Original Investigation | ASSOCIATION OF VA SURGEONS

Effect of a Preoperative Decontamination Protocol on Surgical Site Infections in Patients Undergoing Elective Orthopedic Surgery With Hardware Implantation

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IMPORTANCE Surgical site infections (SSIs), commonly caused by methicillin-resistant *Staphylococcus aureus* (MRSA), are associated with significant morbidity and mortality, specifically when hardware is implanted in the patient. Previously, we have demonstrated that a preoperative decontamination protocol using chlorhexidine gluconate washcloths and intranasal antiseptic ointment is effective in eradicating MRSA in the nose and on the skin of patients.

OBJECTIVE To examine the effect of a decontamination protocol on SSIs in patients undergoing elective orthopedic surgery with hardware implantation.

DESIGN, SETTING, AND PARTICIPANTS A prospective database of patients undergoing elective orthopedic surgery with hardware implantation at the Michael E. DeBakey Veterans Affairs Medical Center in Houston, Texas, was analyzed from October 1, 2012, to December 31, 2013. Cohort groups before and after the intervention were compared.

INTERVENTIONS Starting in May 2013, during their preoperative visit, all of the patients watched an educational video about MRSA decontamination and were given chlorhexidine washcloths and oral rinse and nasal povidone-iodine solution to be used the night before and the morning of scheduled surgery.

MAIN OUTCOMES AND MEASURES Thirty-day SSI rates were collected according to the definitions of the Centers for Disease Control and Prevention National Nosocomial Infections Surveillance. Data on demographics, comorbidities such as chronic obstructive pulmonary disease and coronary artery disease, tobacco use, alcohol use, and body mass index were also collected. Univariate analysis was performed between the 2 groups of patients. Multivariate analysis was used to identify independent predictors of SSI.

RESULTS A total of 709 patients were analyzed (344 controls and 365 patients who were decolonized). Both groups were well matched with no significant differences in age, body mass index, sex, or comorbidities. All of the patients (100%) completed the MRSA decontamination protocol. The SSI rate in the intervention group was significantly lower (1.1%; 4 of 365 patients developed an SSI) than the SSI rate in the control group (3.8%; 13 of 344 patients developed an SSI) (P = .02). Multivariate logistic regression identified MRSA decontamination as an independent predictor of not developing an SSI (adjusted odds ratio, 0.24 [95% CI, 0.08-0.77]; P = .02).

CONCLUSIONS AND RELEVANCE Our study demonstrates that preoperative MRSA decontamination with chlorhexidine washcloths and oral rinse and intranasal povidone-iodine decreased the SSI rate by more than 50% among patients undergoing elective orthopedic surgery with hardware implantation. Universal decontamination using this low-cost protocol may be considered as an additional prevention strategy for SSIs in patients undergoing orthopedic surgery with hardware implantation and warrants further study.

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Approximately 15 million operations are performed annually in the United States, resulting in about 300 000 to 500 000 surgical site infections (SSIs).[1] A 2009 report from the National Healthcare Safety Network estimated that, between 2006 and 2008, approximately 6000 to 20 000 SSIs have been associated with hip and knee arthroplasties annually in the United States.[2]

Staphylococcus aureus is currently the most common cause of SSIs, causing as many as 37% of cases of SSI in community hospitals. Moreover, methicillin-resistant *S aureus* (MRSA) has become the single most common etiologic agent of SSIs in community hospitals.[3] Engemann el al[4] estimate that 1 case of MRSA SSI costs approximately $118 500 compared with approximately $73 000 for a case of methicillin-susceptible *S aureus* infection in a patient who has had hardware implanted. The difference of approximately $45 000 per infection can result in a significant cost savings even if 1 case of infection is prevented.[4]

Surgical site infections, which represent the second most common type of health care–associated infection in the United States (ie, 22% of health care–associated infections are SSIs),[5] are in most cases preventable when the patient and hospital staff members adhere to proper prevention practices such as appropriate timing and type of prophylactic antibiotic used, minimizing operating room traffic, the use of hand hygiene practices and nasal screening, and decolonization of *S aureus* carriers, among others.[6] Of those prevention strategies that have been reported to decrease SSI rates, few of them are performed preoperatively. Decolonization of *S aureus* carriers with either mupirocin ointment alone or in combination with chlorhexidine gluconate baths has demonstrated a decrease in SSI rates.[7-9] Nevertheless, the majority of previous studies have only focused on the efficacy of nasal decontamination, for patients who are nasal carriers of *S aureus*, on SSI rates.

In the present study, we sought to assess the effect on SSIs of a decontamination protocol consisting of the application of both chlorhexidine washcloths, 2%, and oral rinse, 0.12%, the night before and the morning of the day of surgery, along with intranasal povidone-iodine solution, 5%, once the morning of the day of surgery for patients undergoing elective orthopedic surgery with hardware implantation. We hypothesized that the use of this preoperative decontamination protocol would reduce the rate of SSIs among patients undergoing elective orthopedic surgery with hardware implants.

Methods

Study Design, Population, and Definitions

Our prospective clinical study was conducted at the Michael E. DeBakey Veterans Affairs Medical Center (MEDVAMC) in Houston, Texas, under a protocol approved by the institutional review board of the center. Because this was a retrospective review of de-identified data, oral or written informed consent was waived. The Veterans Affairs Surgical Quality Improvement Program report provides quarterly data, including SSI rates for all surgical services. We found the orthopedic surgical service to be a high outlier with regard to SSI rates. For this reason, a universal decontamination protocol was implemented starting in May 2013. From October 1, 2012, to December 31, 2013, all patients undergoing elective orthopedic surgery with hardware implantation were evaluated. We included all patients who were English speakers, 18 years of age or older, and able to visit the clinic 5 days prior to surgery. Patients who underwent additional procedures fulfilling the previous criteria were included provided the surgical procedures were at least 30 days apart. Patients without available follow-up information within 30 days after surgery and those who developed a chronic joint or bone infection at the surgical site were excluded. Subsequent procedures in the same patient were also excluded. An SSI was defined according to the Centers for Disease Control and Prevention National Nosocomial Infections Surveillance criteria.[10,11]

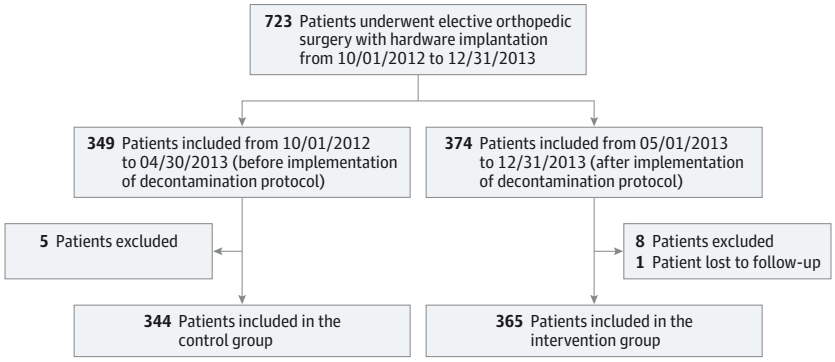
Study Intervention and Outcomes

Starting May 1, 2013, the MEDVAMC Section of Orthopedic Surgery established as standard of care a decontamination protocol, consisting of the application of both chlorhexidine washcloths, 2%, and oral rinse, 0.12%, along with an intranasal povidone-iodine solution, 5%. The washcloths and the oral rinse were both applied once the night before and the morning of the day of surgery. The intranasal povidone-iodine solution was applied once in the morning of the day of surgery. Patients operated on during the period from October 1, 2012, to April 30, 2013, were defined as the control group, and those operated on during the period from May 1, 2013, to December 31, 2013, were defined as the intervention group (**Figure**). All patients from the control and intervention groups underwent follow-up for a 30-day postoperative period. The occurrence of an SSI within that period was defined as the primary outcome. With the exception of the establishment of a decontamination protocol, the remaining standard perioperative prevention measures routinely applied at the MEDVAMC, such as those recommended by the Surgical Care Improvement Project, did not change during the entire study period. The following information about patient demographics and comorbidities were gathered, including age, sex, race, body mass index (calculated as weight in kilograms divided by height in meters squared), and the presence of hypertension, coronary artery disease, chronic obstructive pulmonary disease (COPD), chronic kidney disease, and type 2 diabetes mellitus. Data on tobacco smoking, alcohol use, length of surgery, and MRSA colonization status on the day of surgery were also collected. Testing for MRSA nasal colonization status was performed for patients who were admitted for more than 24 hours as per the hospital-wide screening of all admitted patients. Culture results from wounds of patients with an SSI were also collected when available.

Statistical Analysis

Descriptive statistics were calculated for the data on demographics, comorbidities, MRSA colonization status, and length of surgery for both control and intervention groups. Univariate analysis was performed using a 2-sided *t* test, the Pearson χ^2 test, and the Fisher exact test, as appropriate. It was performed at 2 levels. First, descriptive statistics of all variables

Figure. Patient Flowchart



were compared between control and intervention groups to verify the absence of any significant difference and minimize selection bias. Second, we compared the rate of SSI with the rest of recorded variables in order to identify possible predictors to include in the multivariate analysis. Multivariate logistic regression analysis was then performed to assess the relationship between the development of SSI (independent variable) and previously identified covariates, at the primary end point of 30 days. Variables were included in the multivariate analysis if the significance level reached $P \leq .10$ in the univariate analysis. All analyses were calculated using IBM SPSS statistics software, version 21. All tests with $P \leq .05$ were considered to be statistically significant.

Results

A total of 723 patients underwent elective orthopedic surgery with hardware implants from October 1, 2012, to December 31, 2013 (Figure). A total of 349 patients were included during the study period prior to the implementation of a decontamination protocol, which started on May 1, 2013. Of these 349 patients, 5 were excluded, resulting in a control group of 344 patients. After the institution of the protocol, 374 patients were identified, of whom 8 were excluded and 1 was lost to follow-up, resulting in 365 patients for the intervention group. Of 709 patients studied, the mean (SD) age was 56.8 (14.2) years, and 646 (91.1%) were male. Hypertension was present in 445 patients (62.8%), 106 patients (15.0%) had coronary artery disease, 64 patients (9.0%) had COPD, 33 patients (4.7%) had chronic kidney disease, and 143 patients (20.2%) had type 2 diabetes. Of 469 patients tested for MRSA colonization status, 19 (4.1%) were found to be MRSA nasal carriers on the day of admission following surgery. A total of 419 patients (59.1%) were tobacco smokers, and 388 patients (54.7%) actively consumed alcohol. Patients had a mean (SD) body mass index of 29.7 (5.7), and the mean (SD) duration of surgery was 117.4 (58.9) minutes. Of 709 patients, 17 (2.4%) developed an SSI.

The characteristics of patients according to group are shown in **Table 1**. There were no significant baseline differences between the patients in the control group and those in the intervention group besides those regarding hospital stay greater than 24 hours ($P = .001$), MRSA carrier status ($P = .05$), and the presence of an SSI ($P = .02$). Of the 13 patients with an SSI (3.8%) in the control group, 7 had a superficial SSI, 5 had a deep SSI, and 1 had an organ/space SSI (**Table 2**). Methicillin-susceptible *S aureus* was cultured in 4 of these 13 cases, MRSA in 2, *Staphylococcus epidermidis* in 1, and vancomycin-resistant *Enterococcus* in 1 (coinfected with MRSA). One case had a negative result, and in 5 of the 13 cases, wound culture was not performed. Of the 4 patients with an SSI (1.1%) in the intervention group, 2 had a coinfection of *S epidermidis* and *Enterococcus*, 1 had a methicillin-susceptible *S aureus* infection, and 1 was not tested. Of the 709 patients included in our study, 469 (66.1%) had a hospital stay of more than 24 hours (244 of 344 patients [70.9%] in the control group and 225 of 365 patients [61.6%] in the intervention group). Among the 469 patients tested for MRSA nasal carriage on the day of admission, 14 of 244 patients (5.7%) in the control group and 5 of 225 patients (2.2%) in the intervention group were positive ($P = .05$).

The results of univariate analysis comparing uninfected patients with those who acquired an SSI (ie, infected patients) are presented in **Table 3**. Variables that were identified as potential risk factors ($P \leq .10$) included age, hypertension, COPD, duration of surgery, and decontamination and were included as predictors in the multivariate analysis. Of these, only COPD, duration of surgery, and decontamination showed a statistically significant difference ($P < .05$).

The results of multivariate analysis are shown in **Table 4**. We found that COPD (odds ratio [OR], 6.76 [95% CI, 2.16-21.19]), a duration of surgery that was longer than 150 minutes (OR, 4.59 [95% CI, 1.67-12.65]), and decontamination before surgery (OR, 0.24 [95% CI, 0.08-0.77]) are all significant independent risk factors associated with the development of an SSI within 30 days after surgery.

Discussion

Surgical site infections remain one of the most devastating complications for orthopedic patients, leading to considerable morbidity and financial burden for both the patient and the health care professional. Patients who develop an SSI have an 11-fold higher mortality rate than patients who do not de-

Table 1. Characteristics of 709 Patients Assessed for Surgical Site Infections After Undergoing Orthopedic Surgery With Hardware Implants, by Group

Characteristic	Patients, No. (%)		*P* Value
	Control Group (n = 344)	Intervention Group (n = 365)	
Male sex	318 (92.4)	328 (89.9)	.23
Age, mean (SEM), y	56.9 (0.8)	56.6 (0.7)	.82
Race			
White	212 (61.6)	220 (60.3)	.54
Black	96 (27.9)	106 (29.0)	
Hispanic	30 (8.7)	27 (7.4)	
Other	6 (1.7)	12 (3.3)	
BMI, mean (SEM)	29.8 (0.3)	29.5 (0.3)	.58
Comorbidities			
Hypertension	218 (63.4)	227 (62.2)	.75
Coronary artery disease	52 (15.1)	54 (14.8)	.90
COPD	27 (7.8)	37 (10.1)	.29
Chronic kidney disease	17 (4.9)	16 (4.4)	.72
Type 2 diabetes mellitus	77 (22.4)	66 (18.1)	.15
Hospital stay >24 h	244 (70.9)	225 (61.6)	.001
Positive for MRSA on admission after surgery[a]	14 (5.7)	5 (2.2)	.05
Tobacco smoking	209 (60.8)	210 (57.5)	.38
Alcohol use	197 (57.3)	191 (52.3)	.19
Duration of surgery, mean (SEM), min	119.4 (3.2)	115.5 (3.0)	.38
Surgical site infection	13 (3.8)	4 (1.1)	.02

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); COPD, chronic obstructive pulmonary disease; MRSA, methicillin-resistant *Staphylococcus aureus*.

[a] Percentages were derived based on the valid numbers of patients (244 patients in the control group and 225 patients in the intervention group).

Table 2. Types of Surgical Site Infection

Surgical Site Infection	Patients, No.	
	Control Group (n = 13)	Intervention Group (n = 4)
Superficial	7	2
Deep	5	2
Organ/space	1	0

velop an SSI, with 77% of the deaths being attributable directly to SSIs.[1] Furthermore, the cost of the occurrence of 1 case of SSI caused by MRSA can reach $118 500 for patients undergoing surgery with hardware implantation.[4] Yet, it has been estimated that around 40% to 60% of SSI cases are actually preventable.[9,12,13]

To our knowledge, this is the first study to focus on the effect of a decontamination protocol combining chlorhexidine washcloths and oral rinse and intranasal povidone-iodine solution on SSI rates among patients undergoing elective orthopedic surgery with hardware implants, independent of their carrier status. We found a significant reduction in the number of SSIs of 69.2% due to any cause after the implementation of the decontamination protocol. Furthermore, decontamination turned out to be an independent protective factor against the development of an SSI (OR, 0.24 [95% CI, 0.08-0.77]; $P = .02$). None of the patients with an SSI in the intervention group had an infection that was caused by MRSA. In addition, we found a significant reduction in MRSA nasal carrier status in the intervention group compared with the control group (Table 1). Previous studies[8,9,14,15] examining the effect of decontamination on SSI rates have also reported significant reductions in SSI rates, but most of them have focused on the evaluation of nasal mupirocin and topical chlorhexidine regimens for carriers of *S aureus*.

Over the past years, some concern has grown regarding the development of strains of *S aureus* that are resistant to mupirocin. The development of resistance has been observed when mupirocin-based decolonization regimens have been used for prolonged periods of time, and it has been associated with the failure of decolonization therapy and an increased risk of recolonization.[16,17] In that sense, decontamination regimens containing nasal povidone-iodine could represent a valid alternative. In a randomized controlled clinical trial comparing the efficacy of 2 preoperative decontamination protocols on SSI rates after arthroplasty or spine fusion surgery, Phillips et al[18] reported that the combination of topical chlorhexidine with a single application of nasal povidone-iodine was significantly superior to chlorhexidine plus 5 days of mupirocin at preventing all-cause deep SSIs. Furthermore, the povidone-iodine group had significantly fewer decontamination-related adverse effects than did the mupirocin group.

Adherence to a particular decontamination regimen is a cardinal factor for its success. Buehlmann et al[19] showed an adherence rate of 87% to a 5-day regimen of nasal mupirocin, chlorhexidine oral rinse, and full-body wash with chlorhexidine soap. Among patients who did not become decolonized, 87.5% did not adhere to the protocol. In contrast, our results showed that the implementation of a 2-day protocol resulted in a 100% adherence rate. In addition, a lack of adherence may not only decrease the success rate but also increase the risk of antibiotic resistance. A regimen containing nasal povidone-

Table 3. Univariate Analysis of Risk Factors Associated With the Development of Surgical Site Infections

Characteristic	Patients, No. (%) Uninfected (n = 692)	Infected (n = 17)	*P* Value
Male sex	630 (91.0)	16 (94.1)	.99
Age, mean (SEM), y	56.6 (0.5)	61.4 (2.3)	.06
Race			
White	420 (60.7)	12 (70.6)	.81
Black	198 (28.6)	4 (23.5)	
Hispanic	56 (8.1)	1 (5.9)	
Other	18 (2.6)	0	
BMI, mean (SEM)	29.6 (0.2)	31.7 (1.2)	.13
Comorbidities			
Hypertension	431 (62.3)	14 (82.4)	.09
Coronary artery disease	101 (14.6)	5 (29.4)	.16
COPD	58 (8.4)	6 (35.3)	.002
Chronic kidney disease	33 (4.8)	0	.99
Type 2 diabetes mellitus	140 (20.2)	3 (17.6)	.99
Hospital stay >24 h	453 (65.5)	16 (94.1)	.01
Positive for MRSA on admission after surgery[a]	17 (3.8)	2 (12.5)	.13
Tobacco smoking	407 (58.8)	12 (70.6)	.33
Alcohol use	378 (54.6)	10 (58.8)	.73
Duration of surgery, mean (SEM), min	116.6 (2.2)	147.9 (14.2)	.03
Decontamination	361 (52.2)	4 (23.5)	.02

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); COPD, chronic obstructive pulmonary disease; MRSA, methicillin-resistant *Staphylococcus aureus*.

[a] Percentages were derived based on the valid numbers of patients (453 uninfected patients and 16 infected patients).

iodine instead of mupirocin could potentially dissipate concerns regarding an eventual development of antibiotic resistance and could allow its application into a broader population outside *S aureus* carriers.

Even though *Staphylococcus* remains the single most common organism causing SSIs in orthopedic patients,[20] 40% of cases of SSI are still caused by other organisms such as gram-negative bacilli, which have been described as the second most common cause of SSIs in patients undergoing primary total arthroplasty. We found that of the 11 patients with an SSI that was cultured, 10 (91%) had an SSI that was caused by *Staphylococcus* (4 patients [36.4%] had an SSI caused by *S aureus*, and 2 patients [18.2%] had an SSI caused by MRSA), 3 (27.3%) developed SSIs due to *Enterococcus*, and 3 (27.3%) were found to have more than 1 organism as the cause of their SSIs. Wound culture was not performed in 6 of 17 patients (35.3%). Of these 6 patients, all had a superficial SSI. We believe that this might be due to the less dramatic symptoms of superficial SSIs when compared with deep or organ/space SSIs.

A wider implementation of a regimen without the need of *S aureus* carrier identification and selective decolonization would also allow for cost savings. In our institution, the cost of a polymerase chain reaction screening test for the detection of *S aureus* approaches $45 per patient. In turn, the cost of decontamination with mupirocin and chlorhexidine is approximately $54 per patient. Then, the implementation of a 5-day selective decontamination protocol of mupirocin and chlorhexidine in an institution such as the MEDVAMC, with a prevalence of MRSA carriers of 18%,[21] would have an estimated cost of $54.72 per patient. In contrast, the estimated cost of a 2-day regimen of chlorhexidine washcloths plus oral rinse, along with a single application of nasal povidone-iodine, is $35 per patient.

Table 4. Multivariate Analysis of Independent Risk Factors Associated With the Development of SSIs[a]

Risk Factor	Adjusted OR (95% CI)	*P* Value
Decontamination	0.24 (0.08-0.77)	.02
Duration of surgery ≥150 min	4.59 (1.67-12.65)	.003
COPD	6.76 (2.16-21.19)	.001

Abbreviations: COPD, chronic obstructive pulmonary disease; OR, odds ratio; SSIs, surgical site infections.

[a] Only risk factors found to be statistically significant on multivariate analysis are shown.

It is well known that the development of an SSI is multifactorial. Besides decontamination, we found that COPD and a duration of surgery greater than 150 minutes were found to be independent risk factors for developing an SSI. Patients with COPD had more than a 6-fold greater risk of developing an SSI than patients without COPD (OR, 6.76 [95% CI, 2.16-21.19]; *P* = .001). Likewise, patients who spent more than 2.5 hours in the operating room were 4.59 times more likely to get an SSI the following 30 days than patients who spent less time in the operating room (OR, 4.59 [95% CI, 1.67-12.65]; *P* = .003). Previous studies examining risk factors associated with SSIs have corroborated these findings.[22] We found that a hospital stay of greater than 24 hours is a significant factor in the univariate analysis (Tables 1 and 3). However, it was not a significant independent predictor in the multivariate analysis. We be-

lieve that our results might be attributed to an initial difference in proportions between the control group and the intervention group, leading to selection bias, and a low cutoff value of the variable.

Our study has several limitations. Our population consisted mostly of male veterans with multiple comorbidities who exclusively underwent elective orthopedic surgery with hardware implants, which may undermine the external validity. The lack of group randomization in our study also increases the risk of selection bias and undetected potential confounders. The follow-up period for detection of an SSI was limited to 30 days. This may have affected the sensitivity of SSI identification, although marginally, because it has been shown that most SSIs that develop after total arthroplasty develop within 30 days.[20] Also, information regarding the MRSA carrier status of patients before decontamination was not collected, which would have allowed for an examination of the effect of the protocol on decontamination rates.

In summary, our data demonstrate a significant decrease in overall SSI rates among orthopedic patients after the implementation of a decontamination protocol. This protocol has additional advantages, including its shorter duration, its cost-effectiveness compared with polymerase chain reaction–based protocols, and potentially fewer concerns about long-term antibiotic resistance. Data quality improvement through large-scale randomized controlled clinical trials, as well as additional studies to validate the application of the decontamination protocol to other services implanting hardware, will be the focus of future work in our enterprise against SSIs.

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Study concept and design: Green, Awad.
Acquisition, analysis, or interpretation of data: Bebko, Awad.
Drafting of the manuscript: All authors.
Critical revision of the manuscript for important intellectual content: Bebko, Awad.
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REFERENCES

1. Anderson DJ, Kaye KS. Staphylococcal surgical site infections. *Infect Dis Clin North Am*. 2009;23(1):53-72.

2. Greene LR. Guide to the elimination of orthopedic surgery surgical site infections: an executive summary of the Association for Professionals in Infection Control and Epidemiology elimination guide. *Am J Infect Control*. 2012;40(4):384-386.

3. Anderson DJ, Sexton DJ, Kanafani ZA, Auten G, Kaye KS. Severe surgical site infection in community hospitals: epidemiology, key procedures, and the changing prevalence of methicillin-resistant *Staphylococcus aureus*. *Infect Control Hosp Epidemiol*. 2007;28(9):1047-1053.

4. Engemann JJ, Carmeli Y, Cosgrove SE, et al. Adverse clinical and economic outcomes attributable to methicillin resistance among patients with *Staphylococcus aureus* surgical site infection. *Clin Infect Dis*. 2003;36(5):592-598.

5. Klevens RM, Edwards JR, Richards CL, et al. Estimating health care–associated infections and deaths in U.S. hospitals, 2002. http://www.cdc.gov/HAI/pdfs/hai/infections_deaths.pdf. Published March-April 2007. Accessed January 26, 2015.

6. Bosco JA III, Slover JD, Haas JP. Perioperative strategies for decreasing infection: a comprehensive evidence-based approach. *J Bone Joint Surg Am*. 2010;92(1):232-239.

7. Kallen AJ, Wilson CT, Larson RJ. Perioperative intranasal mupirocin for the prevention of surgical-site infections: systematic review of the literature and meta-analysis. *Infect Control Hosp Epidemiol*. 2005;26(12):916-922.

8. Kim DH, Spencer M, Davidson SM, et al. Institutional prescreening for detection and eradication of methicillin-resistant *Staphylococcus aureus* in patients undergoing elective orthopaedic surgery. *J Bone Joint Surg Am*. 2010;92(9):1820-1826.

9. Bode LG, Kluytmans JA, Wertheim HF, et al. Preventing surgical-site infections in nasal carriers of *Staphylococcus aureus*. *N Engl J Med*. 2010;362(1):9-17.

10. Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR; Hospital Infection Control Practices Advisory Committee. Guideline for prevention of surgical site infection, 1999. *Infect Control Hosp Epidemiol*. 1999;20(4):250-278.

11. Horan TC, Gaynes RP, Martone WJ, Jarvis WR, Emori TG. CDC definitions of nosocomial surgical site infections, 1992: a modification of CDC definitions of surgical wound infections. *Infect Control Hosp Epidemiol*. 1992;13(10):606-608.

12. Cooper RA. Surgical site infections: epidemiology and microbiological aspects in trauma and orthopaedic surgery. *Int Wound J*. 2013;10(suppl 1):3-8.

13. Darouiche RO, Wall MJ Jr, Itani KM, et al. Chlorhexidine-alcohol vs povidone-iodine for surgical-site antisepsis. *N Engl J Med*. 2010;362(1):18-26.

14. Kalmeijer MD, Coertjens H, van Nieuwland-Bollen PM, et al. Surgical site infections in orthopedic surgery: the effect of mupirocin nasal ointment in a double-blind, randomized, placebo-controlled study. *Clin Infect Dis*. 2002;35(4):353-358.

15. Rao N, Cannella BA, Crossett LS, Yates AJ Jr, McGough RL III, Hamilton CW. Preoperative screening/decolonization for *Staphylococcus aureus* to prevent orthopedic surgical site infection: prospective cohort study with 2-year follow-up. *J Arthroplasty*. 2011;26(8):1501-1507.

16. Patel JB, Gorwitz RJ, Jernigan JA. Mupirocin resistance. *Clin Infect Dis*. 2009;49(6):935-941.

17. Simor AE, Phillips E, McGeer A, et al. Randomized controlled trial of chlorhexidine gluconate for washing, intranasal mupirocin, and rifampin and doxycycline versus no treatment for the eradication of methicillin-resistant *Staphylococcus aureus* colonization. *Clin Infect Dis*. 2007;44(2):178-185.

18. Phillips MS, Bosco J III, Rosenberg A, et al. Preventing *Staphylococcus aureus* surgical site infections: an open-label, randomized trial of nasal mupirocin ointment and nasal povidone-iodine solution. In: Proceedings from the IDSA/SHEA Conference; October 20, 2012; San Diego, CA.

19. Buehlmann M, Frei R, Fenner L, Dangel M, Fluckiger U, Widmer AF. Highly effective regimen for decolonization of methicillin-resistant *Staphylococcus aureus* carriers. *Infect Control Hosp Epidemiol*. 2008;29(6):510-516.

20. Benito N, Franco M, Coll P, et al. Etiology of surgical site infections after primary total joint arthroplasties. *J Orthop Res*. 2014;32(5):633-637.

21. Awad SS, Palacio CH, Subramanian A, et al. Implementation of a methicillin-resistant *Staphylococcus aureus* (MRSA) prevention bundle results in decreased MRSA surgical site infections. *Am J Surg*. 2009;198(5):607-610.

22. Korol E, Johnston K, Waser N, et al. A systematic review of risk factors associated with surgical site infections among surgical patients. *PLoS One*. 2013;8(12):e83743.