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ORIGINAL ARTICLE

Reducing surgical site infections following total hip and knee arthroplasty: an Israeli experience

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Abstract
Purpose To assess the changes observed in surgical site infection (SSI) rates following total joint arthroplasty (TJA) after the introduction of an infection control programme and evaluate the risk factors for the development of these infections.
Design Prospective cohort study.
Setting Large tertiary medical centre in Israel.
Methods Data about SSIs and potential prophylaxis-, patient-, and procedure-related risk factors were collected for all patients who underwent elective total hip and total knee arthroplasty during the study period. Multivariant analyses were conducted to determine which significant covariates affected the outcome.
Results During the 76-month study period, SSIs (superficial and deep) occurred in 64 (4.4%) of 1554 patients. As compared with the 34 (7.7%) SSIs that occurred in the first 25 months, there were 23 (4.7%) SSIs in the following 25 months, and only 7 (1.3%) SSIs in the last third of the study ($p = 0.058$ and <0.001, respectively). A multiple logistic regression model indicated that risk factors for prosthetic joint infection were a National Nosocomial Infections Surveillance (NNIS) System surgical patient risk index score of 1 (OR 1.8; 95% CI 1.1–3.1) or 2 (OR 2.8; 95% CI 1.2–11.8). The incidence of SSI was not correlated with the timing, nor the duration of antibiotic prophylaxis.
Conclusions The introduction of preventive measures and surveillance coincided with a significant reduction in SSIs following TJA in our institution. The risk of infection correlated with higher scores in the NNIS System surgical patient risk.

Keywords Surgical site infections · Infection control · Total joint arthroplasty · Hip arthroplasty · Knee arthroplasty · Antibiotic prophylaxis

Introduction

Prosthetic joint arthroplasty is the last resort but the most effective intervention for helping people with severe osteoarthritis to regain physical function and to become free of pain. The number of primary total hip arthroplasty (THA) and total knee arthroplasty (TKA) has been increasing over the past decade with >1.000.000 such procedures performed in the USA in 2010 [1]. According to the Organisation for Economic Co-operation and Development (OECD) data, Israel has one of the lowest rates of THA and TKA among its countries members (52/100.000 population and 46/100.00 population, respectively) [2]. Infection is the most serious complication of prosthetic joint replacement. Organ space SSI (also called periprosthetic joint infection) is particularly devastating and occurs in ranges between 1 and 2.4% of THA and THA [3]. Prevention of SSI is a multifactorial enterprise comprising several environment, surgeon, and patient risk factors. Amenable to intervention factors include conditions in operating room, surgical hand preparation, antibiotic perioperative prophylaxis, use of antibiotic-containing

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cemented prosthesis, screening for *Staphylococcus aureus* carriage and subsequent decolonization, and, probably, many others. However, only some of the many measures to prevent orthopaedic surgical site infection are based on strong evidence and there is insufficient evidence to show which element is superior over any other [4].

Prior to 2004, there was no uniform programme for prevention of SSI or data collection on orthopaedic surgery at our institution. In March 2004, following the approval of the Department of Orthopaedic Surgery, an infection control programme in hip and knee arthroplasty was initiated at our institution. In this article, we report the SSI rates observed during a 76-month period study and evaluate the relationship between several variables and the risk of SSI.

Methods

Design and setting

This was a prospective study, approved by the local ethics committee and conducted at the Rambam Medical Center, Haifa, Israel, a 950-bed tertiary care teaching hospital. Data on primary THA and TKA were collected from all adult patients from 31 March 2004 to 31 July 2010 (study period). During this time, the medical staff involved in these procedures included 8–10 experienced surgeons who did not change significantly. Procedures for revision of a hip or knee prosthesis were excluded.

Data collection

Data collection was consistent throughout the entire study period, and data were obtained using computerized data collection forms developed with this objective. During the study, the collection of data was validated at regular intervals through review of most recently recorded patient files, including difficult-to-diagnose cases of SSIs. During hospitalizations, patients were evaluated daily by surgeons and 1–2 times per week by an infection control nurse who prospectively collected the data and identified cases of SSIs. All patients were followed up for the appearance of postdischarge SSIs if readmitted to our institution and by telephone contact at 30 days and, at least, 1 year after discharge. SSIs were categorized as superficial (involving skin or subcutaneous tissue) or deep (involving fascia, muscle, and joint space). Cultures were obtained as clinically indicated and were processed in the hospital's microbiology laboratory. Data about the surgical procedure, potential SSI risk factors, and infections for patients who developed SSI were collected using the criteria of the US Centers for Disease Control and Prevention [5]. The surveillance process was uniform for the duration of the study.

Infection control measures

Prior initiating the collection of data, an 8-month duration educational programme was introduced and included the dissemination of guidelines, organization of seminars involving surgeons, anaesthetists, and nurses involved in the programme, feedback events and quality circles for surgeons. General measures of our programme included the dissemination of guidelines for surgical hand preparation, the use of 4% chlorhexidine gluconate scrub shower by the patient on the night before and on the morning of the scheduled operation, depilation with a hair-removing cream and scrubbing of all operative sites with a povidone-iodine soap solution and painting with a 10% povidone-iodine ethanol tincture. Specific recommendations for perioperative antibiotic prophylaxis included: (1) the use of cefazolin, intravenously (1 g; 2 g for patients with a body weight of more than 80 kg) and intravenous vancomycin (1 g) as the alternative for patients allergic to cefazolin; (2) antibiotic administration to be started in the preoperative area 30–60 min before incision, and (3) to be continued for no more than 24 h. SSI rates and antibiotic prophylaxis practices were reported biennially. Results were discussed with surgeons, anaesthetists, and nurses involved in the programme. Surgeon and surgical-assistant-specific SSI rates reports were confidentially reported.

Prophylaxis-, patient-, and procedure-related risk factors

Duration of postoperative prophylaxis dosing was divided into 3 categories: up to 24 h, up to 48 h, and more than 48 h. Timing of administration of prophylaxis was assessed as the interval (in minutes) between the administration of the first dose and the incision, and it was divided into 5 categories: within 30 min before incision, 31–60 min before incision, 61–120 min before incision, >120 min before incision, and any time after incision. The choice of the antibiotic used for prophylaxis was also recorded. The use of antibiotic-impregnated bone was not assessed. Potentially patient- and procedure-related risk factors for SSI were recorded separately and included sex, age, physical condition of the patient (according to the American Society of Anaesthesiology (ASA) score [6] and NNIS System surgical patient risk index score [7], duration of surgery of >75th percentile, and duration of preoperative hospital stay (Table 1). The annual volume of surgery for each surgeon was also considered as possible confounder.

Table 1 Univariate analysis: association of selected variables with surgical site infection among 1454 patients following total hip and total knee arthroplasty

Variable	Patients who experienced a SSI ($n = 64$)	Patients who did not experienced a SSI ($n = 1390$)	OR (95% CI)	p[a]
Female sex	47 (5.0)	891 (95.0)	1.5 (0.9–2.7)	0.13
Age, years				
<60	12 (3.4)	339 (96.6)	Reference	
60–69	19 (4.0)	453 (96)	1.2 (0.6–2.5)	0.65
70–79	28 (5.5)	483 (94.5)	1.6 (0.8–3.3)	0.16
≥80	5 (4.2)	115 (95.8)	1.2 (0.4–3.6)	0.70
Type of operation				
Total knee replacement	44 (4.4)	942 (95.6)	Reference	
Total hip replacement	20 (4.3)	448 (95.7)	1.0 (0.6–1.6)	0.87
NNIS risk index category[b]				
0	24 (3.0)	773 (97)	Reference	
1	32 (5.6)	539 (94.4)	1.9 (1.1–3.3)	0.019
2	8 (9.3)	78 (90.7)	3.3 (1.4–7.6)	0.005
ASA score				
1	2 (2.3)	86 (97.7)	Reference	
2	36 (3.7)	947 (96.3)	1.6 (0.4–6.9)	0.50
3	25 (6.7)	350 (93.3)	3.1 (0.7–13.2)	0.13
4 and 5	1 (12.5)	7 (87.5)	6.1 (0.5–5.8)	0.15
Duration of surgery of >75th percentile	24 (6.7)	334 (93.3)	1.9 (1.1–3.2)	0.016
Antibiotic prophylaxis variables				
Duration of prophylaxis				
Up to 24 h	1 (1.5)	67 (98.5)	Reference	
Between 24 and 48 h	56 (4.4)	1218 (95.6)	3.0 (0.4–22.5)	0.35
>48 h	7 (6.3)	105 (93.7)	4.4 (0.5–37.1)	0.16
Antibiotic				
Cefazolin	64 (4.5)	1367 (95.5)	Reference	1.0
Vancomycin	0	15 (100)		
Others	0	8 (100)		
Timing of administration of first dose				
1–30 min before incision	29 (4.7)	588 (95.3)	1.14 (0.6–2.0)	0.75
31–60 min before incision	21 (4.1)	487 (95.9)	Reference	0.79
61–120 min before incision	4 (3.6)	107 (96.4)	0.86 (0.2–2.5)	1.0
>120 min before incision	1 (7.1)	13 (92.9)	1.78 (0.2–14.2)	0.45
Any time after incision	9 (4.4)	195 (95.6)	1.07 (0.4–2.3)	0.83
Duration of preoperative hospital stay, days				
1–3	61 (4.3)	1362 (95.7)	Reference	
4–6	2 (9.5)	19 (90.5)	2.4 (0.5–10.3)	0.25
≥7	1 (10.0)	9 (90)	2.5 (0.3–19.9)	0.39
Surgeons participating in the operation				
High volume[c]	51 (4.3)	1138 (95.7)	Reference	
Low volume	13 (4.9)	252 (95.1)	1.15 (0.6–2.14)	0.65

Data are no. (%) of patients, unless otherwise indicated

NNIS National Nosocomial Infections Surveillance, *ASA* American Society of Anaesthesiology

[a] Univariate analysis by χ^2 and Student's t test

[b] Includes the following elements: ASA score, wound contamination class, and duration of surgery

[c] Participation in >15% of all procedures

Statistical analysis

The first operation was selected for analysis for each patient who underwent THR or TKR, received antibiotic prophylaxis, and had complete data recorded. Logistic regression was used for the calculation of the odds ratios (ORs) with 95% confidence intervals (95% CIs) and p values in univariate modelling. Variables were selected as candidates for the multivariable analysis on the basis of the level of significance of the univariate association with the development of SSI ($p < 0.2$). According to our hypothesis, the variable timing of prophylaxis was forced into the multivariable model. Multivariable regression analysis was performed to account for these possibly confounding risk factors. The Hosmer–Lemeshow goodness-of-fit statistic was calculated. The area under the receiver operating characteristic (ROC) curve was used as a measure of model discrimination. Two-tailed p values of 0.05 or less were considered as statistically significant. All statistical analyses were performed with SPSS, version 21.0, software for Windows (SPSS).

Results

Study population

The study period extended for 76 months (from 31 March 2004 to 31 July 2010), during which 1720 THA or TKA operations were evaluated. Of these, 266 (15.4%) operations were excluded (260 revision procedures and 6 with incomplete data). In order to evaluate the main outcome (SSI rates), we divided the entire duration of the study in 3 almost equal periods of time. Of the 1454 operations performed included for final analysis of SSI rates, 440 (30.3%) were performed in the first 25 months (first period), 486 (33.4%) in the following 25 months, and 528 (36.3%) procedures in the final period of 26 months. There were 985 TKA and 469 THA. The mean age (±SD) was 66.9 ± 8.9 years, and 938 patients (64.5%) were female. The ASA score was ≥3 for 383 patients (26.3%), and the mean duration of the procedure (±SD) was 107 ± 24.9 min. There were 657 patients (45%) classified in the NNIS risk index category 1 and 2. All procedures were considered clean operations; therefore, there were no patients with risk index 3. The average duration of stay (±SD) for patients without SSI was 8.08 ± 2.34 days, compared with 10.93 ± 5.09 days for patients with SSI. The duration of stay before surgery was ≤1 day for 1408 operations (96.8%). Of the 1390 patients who did not experience an SSI, 1362 patients (98%) were admitted up to 3 days before surgery, compared with 61 patients (95.3%) admitted in the same period of time before 64 operations complicated by SSI (P = NS).

Type, timing, and duration of antibiotic administration

All patients received antimicrobial prophylaxis. Cefazolin was the antibiotic of choice in 1431 operations (98.4%) and vancomycin in 15 (1.0%). Other different drugs were administered in only 8 operations (0.6%). A single prophylactic dose was given in only 5 cases. According to our recommendations, only for 35% of the operations the first dose of antibiotic prophylaxis was administered between 31 and 60 min before incision. In addition, in only 4.6% of the cases prophylaxis was stopped within 24 h after first dose and in 7.7% of the cases antibiotic prophylaxis was extended for a period of >48 h. Complete recommendations for prophylaxis (concerning type, timing, and duration) were fulfilled in the same operation in only 261 cases (18%).

Surgical site infections

The overall SSI rate was 4.4% (64 0f 1454 operations). This included 45 (3.1%) superficial skin infections and 19 (1.3%) deep/organ space infections. The timing of detection of the infection was recorded in 45 cases, and 28 of them (62.2%) were postdischarge. A second admission was required for 19 of the 1454 operations (1.3%), and all of them complicated by a SSI ($p = 0.01$). As compared with the 34 (7.7%) SSIs that occurred in the first 25 months of study, there were 23 (4.7%) SSIs in following 25 months and only 7 (1.3%) SSIs in the last 26 months ($p = 0.058$ and <0.001, respectively). Changes of SSI rates in relation to the duration of the study and the number of procedures are shown in Fig. 1.

Microbiology

There were 39 bacterial isolates recovered from the 64 SSIs that occurred in the course of the study. Cultures were negative or not obtained for 36 infections (56.2%), and 11 infections each yielded 2 organisms. Gram-positive cocci accounted for 19 isolates (48.7%), including 10 isolates of *S. aureus* (25.6%) and 4 isolates of coagulase-negative staphylococci (10.2%). Seven of the 10 *S. aureus* isolates (70%) were MRSA. Among the 19 gram-negative bacilli isolated, *Pseudomonas aeruginosa was* the most common (8 isolates; 20.5%).

Univariant analysis

The crude association of the selected prophylaxis-, patient-, and procedure-related variables with SSI is presented in Table 1. The incidence of SSI was not correlated with the timing, nor the duration of antibiotic prophylaxis. Although

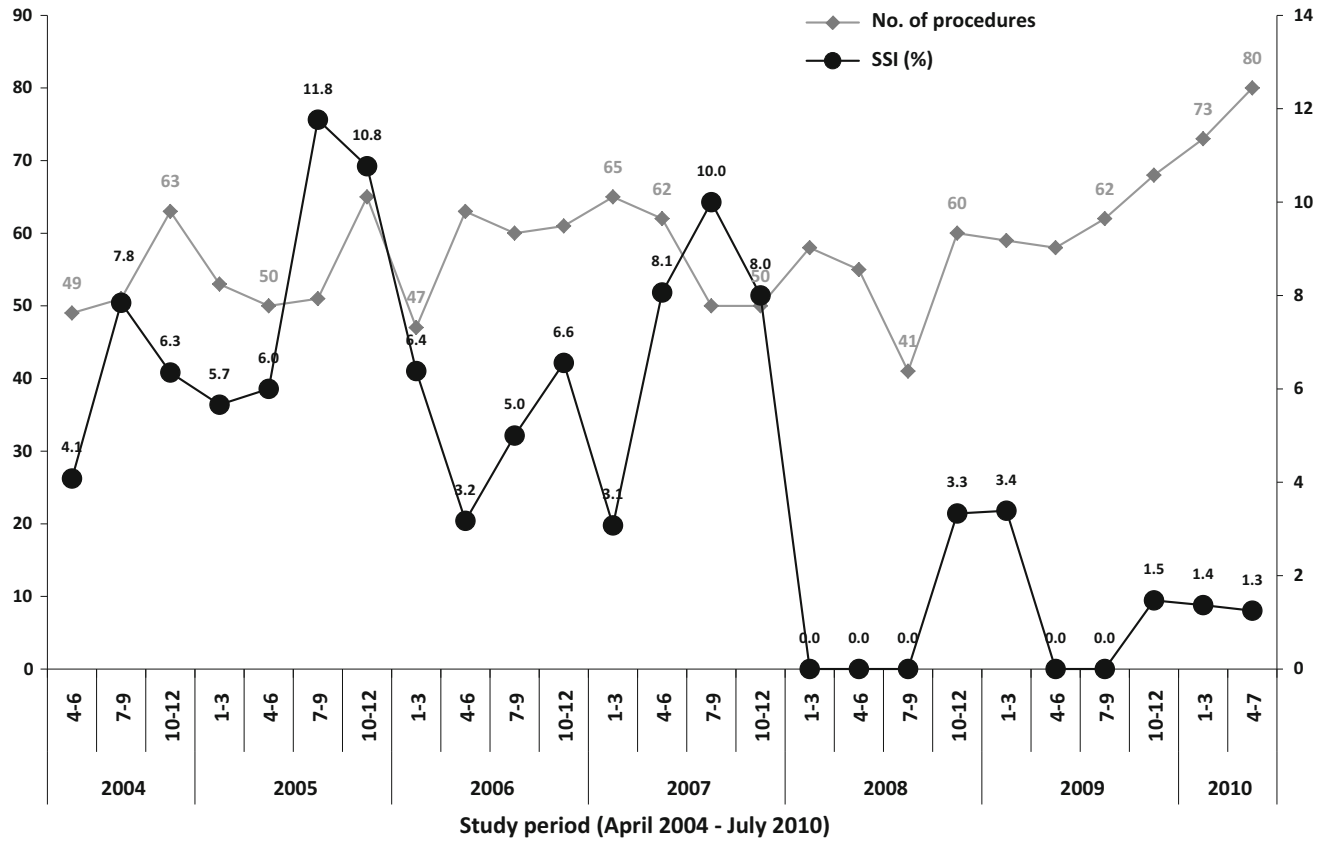

Fig. 1 Relationship between changes in the incidence of surgical site infection (SSI) following total joint arthroplasty and the number of procedures performed in the course of the study

statistically nonsignificant, all 64 cases of SSI occurred among patients who received cefazolin prophylaxis. A group of 4 surgeons, having a higher volume of operations (≥15% of all operations each), participated in 1182 procedures (82%). The SSI rate for these procedures was 4.3% as compared with a SSI rate of 4.9% for 265 procedures performed for surgeons with a lower volume of operations ($p = 0.65$; OR [95% CI] 1.15 [0.6–2.14]). The NNIS surgical wound infection risk index scores 1 and 2 ($p = 0.019$; OR [95% CI] 1.9 [1.1–3.3] and $p = 0.005$; OR [95% CI], 3.3 [1.4–7.6], respectively) and a prolonged duration of surgery (analysed separately from the NNIS risk score) ($p = 0.016$; OR [95% CI] 1.9 [1.1–3.2]) were associated with significantly higher rates of SSI.

Multivariate logistic regression analysis

Of the potential patient- and procedure-related risk factors that were forced in model (timing of prophylaxis) or that reached the threshold of statistical significance and therefore were included in the model, only the NNIS risk index scores of 1 and 2 (OR, 1.8; 95% CI, 1.1–3.1 and OR, 2.9; 95% CI, 1.2–6.7, respectively) were independently and significantly associated with a reduction in SSI rates. The Hosmer–Lemeshow goodness-of-fit statistic was 0.053, and the ROC was 0.71 (95% CI 0.66–0.76; $p < 0.001$).

Discussion

Prosthetic joint replacement is one of the marvels of modern medicine. However, infections associated with these procedures may cause significant morbidity and account for a substantial proportion of healthcare expenditures (3). Several studies have been performed in an attempt to identify risk factors for the development of periprosthetic joint infection following total joint arthroplasty. While some of these risk factors are considered controversial, others appear to be of upmost importance. Infection control is an essential part of SSI prevention, and many years ago, it has been shown that effective infection control programmes can reduce the rate of SSIs by 40% [8, 9]. The effectiveness of infection control strategies used to decrease the incidence of SSIs complicating prosthetic joint arthroplasty has been assessed in recent systematic reviews [3, 4, 10, 11]. Measures considered as very effective include surgical hand preparation, antibiotic prophylaxis, and, with some limitations, the surgeon's skill,

and postponing an elective operation in the case of active remote infection [12–16]. These items, and others, are often combined as multimodal intervention bundles, and this strategy also has been shown to effectively reduce SSIs in general surgery and prosthetic joint arthroplasty [17, 18].

We found a high overall infection rate (4.4%) associated with prosthetic joint replacement in our institution; however, the relative incidence of deep/organ space infections was comparable with those reported in recent reviews [3, 4]. In addition, we observed a progressive and significant reduction of the overall SSI rates over the 6-year period of evaluation, with SSI rates being reduced from 7.7% in the first third of the study to 1.3% in the last. While it is difficult to establish a direct cause-and-effect relationship between the developed programme of infection control and the observed reduction in SSI rates complicating prosthetic join arthroplasty in our institution, such a relationship is supported by the temporal sequence of events and adjustment for potential sources of bias. In this multivariable analysis of prophylaxis-, patient-, and procedure-related risk factors for SSI following prosthetic joint arthroplasty, the NNIS risk index category was the only independent and statistically significant confounding risk factor. The NNIS risk index category has been previously validated in a matched case–control study to determine risk factors for the development of prosthetic joint infection [19] and for many other surgical procedures reported by participating NNIS hospitals [20, 21]. Therefore, our results showing SSI rates increasing from 3.0% for a score of 0, to 5.6% for a score of 1 and 9.3% for a score of 2, confirm this expectancy. However, two other well-recognized risk factors for SSIs, such as timing of administration antimicrobial prophylaxis and surgeons' skill, were not correlated with the rate of SSI. The critical role of parenteral prophylactic antibiotics has been studied, verified, and accepted across most surgical specialties, including for total joint arthroplasty [22–27]. Since the ancillary study of Classen et al. [22] that assessed the relationship between prophylactic antibiotic timing and SSI in a broad group of patients undergoing elective surgery, many studies have shown that the timing of prophylactic antibiotic administration is critical in reducing SSIs. Consequently, current recommendations on prevention of SSIs include the administration prophylaxis within 30 min to 1 h before incision [28]. However, the clear superiority of the 60-min timing metric has yet to be substantiated, particularly in orthopaedic surgery. A previous prospective study that included data of 1922 patients undergoing total hip arthroplasty observed that SSI rates were lower when prophylaxis was administered within 1 h before incision; however, the figures did not reach statistical significance [29]. More recently, results of a retrospective cohort study of colorectal, vascular, gynaecologic, and orthopaedic procedures, including 20528 hip and knee arthroplasties, have shown no significant association between SSI rates and antibiotic prophylactic timing [30].

Implementing recommendations for prevention of SSIs is not a simple task. In a baseline US study, selection of the right antibiotic was averaged at 90%, the right timing of antibiotic administration within 60 min of skin incision was at 80%, and cessation of surgical antibiotic prophylaxis within 24 h was at 67% [31]. In our study, we found the right antibiotic selection in almost 100% of cases; however, in only 4.6% of the cases prophylaxis was stopped within 24 h after first dose. In addition, there was a considerable variation in the timing of antibiotic administration with the first dose being given in the recommended timing in only 35% of the operations, indicating that much improvement is needed.

Our study has several strengths, including the use of accepted definitions, assessing timing as a continuous variable, detailed-procedure level data, and assessment of SSI out of 30 days and $\geq$1 year after the surgical procedure. The limitations are also evident. It was conducted in a single tertiary centre, and the results may not necessarily be representative for others. Although diabetes mellitus, malignancy, the use of corticosteroid, and the presence of other comorbidities are reflected in the ASA score, separate reporting of these known risk factors might have rendered risk assessment more precise. Another limitation of our analysis was the relatively low number of SSIs ($n = 64$), which was the dependent outcome variable of our analysis. Finally, the fact that the post-discharge surveillance depended in most cases on telephone interview by the infection control nurse could have resulted in the underreporting of SSI.

In conclusion, coinciding with the introduction of an infection control programme in our institution this 6-year period study shows a progressive and significant decrease in SSI rates complicating hip and knee arthroplasty and suggests the validity of the NNIS risk index category as a tool for predicting SSIs complicating these procedures. Reduction of SSIs requires a team effort, which involves the orthopaedic surgeons, anaesthesiologists, operation room personnel, and Infectious Disease and Infection Control specialists.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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