

## Clinical Study

# An empiric analysis of 5 counter measures against surgical site infections following spine surgery—a pragmatic approach and review of the literature

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### Abstract

**BACKGROUND CONTEXT:** Surgical site infections (SSI) following spine surgery are debilitating complications to patients and costly to the healthcare system.

**PURPOSE:** Review the impact and cost effectiveness of 5 SSI prevention interventions on SSI rates in an orthopedic spine surgery practice at a major quaternary healthcare system over a 10-year period.

**STUDY DESIGN:** Retrospective observational study.

**PATIENT SAMPLE:** All of the surgical patients of the 5 spine surgeons in our department over a 10-year period were included in this study.

**OUTCOME MEASURES:** SSI rates per year, standardized infection ratios (SIR) for laminectomies and fusions during the most recent 3-year period, year of implementation, and frequency of use of the different interventions, cost of the techniques.

**METHODS:** The SSI prevention techniques described in this paper include application of intra-wound vancomycin powder, wound irrigation with dilute betadine solution, preoperative chlorhexidine gluconate scrubs, preoperative screening with nasal swabbing, and decolonization of *S. aureus*, and perioperative antibiotic administration. Our institution's infection prevention and control data were analyzed for the yearly SSI rates for the orthopedic spine surgery department from 2006 to 2016. In addition, our orthopedic spine surgeons were polled to determine with what frequency and duration they have been using the different SSI prevention interventions.

**RESULTS:** SSI rates decreased from almost 6% per year the first year of observation to less than 2% per year in the final 6 years of this study. A SIR of less than 1.0 for each year was observed for laminectomies and fusions for the period from 2013 to 2016. All surgeons polled at our institution uniformly used perioperative antibiotics, Hibiclens scrub, and the nasal swab protocol since the implementation of these techniques. Some variability existed in the frequency and duration of

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betadine irrigation and application of vancomycin powder. A cost analysis demonstrated these methods to be nominal compared with the cost of treating a single SSI.

**CONCLUSIONS:** It is possible to reduce SSI rates in spine surgery with easy, safe, and cost-effective protocols, when implemented in a standardized manner. © 2018 Elsevier Inc. All rights reserved.

**Keywords:**

Betadine irrigation; Chlorhexidine scrubs; Nasal swab *S. aureus* decolonization; Perioperative antibiotics; Surgical site infection; Vancomycin powder.

## Introduction

Surgical site infections (SSIs) are a serious complication of any procedure but can be especially debilitating following spine surgery. The SSI is defined by the Centers for Disease Control and Prevention as an infection that occurs within 30 days of surgery or within 90 days of placement of foreign bodies, such as spinal instrumentation [1]. In addition to the increase in morbidity, SSIs are a costly complication to the healthcare system; Kuhns et al. found that SSIs following posterior cervical spine surgeries increased costs by \$12,600, whereas Yeramaneni et al. found the increase in cost range from \$15,800 to \$38,700 to treat SSIs following adult deformity spine surgery [2,3]. Reimbursement for this surgical complication has also decreased, as evidenced by a recent Centers for Medicare & Medicaid Services initiative [4]. The SSI prevention strategies have been an important area of research with several simple and cost-effective techniques emerging to become standard of practice for many spine surgeons. Such SSI mitigation protocols may not only be beneficial to the patient, but also lower the total cost to the medical system as they are much cheaper to implement than the cost of treating SSIs at the current incidence rate [5].

Although many methods for reducing SSI have been introduced in the last decade and advocated largely in anecdotal fashion, the empiric assessment and the evidential basis for these methods has been limited. Further, since the implementation of these methods has happened simultaneously for some or all of these measures at many institutions and much of the literature on the topic has been collected in retrospective fashion caused by the comparatively low absolute incidence of SSI, delineating the specific clinical efficacy (ie, the empirically derived incremental effect of each intervention, under ideal, controlled testing conditions) of each method may be challenging or impossible. Thus, it was our hypothesis that the low cost, low risk methods that have been implemented at our institution should be viewed as a singular (“bundled”) multifactorial intervention and determination of the composite clinical effectiveness (ie, performance under “real-world” conditions) of these measures would be most pragmatic and generalizable at this point. Moreover, if we could specifically document the methods that have been implemented over the last decade and then evaluate the SSI rate on an annual basis within our institution and compared with

national norms, we could determine if the composite practice has made a beneficial effect.

Five interventions for reducing SSI have been systematically implemented within our Department of Orthopaedic Surgery—Division of Spine Surgery, over the last decade. These include: (1) intrawound application of vancomycin powder before wound closure, (2) dilute betadine irrigation per 3 minute soak of the surgical site, (3) chlorhexidine gluconate (CHG, Hibiclens) scrub before surgery, (4) administration of weight-based doses of first generation cephalosporin (or vancomycin when allergic) within 1 hour of surgical incision, and (5) nasal swabbing to test for *S. aureus* colonization followed by 5-day treatment with intranasal mupirocin ointment for colonizers [4,6–9]. Several of these methods have been shown in previous works to be effective individually or in limited combination, whereas the composite and individual effect of others remain inconclusive [4,9–17].

Some of the strongest evidence exists for the use of dilute betadine irrigation and topical application of vancomycin powder before incision closure. Several studies investigating these methods applied both individually and together have shown significant reductions in SSIs following spine surgeries at their respective institutions [4,10–16]. Cheng et al. reported a 0% SSI rate in 208 patients in their intervention group, which was exposed to surgical wound irrigation with dilute betadine solution (3.5% betadine), compared with >3% SSI rate in 206 patients in their control group [11]. Hill et al. demonstrated similar results with the application of 1 to 2 g of intrawound vancomycin powder in posterior instrumented and noninstrumented spinal surgeries [12]. Furthermore, Tomov et al. combined both of these methods and demonstrated a 50% reduction in SSI rates following all spine surgeries at their institution [4].

The use of a preadmission CHG scrub on all body skin is less well studied in spine surgery, however its results are very promising in the field of arthroplasty, as evidenced by the Kapadia et al. study which demonstrated more than a sixfold decrease in SSI following total knee arthroplasty [17]. Preoperative screening and decolonization of methicillin-sensitive *S. aureus* (MSSA) and methicillin-resistant *S. aureus* (MRSA) via nasal swabbing and intranasal antibiotic ointment (ie, Mupirocin (Bactroban Nasal) for 5 days) is relatively new to the field of spine surgery, thus data are limited, however similar protocols have shown reductions in SSI rates in general surgery, neurosurgery, and other

orthopedic subspecialties [8,9,18,30]. All or at least some of these 5 methods for reducing SSI have been phased in for all orthopedic spine surgeries performed at our institution over the past decade.

Although these studies sought a more explanatory path, in which the intent was to assess the clinical efficacy of one or a couple interventions, these interventions most likely occurred on a backdrop of continued systematic implementation of SSI mitigation strategies. Thus, identifying the exact incremental effect of these measures in rigorous explanatory studies may have been compromised by the confounding effect of the systematic SSI mitigation initiatives that occurred in concert with their study time frame. Our group took a different angle to this question. Rather than discounting this potential confounding effect, we embraced it and sought to define the effectiveness of a bundled approach to SSI mitigation.

The purpose of this study is to pragmatically review the implementation of these 5 methods for reducing SSIs at our institution over the past decade and assess the impact on SSI rate reduction for the group in composite. Before the initiation of the study, there was a strong anecdotal sense that these measures have resulted in marked reduction in SSIs following major spine surgery performed at our institution. Finally, we determined the cost of the bundled SSI mitigation package and the cost-effectiveness of these simple and safe interventions.

## Methods

Under an institutional review board approved protocol, an observational study was undertaken to assess the impact on SSI rate of 5 SSI prevention techniques implemented by the orthopaedic spine surgery division at our institution over the last decade (2006–2016). The SSI event was defined according to the Centers for Disease Control and Prevention guidelines and validated by an infectious disease physician based on microbiology records; the event was prospectively logged following agreement by both the infectious disease physician and the spine surgeon. These data were then stored in a database maintained by our institution's Infection Prevention and Control surveillance team, which was abstracted for the purpose of this study. Given that SSIs can often present several months after the index surgery, particularly in instrumented procedures, there was a minimum 1 year follow-up for patients in this review. The advantage of our Infection Prevention and Control database is that it is prospectively collected and maintained; thus, a newly diagnosed infection will be documented at any time point over the period studied. This means that effective follow-up ranged from 1- to up to

11-years. The SSI rates from 5 adult spine surgeons from our institution were assessed between 2006 and 2016 for a total of 400 to 450 cases per year during this period; these rates are cumulative for all types of spine procedures and approaches. In addition to the rate of SSI per year, the number of expected infections per year at our institution were compared with expected infection rates via the use of the National Healthcare Safety Network standardized infection ratio (SIR) for 2013 to 2016 for the 2 most common spine procedures—laminectomies and fusions. The expected number of infections per year is calculated using national population data in the National Healthcare Safety Network database based on the procedure. The SIR is a ratio of actual rates over expected rates of SSI. A SIR above 1.0 corresponds to an infection rate that is higher than that of a standard population, although a SIR below 1.0 corresponds to an infection rate that is lower than that of a standard population. In addition, 4 of the 5 orthopedic spine surgeons from our institution (1 had already transitioned at the time of this review) were polled to assess the timing and compliance with which they implemented and used the various SSI prevention protocols within their own practices. The frequency with which 3 of the 5 methods (perioperative antibiotics, chlorhexidine scrubs, and nasal swab protocol) were used was 100% caused by being an institution mandated protocol, hence the 2 measures based on surgeon preference were Betadine irrigation and use of intrawound vancomycin powder. Finally, we obtained the cost data for these 5 interventions from both our infection control department and purchasing managers for our in-patient pharmacy. The cost data are presented in a total cost fashion to maintain the confidentiality of our individual purchasing contracts as requested by our business department. The cost effectiveness calculations were based on a theoretical cohort of 100 patients. Per our infectious disease department, approximately 30% of patients test positive for *S. aureus*, which prompts a reflexive MRSA culture and treatment with Mupirocin for 5 days. We used a “worst-case scenario” approach to calculate the cost-effectiveness of these measures; the highest quoted prices for each measure as well as the lowest published cost of treating an SSI were used. Kuhns et al. cost analysis of the treatment of SSI following dorsal cervical fusions recorded some of the lowest costs in the literature for SSI related to spine surgery, and we thus used these values in our cost-effectiveness analysis of our 5 SSI prevention measures. We calculated the difference in SSI rate between the first and last year of the study to determine the cost savings attributed to a reduced number of SSI following implementation of these measures compared with the cost of the 5 measures. The formula is presented below:

$$\text{Cost Effectiveness} = \frac{\text{Cost per SSI} \times [(\text{SSI Year 1 \%} - \text{SSI Year 11 \%}) \times 100 \text{ patients}]}{100 \text{ patients} \times 70\% \text{ } S. \text{ aureus} \text{ negative patients (Cost of 5 measures)} + 100 \text{ patients} \times 30\% \text{ } S. \text{ aureus} \text{ positive patients (Cost of 5 measures} + \text{Mupirocin} + \text{MRSA culture)}}$$

## Five SSI reducing methods implemented

### *Application of intrawound vancomycin powder*

With recent findings supporting the use of vancomycin powder in the prevention of SSI in spine surgery and other subspecialties, most spine surgeons at our institution have adopted its use. The general technique is to “sprinkle” 1 to 2 g of vancomycin powder liberally throughout the extent of wound at the completion of the case, primarily or exclusively deep to the fascia, although some will place a minor portion of the vancomycin powder in the superficial plane during closure. Two or more grams of vancomycin powder is preferentially used for long constructs (ie, >5 levels) and/or morbidly obese patients.

### *Wound irrigation with dilute betadine solution*

Toward the end of the case, but before the placement of bone-graft, the wound is filled with a 3.5% dilute betadine solution and this is allowed to sit for 3 minutes before suctioning the solution and irrigating copiously with normal saline. This procedure is now a standard practice for all spine surgeons at our institution.

### *Preoperative chlorhexidine gluconate scrubs*

Preoperative patient performed CHG (Hibiclens) “scrubs” were also systematically implemented in the year 2007 and 2008. At preoperative appointments, all patients are provided with CHG packets with instructions on how to scrub the surgical area and other skin the night before surgery and the morning of surgery. Patients are formally instructed to perform this protocol during their outpatient clinic preoperative appointment; however, patient compliance and adequacy of the scrub is not directly assessed.

### *Preoperative screening with nasal swabbing and decolonization of *S. aureus**

A patient’s own flora can be associated with an increased risk of SSI, and thus a relatively new SSI prevention protocol at our institution is the screening of all patients for MSSA and MRSA via nasal swabbing, and the administration of Mupirocin (Bactroban Nasal) nasal ointment for those who screen positive or present for surgery within the 5 day window of surgery; the protocol was implemented by some in 2009, however became recently automated and incorporated into our surgical listing program in 2015. Any patient undergoing a type 1 surgery (ie, clean wound) with no documented history of a Mupirocin allergy is automatically enrolled in the protocol. If any of the following are true regarding surgical scheduling: surgery is scheduled within 5 days or less, 91 days or more, surgical date pending, or the patient will call back to schedule surgery, the patient is prescribed Mupirocin 2% nasal ointment to be applied twice daily for 5 days. Patients are instructed to apply a pea size amount in each naris, and to start as soon

as possible or 5 days before surgery. For the majority of patients scheduled for surgery between 6 and 90 days, a nasal swab is performed for screening purposes. If the results of the nasal swab are positive for *S. aureus*, Mupirocin nasal ointment is prescribed. A positive nasal swab screen for *S. aureus* by Polymerase Chain Reaction is followed for a screen culture for MRSA—if MRSA positive, a weight-based dose of intraoperative intravenous vancomycin is also administered.

### *Perioperative antibiotic administration*

Cefazolin (Ancef), a first-generation cephalosporin with excellent bactericidal coverage of MSSA, is administered once in the operating room within 1 hour before surgical incision. At least 2 additional doses 8 hours apart are provided following initial intraoperative dosing. For prolonged cases (ie, >4 hours of surgical time), the initial preoperative antibiotic is redosed at 4-hour intervals until the completion of the surgery. Dosing is based on the weight of the patient; patients <80 kg receive 1 g of cefazolin, whereas those ≥80 kg receive 2 g of cefazolin. For those patients allergic to beta-lactam antibiotics, clindamycin or vancomycin are generally used. Vancomycin is used for individuals who are demonstrated to be MRSA carriers by nasal swab or those with a prior history of MRSA infection. Because this is a joint commission and hospital standard, protocolized administration of perioperative antibiotic was standard of practice for all 5 spine surgeons over the study period with strict compliance documented as a routine component of intraoperative documentation in all cases.

## Results

Five adult spine surgeons’ practices from our institution were sampled individually and their SSI rates for all spine procedures were pooled. These rates are demonstrated in [Figure 1](#) from 2006 to 2016. A decrease in the pooled SSI rates can be seen from almost 6% per year in 2006 to less than 2% per year in 6 consecutive years for the second half of the data set. In addition to assessing SSI rates, [Tables 1](#) and [2](#) demonstrate the expected number of infections and SIR per year from 2013 to 2016 for laminectomies and fusions performed at our institution, respectively. Each year evaluated reveals SIR values well below 1.0 for both laminectomy and spinal fusion datasets.

The results of the poll of the orthopedic spine surgeons at our institution are displayed in [Figures 2](#) and [3](#). The use of perioperative antibiotics and Hibiclens scrub was universally employed for the entire duration of this review with 100% frequency. The nasal swab protocol is now utilized with 100% frequency caused by its institutional mandate, with all surgeons having initiated its use from its original pilot in the 2008 to 2009 period. There is more variability in the use of betadine irrigation and vancomycin powder use. Betadine irrigation is a relatively new practice with the earliest implementation only 3 years ago, however it is now

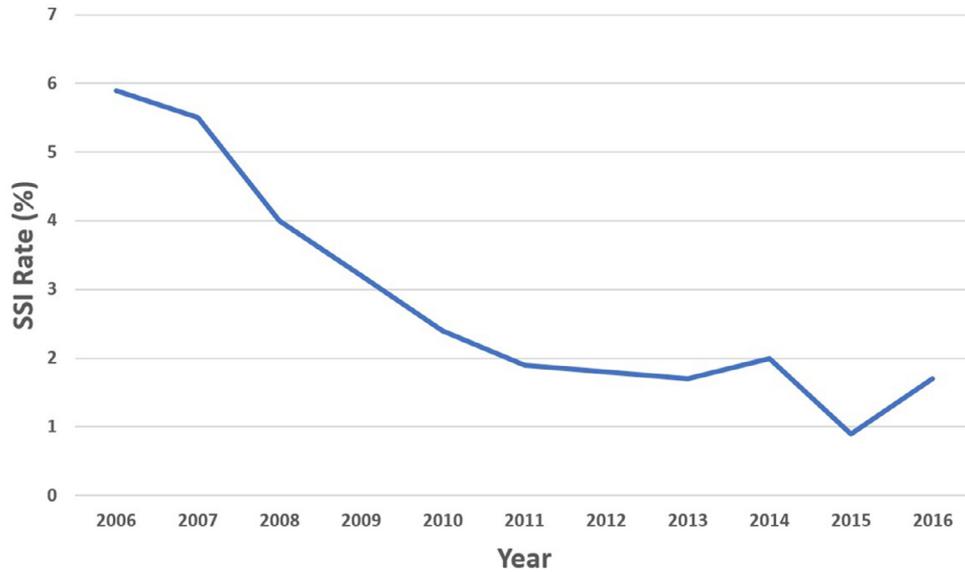


Fig. 1. Surgical site infection rates 2006–2016.

used in approximately 75% of spine cases by 2 of the surgeons, and 100% of cases by the other 2 surgeons. Vancomycin powder is also a relatively new practice and currently used by 3 of the 4 surgeons. Those surgeons that are using vancomycin powder use it with 100% frequency in all of their cases.

The costs for treating 70 *S. aureus* negative patients and 30 *S. aureus* positive patients of a theoretical cohort of 100 patients are demonstrated in Table 3. The ranges represent the costs based on the variable dosing of perioperative cefazolin as well as intrawound vancomycin powder; all other costs were fixed. The published total cost (direct and indirect costs) per SSI from Kuhns et al. (\$15,375–\$28,181) multiplied by the decrease in number of SSI cases over the study period (4.2 fewer cases per 100 patients at the end of

the study period) resulted in a cost savings of \$64,575–\$118,360 per 100 patients. Using these values in our cost effectiveness formula yielded an 8.4 to 16.4-fold decrease in overall cost to the healthcare system.

**Discussion**

The purpose of this paper is not to analyze which specific clinical practice has had the greatest impact in reducing SSI rates in spine surgery at our institution, but rather to demonstrate that a bundled approach of simple and cost-effective protocols have led to a dramatic reduction in infection rates across a busy quaternary care spine division. Because we are not able to fully separate one intervention from another, we are unable to comment on which is the most effective, but the downward trend over the last decade demonstrates that a cumulative effect of the implementation of multiple low-cost, low-risk mitigation strategies can significantly reduce SSI rates to levels below the national standard (ie, SIR data in Tables 1 and 2) and below that commonly reported in the literature [1,4,7–13]. Caused by the current state of infection control practices in our institution and most or all other similar facilities, the ability to dissect out the incremental effect of a specific intervention on mitigating the complex sequence of events that results in an SSI is absent. Our methodology is simply not capable of performing such an analysis. This would require explanatory research, which rigorously controls for each factor and manipulates only 1 to determine clinical efficacy. At this point, our experience as summarized in the data presented shows a marked reduction in SSIs which has occurred coincident to the serial implementation of 5 simple and cost-effective infection prevention measures, which are commonly used in part or whole by other spine surgery groups. Although the pragmatic nature of our work prohibits

Table 1  
Surgical site infection data for laminectomies 2013–2016

Year	Infections (n)	Expected infections	SIR
2013	16	21.254	0.753
2014	8	20.686	0.387
2015	7	10.051	0.696
2016	6	11.331	0.530

SIR, standardized infection ratios.

Table 2  
Surgical site infection data for spinal fusions 2013–2016

Year	Infections (n)	Expected infections	SIR
2013	7	25.178	0.278
2014	10	24.510	0.408
2015	4	21.671	0.185
2016	14	25.643	0.546

SIR, standardized infection ratios.

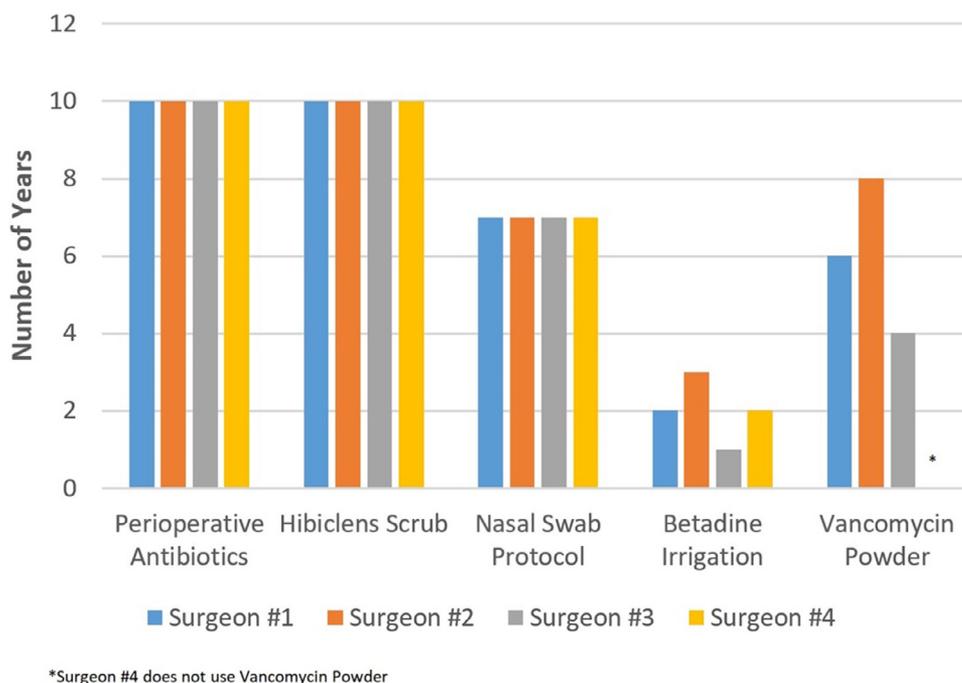


Fig. 2. Number of years SSI protocols were used by individual surgeons. SSI, surgical site infections.

determination of clinical efficacy, we feel the power of our large sample size shines a bright light on the clinical effectiveness of this “bundled” intervention which has become in part or whole standard of care for each surgeon in our group. New methods have been implemented consistently over the past decade at our institution, with the most recent including the nasal swab screening program for *S. aureus* decolonization, and the use of intrawound vancomycin powder. The SSI prevention strategy has evolved over the last decade, whereas the mature surgical practices from which these cases have been collected have remained rather consistent, and thus, the demonstrated significant drop in SSI rates is best attributed to the changes made in our clinical practice regarding SSI mitigation. Furthermore, it is important to acknowledge that there are infectious organisms that can result in a surgical site infection months after an operation. For this reason, the patient follow-up for our dataset is a significant strength of this study, ranging from a minimum of 1 year follow-up at the time of completion of this study from the most recent data, to a 10+ year follow-up from the first year of analysis.

The CHG scrubs implemented in our health system are aimed at reducing extranasal *S. aureus* colonization, whereas the nasal swab screening program is aimed at intranasal decolonization. It is well known that *S. aureus* carriers have an increased risk of SSI, with Kluytmans et al. demonstrating a sevenfold increased risk of postsurgical infection compared with noncarriers [8,19]. In addition to the skin as an obvious source of *S. aureus*, the nares are also commonly an anatomical site for *S. aureus*

colonization, and thus a target for eradication protocols. Both CHG usage and intranasal mupirocin treatment have been proven to be effective in *S. aureus* decolonization in several studies [20–22]. However, there is still debate about the utility of such protocols in reducing SSI rates; there is research that supports their use whereas other studies show no effect [21–23]. The challenge with assessing such protocols is twofold. It is both difficult to evaluate for and eliminate confounding factors such as other SSI reduction practices—as is the case at our institution with several protocols in place—as well as determining the patient compliance with a decolonization regimen. Although well-powered randomized controlled trials would be the ideal means for assessing the direct effect of each intervention, this level of study may be unrealistic at this point, because it would likely require withholding proven, or at least strongly suspected, infection reduction practices which would be unethical. For these reasons, we have chosen a pragmatic approach for this study, evaluating the cumulative effect of

Table 3  
Cost of SSI prevention measures per 100 patients

	Cost
Cost per <i>S. aureus</i> negative patient	\$59.53–64.47
Cost for 70 <i>S. aureus</i> negative patients	\$4167.10–4512.90
Cost per <i>S. aureus</i> positive patient	\$101.61–106.75
Cost for 30 <i>S. aureus</i> positive patients	\$3048.30–3202.50
Total cost for 100 patients	\$7215.40–7715.40

SIR, standardized infection ratios.

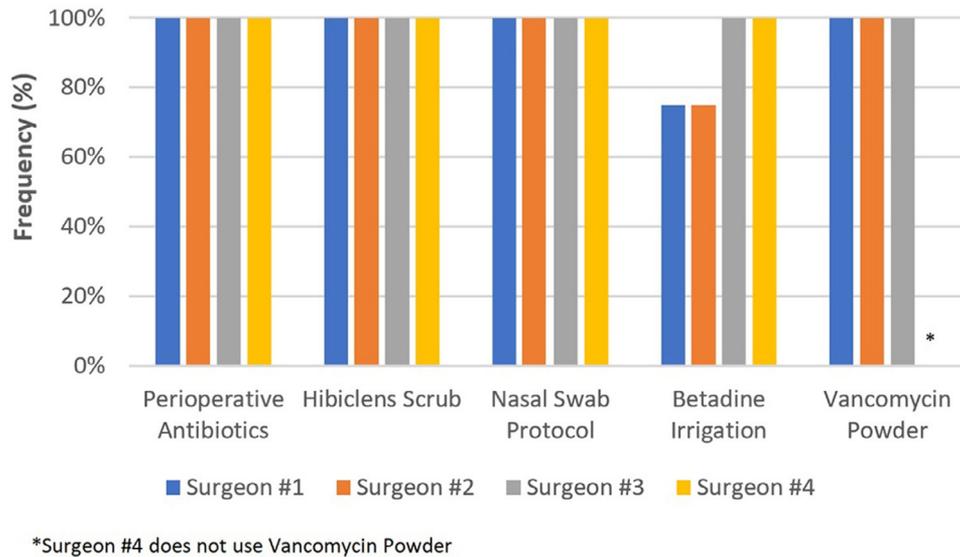


Fig. 3. Frequency of SSI protocols used by individual surgeons.  
SSI, surgical site infections.

these SSI prevention methods against the backdrop of mature steady-state quaternary care clinical practice. We acknowledge that our dataset does not possess the ability to clearly discriminate the additive effect of each intervention, but we do feel that the cumulative impact is persuasive and has proven our anecdotal observations correct. Further, each one of these measures is low-cost and low-risk, thus in our opinion, there is minimal to no down-side of adopting this comprehensive mitigation strategy.

Integration of dilute betadine irrigation and intrawound vancomycin applications have been more controversial than *S. aureus* decolonization strategies. Betadine irrigation in surgery has become common practice across many surgical specialties, and its ease of use and effectiveness has led to adoption in spine surgery as well [11]. There has been some concern regarding povidone-iodine solutions' potentially cytotoxic effect, however this has only been shown in *in vitro* studies and its clinical significance unproven [24]. We do concur with others, that the solutions used should be diluted. We use a 3.5% solution that is allowed to soak in the wound for 3 minutes and then suctioned, and the area is then thoroughly irrigated with normal saline. Further, we do not perform this irrigation step after bone graft has been placed, as a protection against any potential cytotoxic effect on the graft. Although the clinical impact of potential cytotoxicity on wound healing is theoretical at this point, what is clear is that where the addition of betadine irrigation has been implemented and empirically assessed, SSI rates have significantly dropped without reported adverse consequences [11].

Application of vancomycin powder in spine surgery is a relatively new practice, and although initially met with skepticism, numerous studies and meta-analyses have shown it to be a cost-conscious and very effective method in reducing already low SSI rates in spine procedures

[4,10,12–16]. Systemic toxicity of vancomycin application in this manner was initially a concern; however, several studies evaluating both systemic and local levels of vancomycin following its application were able to show that a minimum inhibitory concentration for common pathogens was attainable locally, whereas serum levels were below the toxicity threshold [25,26]. A second potential drawback of widespread use of vancomycin powder is the creation of vancomycin resistant organisms and a pressure toward more gram-negative and polymicrobial SSIs. The study by Chotai et al. evaluated 2,802 patients who underwent elective spine surgery, and of the 1,215 patients exposed to intrawound vancomycin powder application, none had developed an SSI with a vancomycin resistant organism [27]. Several other studies that investigated microbiology trends with the use of vancomycin powder did not discover any occurrences of SSIs with vancomycin resistant organisms [4,28,29]. However, because this practice is still relatively new and SSI rates are low at most institutions, further longitudinal studies of microbiology trends are needed. Although an increase in vancomycin resistant organisms has not been demonstrated, a shift in SSI microbiology in those cohorts exposed to vancomycin powder has been noted. Overall SSI rates have fallen quite dramatically in studies evaluating vancomycin powder use in spine surgery, but there has been an apparent shift toward more gram-negative and polymicrobial SSIs in those patients who become infected despite application of vancomycin powder [4,27–29]. Intuitively, the strong pressure toward gram-positive SSI reduction (ie, CHG, intranasal swabbing protocols and vancomycin powder) could contribute to this trend toward greater gram-negative SSIs. However, gram-positive organisms still remain the most prevalent pathogen in spine surgery SSIs. Further work is needed to clearly

define the magnitude of this migration in microbiology and to determine if gram-negative SSIs portend a worse prognosis and/or more costly treatment. If a second-order effect of the mitigation strategies described here is the generation of more gram-negative or polymicrobial infections, and these infections are more morbid and/or costly, then additional strategies will need to be developed as we continue to evolve toward an optimized SSI prevention strategy. At this time, this trend represents an early observation for which more longitudinal study is warranted.

## Limitations

There are some unexpected variations in the SSI rates that are evident in our data when analyzed in snapshots of 2 year increments. Two examples worth addressing are at both the beginning and end of our time period of the study. Over the 2006 to 2008 timeframe, there were no major implementations in SSI prevention protocols other than the mandated use of perioperative prophylactic antibiotics and Hibiclens scrubs, yet our SSI rate dropped almost 2% from 2006 to 2008. Conversely, despite the 2015 to 2016 period experiencing the greatest use of these 5 measures across the surgical practices surveyed, there was a small increase in SSI rate from 2015 (0.9%) to 2016 (1.7%). When dealing with such a low number of SSI instances, we believe these variations are caused by sampling effect. We are unable to identify a specific cause for the decrease in the infection rate at the beginning of the study, nor a cause for the increase over the last 2 years. However, we believe that this sampling effect is likely quite small as demonstrated by the small magnitude in difference during these 2 separate windows of time. Moreover, the general trend of the data over the entirety of the period we investigated clearly suggests a positive impact in the reduction of SSI rates at our institution.

To further improve the impact of this study, we analyzed the cost of these 5 “bundled” SSI interventions. A limitation of our cost-effectiveness analysis is that it requires assumptions of average cost. To quash this effect, where cost ranges existed we chose the upper end values when determining the cost of the interventions and the lower end values when determining the average cost of treating an SSI, to yield a “worst case analysis” of cost effectiveness. We were unable to determine the healthcare provider time costs associated with these interventions, but these are likely negligible and are almost certainly offset by our worst-case analysis approach when it came to the direct cost data we did include. Likewise, we feel using published SSI treatment costs, which fixate on in-patient care costs, whereas ignoring out-patient additional costs (ie, intravenous antibiotic treatment, manual therapy, rehabilitation, additional clinic visits, and consultations), underestimate the true healthcare cost of treating an SSI. This too would indicate that if anything, our 5 measures are more cost-effective than we have calculated in this study. Lastly, although these 5 SSI mitigation interventions are very safe and benign, it is

possible that they could induce a complication, which has inherent cost that is also not accounted for in our analysis. The greatest risk of this omission probably lies in the use of vancomycin powder where there is some concern that intrawound vancomycin powder may inhibit bone and dural healing [31]. Given the magnitude of savings detected in our study, the likelihood that this omission would eliminate the cost-effectiveness of these interventions is very low.

A final limitation of this study is that it relied on a process improvement database for identification of cases. Although this database contains robust data that were prospectively abstracted from primary source records, it is de-identified; therefore, we were unable to return to the primary source records to abstract additional information. This, along with the fact that compliance with all of these measures cannot be reliably abstracted in the retrospect, led us to include the surgeon survey data to approximate the timing and compliance with the initiation of each of these measures. Although these limitations impact the ability to strictly assess clinical efficacy of each individual intervention, our pragmatic approach does allow for the determination of clinical effectiveness of this “bundled” practice. Lastly, this “bundled” analysis approach is subject to the same confounding concerns raised in our Introduction, regarding the explanatory studies published on this topic. Namely, these measures may not have been implemented in a vacuum. To this end, we can say that we attempted to include and assess all of the major SSI initiatives introduced over the study period. For instance, there were no concurrent changes to our environmental infection control measures (ie, implementation of advanced air filtration systems or use of pulsed-ultra-violet robots).

## Conclusions

SSI rates for spine surgery at our institution—a large quaternary care center engaged in a disproportionate amount of complex spinal surgery in highly morbid patients—are a third of what they used to be 1 decade ago before the implementation of several easy, safe, and cost-effective protocols. With further standardization of these practices and the advent of new infection prevention techniques, we hope to continue to reduce SSI rates at our institution. However, these efforts probably represented the “low hanging fruit” and we are probably in the flat end of the marginal return curve at this point. Further interventions that target host immunity (ie, *S. aureus* vaccination) and environmental cleansing (ie, pulse-ultra-violet light) will be challenged to demonstrate similar magnitudes of effect caused by gains made over the last decade. That said, SSI is such a devastating complication, that providers and scientists need to continue to push the limit. For now, the results of this study, reinforce the value of these 5 simple interventions and serve as a general recommendation for those who have not yet implemented them.

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