costs in a large community hospital setting.

Materials and Methods

A prolonged period of high infection at the beginning of 1996 prompted aggressive surveillance and the collection of clinical data for this study. Study patients included a subset of those undergoing CABG and CABG/valve surgery at a large, Midwestern community medical center between April 1996 and March 1998. During this time, 1,519 procedures were performed with a deep chest surgical site infection rate of 2.7%. All patients were given a preoperative dose of either cefazolin (95%) or vancomycin (5%) between 0 and 138 min prior to incision as a prophylaxis against nosocomial infections. The majority of patients (94%) received the prophylaxis within 1 h prior to incision. Most of the patients receiving cefazolin were given a dose of 1 g (99%), although a few received 1.5 g (0.5%) or 2 g (0.5%). Of the patients who were given vancomycin, 75% received 0.5 g and 25% received 1 g. Hair removal prior to incision was done with a razor (133 male and 28 female patients). Skin preparation on the chest was performed with a Betadine (Purdue Frederick; Norwalk, CT)/alcohol solution or DuraPrep (3M; St. Paul, MN).

Prospective surveillance identified 41 patients who developed deep chest surgical site infections, defined as a deep incisional or organ space surgical site infection according to NNIS criteria.[17] To be counted, the infection must have (1) occurred within 30 days after the operation, or within 1 year if sternal wires were used, and (2) involved fascial and muscle layers or any organs or spaces manipulated during the operation. In addition, one of the following must have been present: (1) purulent drainage from the deep incision or organ space; (2) an organism isolated from a culture of fluid or tissue in the organ space; (3) spontaneous dehiscence or intentional opening by a surgeon as a result of fever (> 38°C), localized pain, or tenderness; (4) an abscess or other evidence of infection; or (5) diagnosis of mediastinitis by a surgeon or attending physician. A control group (n = 160) was systematically selected as every tenth uninfected patient undergoing CABG during this time period. Clinical data were abstracted from patient charts using a standardized data collection tool.

The cost analysis proceeded from the perspective of the health-care provider. Cost data were derived from the computerized internal cost accounting database for the hospital (McKesson-HBO; Atlanta, GA). This cost accounting database produces estimated costs by a ratio of cost to charges (RCC) methodology. This is a standard method of cost accounting that generates costs by multiplying patient charges in each hospital department by the RCC reported in the annual Medicare cost report of the hospital, and then adds all patient costs incurred in each department. At this hospital, cardiac surgery is included with all other surgical services in a single department. As long as the level of aggregation remains at the department level or higher, cost estimates produced by the RCC method are reasonably accurate.[18,19]

We defined total cost and length of stay as all costs and patient days accumulated for the initial CABG surgery admission plus readmissions for deep chest surgical site infection and/or related bacteremia up to 1 year postoperatively. Readmissions were carefully monitored to ensure that none were missed. All readmissions within the health system were found, and three patients with infections were readmitted to hospitals outside of the health system. Clinical information was obtained for readmissions outside the health system, but cost data were not. Connective tissue disease was defined as a diagnosis by a physician of either (1) a history of connective tissue disease, or (2) a history of or presence of systemic lupus erythematosus, rheumatoid arthritis, or scleroderma. Renal insufficiency was defined as a diagnosis by physician of renal insufficiency, dialysis, or renal failure. Obesity was also defined as a diagnosis by physician of obesity.

Univariate and multivariate analyses were performed to (1) identify demographic, preoperative, and perioperative factors that contribute to the risk of developing deep chest surgical site infection; and (2) estimate the impact of surgical site infection on length of stay, costs, and mortality. Data analyses were carried out

using SAS version 6.12 (SAS Institute; Cary, NC). Differences in patient characteristics and outcomes were tested by Student *t* tests for continuous variables and by Fisher's Exact Test for categorical variables. Results were considered significant if two-tailed p values were < 0.05.

Multivariate analysis of the risk of infection was performed by weighted logistic regression. We tested the impact of a range of demographic, preoperative, and perioperative risk factors on the probability of developing a surgical site infection. Differences in mortality between the surgical site infection cohort and the control cohort were tested by Fisher's Exact Test; differences in length of stay were tested with Wilcoxon's rank sum test. Univariate analysis of the difference in costs between infected and uninfected patients was performed with a Student *t* test. A multivariate cost analysis was also performed using linear regression to control for factors other than surgical site infection that may have had an independent effect on the cost of care for CABG patients.

Results

Demographics

Characteristics of patients are reported in Table 1 and indicate that patient groups match very closely on demographic factors such as age ($p = 0.70$), sex ($p = 0.99$), and race ($p = 0.79$). The groups were also similar in their proportions of patients with congestive heart failure ($p = 0.85$), connective tissue disease ($p = 0.11$), and duration of preoperative length of stay ($p = 0.21$). Significant differences were observed between the two groups in other variables that are suggestive of risk factors for infection. Forty-two percent of the surgical site infection group were obese vs 9% of the control group ($p = 0.0001$), 22% of the surgical site infection group had renal insufficiency vs 7% of the control group ($p = 0.0007$), and 12.2% of the cases required reexploration for bleeding during the immediate postoperative period vs 2.5% of control subjects ($p = 0.019$).

Table 1—*Characteristics of Infected vs Uninfected Patients**

Variables	No Infection (n = 160), Mean	Infection (n = 41), Mean	p Value
Demographic			
Age, yr	65	64	0.698
Black	12.5	9.8	0.79
Female	33.1	34.1	0.999
Preoperative			
Smoker	27.5	26.8	0.999
Obesity	9.4	41.5	0.0001
Diabetes	35.0	51.2	0.072
Renal insufficiency	6.9	22.0	0.0007
Connective tissue disease	0.6	4.9	0.106
COPD	21.9	31.7	0.219
Congestive heart failure	29.4	26.8	0.848
Preoperative LOS, d	2.0	2.5	0.214
Perioperative			
Radial artery graft	31.3	34.1	0.711
Intra-aortic balloon pump	5.6	9.8	0.307
Reexploration for bleeding	2.5	12.2	0.019
AB prophylaxis > 60 min before incision	3.1	14.6	0.011
Clamp duration, min	69.2	74.0	0.473
Surgery duration, min	210.8	229.3	0.085
Bilateral graft	82.5	85.4	0.817
Outcomes			
LOS, d	7.4	27.5	0.0001
Cost	$14,205.74	$34,218.10	0.006
Mortality	0.6	22.0	0.0001

*Data are presented as % unless otherwise indicated. LOS = length of stay; AB = antibiotic.

Pathology of Infections

The organisms responsible for primary infection are listed in Table 2. Similar to results reported in previous studies, the most common infecting agent was *Staphylococcus aureus*, representing 29 cases (63%).[4,7,13] Seven of these cases (24%) were methicillin resistant. There were eight cases (17%) cases that were culture positive for coagulase-negative staphylococcus species, two cases (4%) of *Escherichia coli*, and two cases (4%) of *Pseudomonas aeruginosa*. All other organisms were single occurrences. We tested whether the infections were randomly distributed across the time period or whether they occurred in clusters. Using the Wald-Wolfowitz runs test, we found no evidence that the infections occurred in clusters ($p = 0.31$).

Risk Factors for Deep Chest Surgical Site Infection

Weighted logistic regression results are contained in Table 3 and indicate that several factors were important risk factors for developing deep chest surgical site infection. Obese patients were at greater risk for deep chest surgical site infection (odds ratio [OR], 11; $p < 0.0001$). When obesity was redefined in terms of body mass index > 30, obesity was no

Table 2—*Pathology of Infections*

Organisms	Frequency, No.	%
S aureus	29	63.0
Methicillin sensitive	21	45.7
Methicillin resistant	7	15.2
Coagulase-negative staphylococcus	8	17.4
E coli	2	4.4
P aeruginosa	2	4.4
Enterococcus	1	2.2
Group B species streptococcus	1	2.2
Proteus mirabilis	1	2.2
Serratia marcescens	1	2.2
Yeast	1	2.2
Total	46	100.0

Table 3—*Factors Affecting the Likelihood of Surgical Site Infection

Variables	OR	p Value	95% Confidence Interval
Connective tissue disease	25.44	0.0003	3.31–129.85
Obesity	11.00	0.0001	4.91–25.20
Renal insufficiency	8.87	0.0001	3.08–25.38
Reexploration for bleeding	8.21	0.0015	2.00–28.23
AB prophylaxis > 60 min before incision	5.30	0.0128	1.35–19.12
Clamp duration > 75 min	2.34	0.0648	0.93–5.71
Operating room duration > 240 min	1.37	0.5301	0.52–3.70
Diabetes	1.41	0.3778	0.66–3.05
Smoker	1.16	0.7323	0.48–2.66
COPD	1.14	0.7738	0.47–2.63
Preoperative LOS > 5 d	0.92	0.8713	0.30–2.53
Internal mammary artery graft	0.86	0.7831	0.32–2.66
Congestive heart failure	0.54	0.1881	0.21–1.29
Radial artery graft	0.46	0.0826	0.19–1.07

*See Table 1 for abbreviations. C statistic = 0.82.

longer significant. Patients with renal insufficiency (OR, 8.9; p = 0.0001) were also more likely to develop a deep chest surgical site infection, as were patients with connective tissue disease (OR, 25.4; p = 0.0003), who underwent reexploration for bleeding (OR, 8.2; p = 0.0015), or whose antibiotic prophylaxis was administered > 60 min prior to incision (OR, 5.3; p = 0.0128). Patients on cardiopulmonary bypass who had an aortic cross-clamp duration > 75 min were more likely to develop a postsurgical infection (OR, 2.34; p = 0.065), but this effect was not statistically significant. None of the other variables studied were statistically significant predictors of surgical site infection in our sample, including factors that have been linked to surgical site infection in other studies, such as diabetes (OR, 1.4; p = 0.38), smoking (OR, 1.16; p = 0.73), COPD (OR, 1.14; p = 0.77), preoperative length of stay (OR, 0.92; p = 0.87), and internal mammary artery graft (OR, 0.86; p = 0.78).

These risk factors are largely consistent with those reported in previous studies.[4,7,12,20,21] Most surprising was the magnitude of the effect of connective tissue disease. Two of the three patients with diagnosed connective tissue disease developed infections. One of these patients was taking steroids. Although it is not commonly reported, other studies have also identified connective tissue disease as a risk factor for infection.[16] It seems likely that in this study, the effect of connective tissue disease is due to the small number of observations. The fact that diabetes was not significant was also surprising, since it is one of the most common risk factors noted in other studies. The reason for this was that while 51% of infected patients had diabetes, 35% of the uninfected group also had diabetes. Furthermore, our data collection tool did not distinguish between insulin-dependent diabetes and adult-onset diabetes, and we did not have information on glucose levels or glucose control. We tested whether there were interactions between diabetes and other factors such as internal or bilateral internal mammary artery grafts, and found that the interactions were also insignificant.

Clinical and Economic Outcomes

As seen in Table 1, mortality rates were much higher in the surgical site infection cohort. Only one patient in the control group died, while 22% of patients who developed deep chest surgical site infection died within 1 year (p = 0.0001). The infected cohort also accumulated more hospital days than uninfected patients, requiring an average of 20 additional hospital days vs the control group (p = 0.0001).

Table 1 also shows that patients who developed deep chest surgical site infection required more costly care than patients who did not, costing on average $20,012 more in the first postoperative year. Results of a multivariate analysis reported in Table 4 suggest that deep chest surgical site infection is one of a host of factors that increase hospital costs for a CABG procedure, and it is one of the most expensive complications. The average 1-year cost for a low-risk CABG procedure (*ie*, no deep chest surgical site infection, no renal insufficiency, no intra-aortic balloon pump, etc.) was approximately $11,002 (p = 0.085). Surgical site infection resulted in an

Table 4—*Multivariate Analysis of Factors Affecting the Cost of CABG

Variables	Parameter Estimate, $	p Value
Intercept†	11,002.00	0.0852
Surgical site infection	18,938.00	0.0001
Intra-aortic balloon pump	18,452.00	0.0039
Age > 70 yr	9,019.20	0.0062
Smoker	5,845.05	0.0958
COPD	3,049.80	0.3963
Renal insufficiency	2,104.23	0.6965
Obese	2,002.53	0.6451
Preoperative LOS	1,173.60	0.1067
Reexploration for bleeding	1,130.06	0.8751
Clamp duration, per min	131.14	0.0338
Surgery duration, per min	−56.69	0.1311
Congestive heart failure	−3,756.70	0.3034
Diabetes	−5,402.52	0.0828

*See Table 1 for abbreviation. $R^2 = 0.24$.

†The intercept represents average costs for patients with no risk factors.

additional $18,938 ($p = 0.0001$) in costs. Use of an intra-aortic balloon pump added $18,452 ($p = 0.0039$) in costs, age > 70 years added an additional $9,019 ($p = 0.0062$), and each minute the aorta was cross-clamped added an additional $131 ($p = 0.033$) in costs. Other factors tested did not significantly impact the cost of the CABG procedure.

Finally, the average cost for infected patients who survived was approximately $20,927, while the average cost for patients who died was $81,474 ($p = 0.034$). Thus, while 22% of infected patients died, these patients incurred approximately 74% of the total excess costs attributable to surgical site infection. While patients who died did have a longer average hospital stay—46 days vs 22 days—the difference was not statistically significant ($p = 0.50$).

Discussion

Patients who develop deep chest surgical site infections following CABG require more costly care and experience worse clinical outcomes than patients who do not develop deep chest surgical site infections. In our study of 201 CABG patients at a large, Midwestern community medical center, patients who developed deep chest surgical site infection had a mortality rate that was 21 percentage points higher, accumulated 20 additional hospital days, and incurred $20,012 in additional costs in the first year postoperatively. We also found that CABG patients who developed an infection and subsequently died cost approximately $60,546 more than infected patients who survived.

These estimates of the economic impact of surgical site infection following CABG surgery are substantially higher than those reported in earlier studies. Unlike previous studies of surgical site infections following CABG, superficial chest infections and leg infections were not included in our cost estimates, because deep chest infections are associated with more costly outcomes.[15] We also compared the outcomes of infected patients to a control group and used multivariate techniques to control for potentially confounding factors.

There are several limitations to this study. First, the fact that all of the patients in this study were from a single, Midwestern community hospital means that our results may not be representative of the resource utilization of CABG patients who develop deep chest surgical site infection in other settings. Second, costs used in this study were based on hospital costs generated by RCC. They cannot, therefore, be interpreted as activity-based costs. Furthermore, there are indirect costs of deep chest surgical site infection that we were unable to capture. For example, surgical site infections may be associated with lower patient satisfaction, fewer referrals, and an increased risk of litigation. While these costs are more difficult to quantify, they are no less real or important.

The fact that indirect costs are not included in our estimates implies that the cost estimates reported here actually understate the full economic impact of deep chest infections. The substantial impact of deep chest surgical site infection on both clinical and economic outcomes for CABG surgery patients highlights the need for further studies of the economic impact of infections. For example, the high cost of deep chest surgical site infections may imply that medical management of some high-risk patients may be cost-effective compared to surgical management. The results of this study also emphasize the need for improvements in infection control efforts to reduce deep chest surgical site infection rates.

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