Risk Factors Associated with Deep Surgical Site Infections After Primary Total Knee Arthroplasty

An Analysis of 56,216 Knees

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Background: Deep surgical site infection following total knee arthroplasty is a devastating complication. Patient and surgical risk factors for this complication have not been thoroughly examined. The purpose of this study was to evaluate risk factors associated with deep surgical site infection following total knee arthroplasty in a large U.S. integrated health-care system.

Methods: A retrospective review of a prospectively followed cohort of primary total knee arthroplasties recorded in a total joint replacement registry from 2001 to 2009 was conducted. Records were screened for deep surgical site infection with use of a validated algorithm, and the results were adjudicated by chart review. Patient factors, surgical factors, and surgeon and hospital characteristics were identified with use of the total joint replacement registry. Cox regression models were used to assess risk factors associated with deep surgical site infection.

Results: A total of 56,216 total knee arthroplasties were identified; 63.0% were done in women, the average age of the patients was 67.4 years (standard deviation [SD] = 9.6), and the average body mass index (BMI) was 32 kg/m^2 (SD = 6). The incidence of deep surgical site infection was 0.72% (404/56,216). In a fully adjusted model, patient factors associated with deep surgical site infection included a BMI of ≥35 (hazard ratio [HR] = 1.47), diabetes mellitus (HR = 1.28), male sex (HR = 1.89), an American Society of Anesthesiologists (ASA) score of ≥3 (HR = 1.65), a diagnosis of osteonecrosis (HR = 3.65), and a diagnosis of posttraumatic arthritis (HR = 3.23). Hispanic race was protective (HR = 0.69). Protective surgical factors included use of antibiotic irrigation (HR = 0.67), a bilateral procedure (HR = 0.51), and a lower annual hospital volume (HR = 0.33). Surgical risk factors included quadriceps-release exposure (HR = 4.76) and the use of antibiotic-laden cement (HR = 1.53). In a subanalysis, operative time was a risk factor, with a 9% increased risk per fifteen-minute increment.

Conclusions: Use of a comprehensive infection surveillance system, combined with a total joint replacement registry, identified patient and surgical factors associated with infection following total knee arthroplasty in a large sample. High-risk patients should be counseled, and modifiable clinical conditions should be optimized. Use of antibiotic irrigation should be encouraged, but antibiotic-laden cement may not be useful.

Level of Evidence: Prognostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Total knee arthroplasty is an effective and widely performed surgical procedure for the treatment of end-stage arthritis. While infrequent, deep surgical site infection following total knee arthroplasty is a devastating complication and the most common reason for reoperations[1]. As the number of total knee arthroplasty procedures is expected to rise dramatically in the coming decades[2], the burden of deep surgical site infection will also increase.

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A commentary by Donald W. Roberts, MD, is linked to the online version of this article at jbjs.org.

Prior studies have demonstrated incidence rates of infection following total knee arthroplasty ranging from 0.5% to 1.8%[3-6]. Several patient and surgical factors have been identified as risk factors for deep surgical site infection following total knee arthroplasty. These patient factors include male sex[4,7], preoperative comorbidities[4], obesity[8-11], a diagnosis of rheumatoid arthritis[7,12,13], diabetes mellitus[8,11], and prior fractures about the knee[7]. Surgical factors associated with deep surgical site infection following total knee arthroplasty include longer operative time[8,10,14], hospital case volume[15], and use of antibiotic-laden cement[7,16]. Although prior studies have identified the incidence of infection and risk factors in various samples, these studies have been limited in several ways. First, some were single-center and cohort studies that lacked the statistical power to detect this rare adverse event. Others were reports from tertiary care centers and therefore often lacked a denominator with which to calculate the rate of this uncommon event. Others were administrative database studies, which provide a large sample size and the necessary denominator, but lack details regarding patient and surgical factors and are subject to miscoding errors. National total joint replacement registries, such as the Finnish and Swedish registries, provide the necessary level of detail and the large sample sizes necessary to detect deep surgical site infections associated with total knee arthroplasty[7,13]. Studies by the Finnish and Swedish registries have been published on this topic, but since their patient populations lack heterogeneity, it may not be possible to generalize their findings to the U.S. population. U.S. registries provide a unique opportunity for evaluating deep surgical site infection associated with total knee arthroplasty in a large U.S. sample with the necessary patient and surgical variables, sample size, denominator, and follow-up.

The purpose of this study was to evaluate the cumulative incidence of deep surgical site infection following total knee arthroplasty and to identify patient, procedure, surgeon, and hospital risk factors for this devastating complication with use of a large integrated health system's total joint replacement registry and comprehensive infection surveillance system.

Materials and Methods

This study was a retrospective review of data collected prospectively by a total joint replacement registry from April 1, 2001, to December 30, 2009. During the study period, forty-five locations in six U.S. geographical regions contributed cases to the total joint replacement registry, which was used to identify the study sample. Details of the data collection and validation of the registry data have been published previously[17,18]. In brief, the registry collects information on paper forms filled out at the time of the arthroplasty procedure and enhances this information with data from the patients' electronic health records and administration claims available in this health-care system. Postoperative registry data are collected via direct reporting by the surgeons as well as electronic screening of the patients' electronic health records with a validated algorithm.

Institutional review board approval was obtained before this study was conducted.

Study Sample

All primary elective total knee arthroplasties registered in the total joint replacement registry during the study period were included in the study. Primary total knee arthroplasties for nonelective reasons as well as unicompartmental, bicompartmental, and conversion procedures (conversions from partial to total knee arthroplasty) were excluded from the study. Revision total knee arthroplasties were also excluded.

Outcome Assessment

Deep surgical site infection, as defined by the Centers for Disease Control and Prevention (CDC)/National Healthcare Safety Network (NHSN) guidelines[19], was the main outcome of this study. Infections were identified with use of a validated surveillance electronic algorithm[6], and the results then were individually adjudicated by electronic chart review by a trained clinical research assistant. Superficial deep surgical site infections were excluded from the study.

Exposures of Interest

The total joint replacement registry was used to examine the relationship between patient, surgeon, hospital, and procedural variables and deep surgical site infection. Patient characteristics included demographics (age, sex, and race), body mass index (BMI, categorized as either <35 kg/m^2 or ≥ 35 kg/m^2), diabetic status, American Society of Anesthesiologists (ASA) score as a measure of general health status (categorized as ≤ 2 or ≥ 3), and the diagnosis (osteoarthritis, rheumatoid arthritis, posttraumatic arthritis, osteonecrosis, and other) for which the arthroplasty had been performed. The average yearly volumes of the hospitals were categorized as low (fewer than 100 cases per year), medium (between 100 and 199 cases per year), or high (200 or more cases per year). The surgeons' average annual volumes were also categorized as low (fewer than twenty cases per year), medium (twenty to forty-nine cases per year), or high (fifty or more cases per year). The surgeon's arthroplasty fellowship training status was recorded and evaluated as well. Procedural variables included whether the procedure was bilateral (performed on both knees on the same day) or unilateral, type of anesthesia (epidural, general, regional, spinal, or other), infection prophylaxis measures (antibiotic irrigation, antibiotic-laden cement, clean air, intravenous antibiotics, laminar airflow, body exhaust suits, or other), type of surgical exposure (medial parapatellar, midvastus, subvastus, trivector, other, with or without a quadriceps release, and with or without a tibial tubercle osteotomy), and operative time (recorded in minutes).

Statistical Analysis

Means, standard deviations (SD), medians, and frequencies and proportions were used to describe the overall sample as well as the groups identified by the presence or absence of deep surgical site infection. Categorical patient, surgeon/hospital, and procedure characteristic distributions were compared between patients with deep surgical site infection and those without deep surgical site infection by using chi-square tests (or Fisher exact tests where appropriate). Continuous variables such as age and operative time were compared by using t tests for two independent samples. Univariate Cox proportional hazard models of association between each of the exposures of interest and the outcome were built. All variables found to be independently associated with the outcome were included in the multivariable Cox proportional hazard model. Variables that were not significant in the multivariable model and that had no effect on the associations of other variables with the outcome were removed. Hazard ratios (HR) and 95% confidence intervals (CI) are provided for identified risk factors. While the multivariable models were built, collinearity and potential confounding by covariates were assessed. Standard errors were adjusted upward with use of a modified sandwich estimator to address possible surgeon clustering. Since operative time was missing for a proportion of the cases, models were built with and without operative time to determine if operative time was a risk factor for deep surgical site infection and/or a confounder of other risk factors and infection. All models used lost-to-follow-up dates (either the time of membership termination or death) to censor patients, and the end date of the follow-up was the date on which the deep surgical site infection was diagnosed. A p value of <0.05 was used as the significance threshold.

Source of Funding

This study did not receive any external funding.

Results

A total of 56,216 primary total knee arthroplasties were identified by the registry and included in the study. The cohort consisted mostly of women (63.0%) and white (61.6%) patients. The prevalence of diabetes was 25.7%, and the average age was 67.4 years (SD = 9.6). The diagnosis for which the surgery was performed was almost always osteoarthritis (96.8%). During the study period, a deep surgical site infection developed in 404 knees (0.72%; 95% CI, 0.65% to 0.79%). In the group that developed deep surgical site infection, there was a higher prevalence of diabetes (35.9% versus 25.6%, $p < 0.001$), a higher prevalence of ASA scores of ≥3 (53.5% versus 38.2%, $p < 0.001$), a higher proportion of patients with a BMI of ≥35 (36.6% versus 26.2%, $p < 0.001$), and slightly higher percentages of patients with posttraumatic arthritis (4.2% versus 1.2%, $p < 0.001$) and osteonecrosis (1.2% versus 0.4%, $p = 0.011$). Table I shows other comparisons of characteristics between the patients with and those without deep surgical site infection.

Table II shows the comparisons of hospital surgical volume, surgeon volume, surgeon fellowship training, and procedural characteristics between the groups with and without deep surgical site infection. A higher proportion of total knee arthroplasties followed by deep surgical site infection were performed in medium-volume hospitals (24.0% versus 19.3%, $p = 0.004$), but no difference was observed on the basis of surgeon volume or surgical fellowship training status. A lower proportion of patients with deep surgical site infection had had a bilateral procedure (4.2% versus 8.6%, $p = 0.002$), spinal anesthesia (53.7% versus 60.8%, $p = 0.004$), and antibiotic irrigation for infection prophylaxis (11.4% versus 15.2%, $p = 0.032$). A higher proportion of patients with deep surgical site infection had had general anesthesia (38.9% versus 32.4%, $p = 0.006$), had received antibiotic-laden

TABLE I Patient Demographics and Characteristics in Total Sample and According to Status Regarding Deep Surgical Site Infection

	Total Sample* (N = 56,216)	No Deep Surgical Site Infection* (N = 55,812)	Deep Surgical Site Infection* (N = 404)	P Value
Female†	35,419 (63.0%)	35,225 (63.1%)	194 (48.0%)	<0.001
Race				0.003
Asian	2452 (4.4%)	2435 (4.4%)	17 (4.2%)	
Black	4154 (7.4%)	4112 (7.4%)	42 (10.4%)	
Hispanic	6715 (11.9%)	6676 (12.0%)	39 (9.7%)	
Other/multiple	1010 (1.8%)	1004 (1.8%)	6 (1.5%)	
Unknown	7273 (12.9%)	7243 (13.0%)	30 (7.4%)	
White	34,612 (61.6%)	34,342 (61.5%)	270 (66.8%)	
Diabetes	14,432 (25.7%)	14,287 (25.6%)	145 (35.9%)	<0.001
BMI†				<0.001
<30 kg/m^2	24,119 (42.9%)	23,968 (42.9%)	151 (37.4%)	
30-34 kg/m^2	16,036 (28.5%)	15,939 (28.6%)	97 (24.0%)	
≥35 kg/m^2	14,784 (26.3%)	14,636 (26.2%)	148 (36.6%)	
ASA score†				<0.001
1 or 2	33,460 (59.5%)	33,284 (59.6%)	176 (43.6%)	
≥3	21,555 (38.3%)	21,339 (38.2%)	216 (53.5%)	
Diagnosis				
Osteoarthritis	54,406 (96.8%)	54,025 (96.8%)	381 (94.3%)	0.005
Posttraumatic arthritis	689 (1.2%)	672 (1.2%)	17 (4.2%)	<0.001
Rheumatoid arthritis	1240 (2.2%)	1231 (2.2%)	9 (2.2%)	0.976
Osteonecrosis	238 (0.4%)	233 (0.4%)	5 (1.2%)	0.011
Other diagnosis	512 (0.9%)	504 (0.9%)	8 (2.0%)	0.023
Age *(yr)*				0.037
Mean (SD)	67.4 (9.6)	67.4 (9.5)	66.5 (10.4)	
Median	68	68	67	
Time to infection *(days)*				
Mean (SD)			104.4 (103.7)	
Median			52.0	

*The values are given as the number of patients with the percentage in parentheses unless otherwise indicated. †The numbers do not add up to 100% because of missing data. Missing data: nine (0.02%) for sex, 1277 (2.3%) for BMI, and 1201 (2.1%) for ASA score.

TABLE II Hospital, Surgeon, and Procedure Characteristics in Total Sample and According to Status Regarding Deep Surgical Site Infection

	Total Sample* (N = 56,216)	No Deep Surgical Site Infection* (N = 55,812)	Deep Surgical Site Infection* (N = 404)	P Value
Hospital volume				0.004†
<100 cases/yr	2214 (3.9%)	2208 (4.0%)	6 (1.5%)	
100-199 cases/yr	10,854 (19.3%)	10,757 (19.3%)	97 (24.0%)	
≥200 cases/yr	43,148 (76.8%)	42,847 (76.8%)	301 (74.5%)	
Surgeon volume				0.191
20-49 cases/yr	20,787 (37.0%)	20,626 (37.0%)	161 (39.9%)	
<20 cases/yr	3827 (6.8%)	3794 (6.8%)	33 (8.2%)	
≥50 cases/yr	31,602 (56.2%)	31,392 (56.2%)	210 (52.0%)	
Fellowship trained†	19,267 (34.3%)	19,137 (34.3%)	130 (32.2%)	0.412
Bilateral	4807 (8.6%)	4790 (8.6%)	17 (4.2%)	0.002†
Anesthesia				
Epidural	3176 (5.6%)	3153 (5.6%)	23 (5.7%)	0.970
Femoral nerve block	4376 (7.8%)	4351 (7.8%)	25 (6.2%)	0.229
General	18,225 (32.4%)	18,068 (32.4%)	157 (38.9%)	0.006†
Regional	2676 (4.8%)	2656 (4.8%)	20 (5.0%)	0.857
Spinal	34,129 (60.7%)	33,912 (60.8%)	217 (53.7%)	0.004†
Other	855 (1.5%)	849 (1.5%)	6 (1.5%)	0.953
Infection prophylaxis				
Antibiotic irrigation	8553 (15.2%)	8507 (15.2%)	46 (11.4%)	0.032†
Antibiotic-laden cement	6783 (12.1%)	6707 (12.0%)	76 (18.8%)	<0.001†
Clean air	15,432 (27.4%)	15,325 (27.5%)	107 (26.5%)	0.662
Intravenous antibiotics	52,034 (92.6%)	51,657 (92.6%)	377 (93.3%)	0.562
Laminar airflow	16,693 (29.7%)	16,588 (29.7%)	105 (26.0%)	0.102
Body exhaust suits	42,199 (75.1%)	41,903 (75.1%)	296 (73.3%)	0.402
Other	2275 (4.0%)	2262 (4.1%)	13 (3.2%)	0.396
Unknown	1326 (2.4%)	1323 (2.4%)	3 (0.7%)	0.032†
Surgical exposure				
Midvastus	9280 (16.5%)	9208 (16.5%)	72 (17.8%)	0.475
Parapatellar	37,371 (66.5%)	37,094 (66.5%)	277 (68.6%)	0.373
Subvastus	2535 (4.5%)	2520 (4.5%)	15 (3.7%)	0.439
Trivector	593 (1.1%)	590 (1.1%)	3 (0.7%)	0.538
Tibial tubercle osteotomy	21 (0.04%)	20 (0.04%)	1 (0.2%)	0.028†
Quadriceps release	50 (0.1%)	48 (0.1%)	2 (0.5%)	0.006†
Other	408 (0.7%)	404 (0.7%)	4 (1.0%)	0.530
Operative time† *(min)*				<0.001†
Mean (SD)	96.4 (33.3)	96.4 (33.3)	106.6 (41.5)	
Median	90	90		

*The values are given as the number of patients with the percentage in parentheses unless otherwise indicated. †A significant p value. ‡The numbers do not add up to 100% because of missing data. Missing data: two (<0.01%) for fellowship training status and 11,035 (19.6%) for operative time.

cement (18.8% versus 12.0%, $p < 0.001$), had had a tibial tubercle osteotomy (0.2% versus 0.04%, $p = 0.028$), and had required quadriceps release (0.5% versus 0.1%, $p = 0.006$).

Table III shows all of the univariate associations between the variables that were studied and deep surgical site infection. The univariate analysis of patient, procedure, and surgeon/hospital-volume factors showed several variables to be significantly associated with the development of deep surgical site infection. The results of the final multivariable model are shown in Table IV. This model showed that, after adjustment

TABLE III Univariate Cox Proportional Hazard Regression Model for Risk Factors for Deep Surgical Site Infection

	Hazard Ratio	95% CI	P Value
Patient characteristics			
Age: per 1-yr increment	0.99	0.98, 1.00	0.036*†
Male vs. female	1.85	1.52, 2.25	<0.001*†
Race			
Unknown vs. white	0.53	0.36, 0.77	0.001*†
Hispanic vs. white	0.74	0.53, 1.04	0.083*
Black vs. white	1.30	0.94, 1.80	0.115*
Other/multiple vs. white	0.76	0.34, 1.72	0.515*
Asian vs. white	0.89	0.54, 1.45	0.635*
Diabetes	1.63	1.33, 1.99	<0.001*†
ASA score: ≥3 vs. 1 or 2	1.91	1.57, 2.33	<0.001*†
BMI: ≥35 vs. <35 kg/m^2	1.63	1.28, 2.06	<0.001*†
Diagnosis			
Osteoarthritis	0.55	0.36, 0.84	0.005*†
Posttraumatic arthritis	3.58	2.20, 5.82	<0.001*†
Rheumatoid arthritis	1.01	0.52, 1.95	0.979
Osteonecrosis	2.96	1.23, 7.16	0.016*†
Other diagnosis	2.22	1.10, 4.47	0.025*†
Hospital/surgeon characteristics			
Hospital volume			
<100 vs. ≥200 cases/yr	0.39	0.17, 0.87	0.022*†
100-199 vs. ≥200 cases/yr	1.28	1.02, 1.61	0.033*†
20-49 vs. ≥50 cases/yr	1.17	0.95, 1.43	0.140
<20 vs. ≥50 cases/yr	1.30	0.90, 1.88	0.160
Surgeon not fellowship-trained	1.09	0.89, 1.35	0.411
Procedure characteristics			
Operative time (15-min increments)	1.11	1.07, 1.15	<0.001*†
Bilateral	0.47	0.29, 0.76	0.002*†
Anesthesia			
Epidural	1.01	0.66, 1.53	0.977
General	1.33	1.09, 1.62	0.005*†
Regional	1.04	0.67, 1.64	0.851
Spinal	0.75	0.62, 0.91	0.004*†
Infection prophylaxis			
Antibiotic irrigation	0.72	0.53, 0.97	0.033*†
Antibiotic-laden cement	1.69	1.32, 2.18	<0.001*†
Clean air	0.95	0.76, 1.19	0.664*
Laminar airflow	0.83	0.66, 1.04	0.100*
Body exhaust suits	0.91	0.73, 1.13	0.401*
Other	0.79	0.45, 1.37	0.395*
Exposure			
Midvastus	1.10	0.85, 1.41	0.478
Parapatellar	1.10	0.89, 1.36	0.371
Subvastus	0.82	0.49, 1.37	0.440
Trivector	0.70	0.23, 2.19	0.543
Tibial tubercle osteotomy	6.76	0.95, 48.10	0.056*
Quadriceps release	5.73	1.43, 23.00	0.014*†
Other	1.37	0.51, 3.68	0.527

*Variable investigated in a multivariable model. †A significant p value.

TABLE IV Final Multivariate Cox Proportional Hazard Regression Model for Risk Factors for Deep Surgical Site Infection

	Hazard Ratio	95% CI	P Value
Patient characteristics			
Age: per 1-yr increment	0.99	0.98, 1.00	0.174
Male vs. female	1.89	1.54, 2.32	<0.001*
Race			
Asian vs. white	0.99	0.60, 1.62	0.962
Black vs. white	1.23	0.88, 1.71	0.223
Hispanic vs. white	0.69	0.49, 0.98	0.038*
Other/multiple vs. white	0.74	0.33, 1.66	0.459
Unknown vs. white	0.55	0.36, 0.85	0.007*
Diabetes	1.28	1.03, 1.60	0.025*
BMI: ≥35 vs. <35 kg/m^2	1.47	1.17, 1.85	0.001*
ASA score: ≥3 vs. 1 or 2	1.65	1.33, 2.04	<0.001*
Diagnosis			
Osteoarthritis	1.19	0.66, 2.17	0.562
Osteonecrosis	3.65	1.41, 9.46	0.008*
Posttraumatic arthritis	3.23	1.68, 6.23	<0.001*
Other reason	1.48	0.69, 3.16	0.313
Hospital/surgeon characteristics			
Hospital volume			
100-199 vs. ≥200 cases/yr	1.19	0.92, 1.53	0.187
<100 vs. ≥200 cases/yr	0.33	0.12, 0.90	0.030*
Procedure characteristics			
Bilateral	0.51	0.31, 0.83	0.007*
Anesthesia: general	1.22	0.99, 1.51	0.066
Exposure			
Quadriceps release	4.76	1.18, 19.21	0.029*
Tibial tubercle osteotomy	5.28	0.73, 38.07	0.099
Infection prophylaxis			
Antibiotic irrigation	0.67	0.48, 0.92	0.014*
Antibiotic-laden cement	1.53	1.18, 1.98	<0.001*
Clean air	0.93	0.73, 1.18	0.552
Laminar airflow	0.91	0.71, 1.16	0.436
Body exhaust suits	0.87	0.68, 1.11	0.258
Other	0.72	0.41, 1.29	0.271

*A significant p value.

for other risk factors, men had a 1.89 (95% CI, 1.54 to 2.32) higher risk of deep surgical site infection than women, Hispanic patients had a lower risk than white patients (HR = 0.69; 95% CI, 0.49 to 0.98), patients with a BMI of ≥35 kg/m^2 had a 1.47 (95% CI, 1.17 to 1.85) higher risk than patients with a BMI of <35 kg/m^2, patients with a higher ASA score had a 1.65 (95% CI, 1.33 to 2.04) higher risk in comparison with patients with an ASA score of ≤2, patients with diabetes had a 1.28 (95% CI, 1.03 to 1.60) higher risk than patients without diabetes, and patients with a diagnosis of osteonecrosis (HR = 3.65; 95% CI, 1.41 to 9.46) or posttraumatic arthritis (HR = 3.23; 95% CI, 1.68 to 6.23) had a higher risk of deep surgical site infection when compared with patients without these diagnoses. Patients who had the procedure performed at a lower-volume center had a lower risk of deep surgical site infection when compared with patients treated at a high-volume center (HR = 0.33; 95% CI, 0.12 to 0.90). Those with a bilateral total knee arthroplasty had a lower risk of deep surgical site infection (HR = 0.51; 95% CI, 0.31 to 0.83), as did those who received antibiotic irrigation during the total knee arthroplasty (HR = 0.67; 95% CI, 0.48 to 0.92). The use of a quadriceps release was a significant risk factor for deep surgical site infection (HR = 4.76; 95 CI, 1.18 to 19.21). Finally, the use of antibiotic-laden bone cement was associated with a higher risk of deep surgical site infection (HR = 1.53; 95% CI, 1.18 to 1.98).

In the subanalysis of operative time, each fifteen-minute increase in operative time was found to be associated with a 9% (95% CI, 4% to 13%) increase in the risk of deep surgical site infection.

Discussion

In a large integrated U.S. health-care system with a total joint replacement registry and comprehensive infection surveillance system, the cumulative incidence of deep infection following total knee arthroplasty was 0.72% in a cohort of 56,216 primary total knee arthroplasties. This rate is similar to those reported by other national registries[7,13].

Patient Factors

Our results, which were similar to those of other studies[9,11,20], indicated that BMI, male sex[4,7,11], diabetes[21,22], and higher ASA scores[4,10] were associated with an increased risk of deep surgical site infection. In contrast to previous studies[7,12,13], we did not find an association between deep surgical site infection and rheumatoid arthritis. However, the proportion of patients with this diagnosis was small in our patient sample (2.2%) compared with the proportions in a Finnish study[7] and a Swedish study[13] (7.6% and 11.3%, respectively). The more contemporary time period of our study may also represent improvement of disease-modifying drugs, which may have influenced our findings.

Our study did not show an association between age and deep surgical site infection. This is in contrast to the findings of a single-center analysis of 8494 joint arthroplasties that included both hip and knee procedures, in which younger age was associated with an increased risk of infection[11]. Our results did confirm those by the Finnish Arthroplasty Register, containing 40,135 primary total knee arthroplasties, and those of a U.S. Medicare sample study of 69,663 total knee arthroplasties[4,7].

Unlike the relatively homogeneous populations in countries with existing national registries (Scandinavian countries), health care in the U.S. involves heterogeneous patient populations. In our study, we found Hispanic race to be protective against deep surgical site infection following total knee arthroplasty when Hispanics were compared with white patients. This finding differs from that in a study utilizing California's Office of Statewide Health Planning and Development (OSHPD) Patient Discharge Database, in which Hispanic patients were observed to have an odds ratio of 1.21 for developing deep infection following total knee arthroplasty compared with whites[23]. In contrast to a study using a Veterans Administration database that demonstrated an increased risk of infection among black patients compared with whites[24], we did not observe a significant difference between black and white patients in this regard.

Surgical Factors

Among the surgical factors, use of antibiotic-laden cement was associated with a paradoxical increase in the risk of infection. We previously reported this finding[9] and hypothesized that the effect was due to surgeon selection of high-risk patients. The authors of another study also did not find that the use of antibiotic-laden cement reduced the prevalence of deep infection following total knee arthroplasty, in a cohort of 1625 patients in which 50% had received antibiotic-laden cement[25]. Jämsen et al. reported a hazard ratio of 1.35 for infection if antibiotic-laden cement was not used[7].

The addition of antibiotics to the irrigation solution was protective against deep surgical site infection following total knee arthroplasty. The use of intravenous antibiotic prophylaxis has been well established[26] for joint arthroplasty procedures; however, the addition of prophylactic antibiotics to the irrigation fluid has never been proven to influence deep infection rates, to our knowledge. We believe that this is the first report documenting the efficacy of this widely practiced prophylactic measure. Among other commonly used prophylactic techniques, the use of operating room laminar airflow or body exhaust suits was not found to be associated with a lower risk of infection after total knee arthroplasty in our study.

Decreased operative time was also associated with a lower risk of infection following total knee arthroplasty in our study, as it was in a previous study[10]. In a subset of our data, we observed an increased risk of infection per every additional fifteen minutes of operative time. As is the case for the observed increase in the risk of infection after total knee arthroplasties in which a quadriceps release or a tibial tubercle osteotomy was required, increased operative time is likely a proxy for the complexity of the surgical procedure. In agreement with our findings, a total knee arthroplasty operative time of longer than 210 minutes, compared with less than 120 minutes, was associated with an increased risk of infection in the Medicare population[4].

Hospital Factors

We observed an increased risk of infection at high-volume hospitals compared with the risk at low-volume institutions. Referral of higher-risk patients to centers at which high-volume surgeons practice may partially explain this finding. Evaluation of total knee arthroplasty infection rates according to Nationwide Inpatient Sample data showed a greater incidence of infection in urban, higher-volume hospitals, as opposed to rural hospitals[27].

Limitations and Strengths of Study

Some limitations of this study must be highlighted. While the data were obtained from a comprehensive total joint replacement registry, there were still known infection risk factors that could not be evaluated, such as postoperative wound classification[10,28]. Wound classifications are not collected by the total joint replacement registry. Residual confounding due to selection of patients for treatment with antibiotic-laden cement is also a possible limitation of this study. Similarly, confounding due to the indications for bilateral procedures may explain our finding that bilaterality was protective against infection. Also, we did not have access to radiographic analysis or microbiological data on the infections. Finally, while we were able to identify antibiotic irrigation as a protective factor against infection, we lacked detailed information on the type and dosage of the antibiotics or the number of irrigations.

The strengths of this study include the comprehensive infection surveillance system used to identify the deep surgical site infections, the community-based sample used for the study, and the ability to evaluate many different

procedure-specific risk factors. Because of the comprehensive infection surveillance system implemented by this institution to capture all deep surgical site infection following joint arthroplasty, we had a high level of sensitivity and accuracy in capturing deep surgical site infections[6]. Our study setting, which included several medical centers with different surgeon volumes and training levels, also allowed the evaluation of different medical and surgeon characteristics and is more likely to be representative of a community-based sample. Similarly, the heterogeneity of our study sample, with different races, age groups, and characteristics, allowed for the inferences of risk in a larger representative sample of the U.S. population.

Conclusions

The findings of this study suggest that optimization of patient weight and diabetes mellitus control may decrease rates of deep surgical site infection following total knee arthroplasty. Males should be counseled about their inherent increased risk. The use of antibiotic-laden cement in routine primary total knee arthroplasty is not supported by our findings, although the addition of antibiotics to irrigation fluid appears to reduce the risk of infection. ■

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