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Reducing the Risk of Surgical Site Infections: Did We Really Think SCIP Was Going to Lead Us to the Promised Land?

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Abstract

Background: Surgical site infections (SSIs) are associated with substantial patient morbidity and death. It is estimated that 750,000–1 million SSIs occur in the U.S. each year, utilizing 3.7 million extra hospital days and costing more than $1.6 billion in excess hospital charges.
Method: Review of pertinent English-language literature.
Results: The Surgical Care Improvement Project (SCIP) was embraced as a "one-size-fits-all" strategy to reduce postoperative infectious morbidity 25% by 2010. Unfortunately, the evidence suggests that SCIP by itself has had little efficacy in reducing the overall risk of SSI. Whereas the SCIP initiative represents a first national effort to focus on reducing postoperative infectious morbidity and deaths, it fails to consider salient risk factors such as body mass index and selected surgical practices, including tourniquet application prior to incision.
Conclusion: Rather than focus on a single risk-reduction strategy, future efforts to improve surgical outcomes should embrace a "SCIP-plus" multi-faceted, tiered interventional strategy that includes pre-admission antiseptic showering, state-of-the-art skin antisepsis, innovative antimicrobial technology, active staphylococcal surveillance, and pharmacologic-physiologic considerations unique to selective patient populations.

Nationalizing Risk Reduction—The SCIP Mandate

Traditionally, the three cornerstones viewed as essential for reducing the risk of postoperative surgical site infection (SSI) were exquisite surgical technique, timely and appropriate antimicrobial prophylaxis, and peri-operative skin antisepsis. However, recognition of the influence of certain patient co-morbidities has required additional considerations. It is estimated that 750,000–1 million SSIs occur yearly, resulting in an additional 2.5 million hospital days at a cost exceeding $1 billion [1,2].

The Surgical Care Improvement Project (SCIP), developed by the Centers for Medicare and Medicaid Services and implemented in 2006, was designed as an evidence-based initiative to be applied broadly across selected surgical services, with a stated goal of reducing morbidity and mortality rates 25% by the year 2010 [3]. The specific infection prevention measures are improvements in antimicrobial prophylaxis that involve timing, choice of agent, and discontinuation within 24 h; appropriate hair removal (clipping rather than shaving); normalizing core body temperature within a defined time in colorectal procedures; and glycemic control in cardiac patients, which has been translated in most institutions to include the development of tight glycemic control protocols.

Implementation of the SCIP initiative required a multidisciplinary approach to achieve 95% compliance with each core process measure. Failure to achieve a national benchmark goal results in a punitive reduction in CMS reimbursement (2%), which corresponds to a "pay-for-performance" carrot-and-stick approach to improving patient outcomes. The original SCIP normothermia process measure has been expanded to include patients other than those having colorectal surgery,

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and many institutions have applied their tight glycemic control protocols to other specialties such as vascular and orthopedic surgery.

The overall success of SCIP has been decidedly mixed. Several recent reports suggest a reduction in some SSI rates following increased institutional compliance with the SCIP process initiatives. For example, Hedrick et al. reported a 10 percentage point reduction in the colorectal infection rate (26% to 16%) following implementation of the SCIP protocols [4]. In a study involving a larger sample of patients undergoing colorectal resection, the investigators observed a significant increase in compliance with SCIP process measures over two consecutive 14-mo study periods ($p < 0.001$). However, this greater compliance did not result in a significant reduction of SSIs in patients undergoing colorectal procedures, the difference having a p value of 0.92 [5]. In a retrospective study using the Premier, Inc. Perspective Database, SCIP compliance data for 405,720 patients from 398 hospitals were analyzed using a hierarchical logistic model. No relationship was found between adherence to SCIP process measures and occurrence of SSIs. Indeed, the authors documented an increase in SSIs despite substantial improvement in SCIP compliance over a two-year period [6]. Furthermore, the authors suggested that even if compliance had been 100%, the stated SCIP goal of a 25% reduction in SSI was unachievable. A companion editorial clearly identified the problems inherent in relying solely upon SCIP to improve patient outcomes; "SCIP focuses on incremental and narrow process measures that are purported to measure the overall quality of an episode of surgical care [7]." In essence, "one-size-fits-all" does not appear to improve outcome, and whereas U.S. hospitals continue to commit substantial personnel and fiscal resources to this endeavor, the return on this investment appears questionable.

Documenting the Limitations of Selected SCIP Core Initiatives

The fundamental mantra of SCIP is adherence to evidence-based strategies to improve patient outcomes, which at first glance appears prudent, if not sound intellectually. However, evidence-based medicine is a moving target, and our ability to adjust to a rapidly changing scientific environment is fraught with professional and administrative hurdles.

An example is the INF-4 SCIP measure mandating glycemic control in cardiac patients (6 AM postoperative blood glucose $\leq$200 mg/dL). The evidence for the value of this process comes in part from the report of Zerr et al., which was published in 1997, documenting a significant reduction ($p < 0.02$) in the risk of sternal (deep incisional) SSI if the blood glucose concentration was <200 mg/dL [8]. However, a publication in 2001 raised the bar substantially, suggesting that the target should be <150 mg/dL [9]. This led to institutions embracing tighter glycemic control in an effort to normalize blood glucose concentrations. However, three recent publications call into question the benefits of tight glycemic control as a benign risk-reduction strategy [10–12]. The conclusion of these publications is that such control can lead to a significant risk of hypoglycemia and death in critically ill surgical patients. That is, in an effort to improve patient outcomes, we advertently run the risk of creating a sentinel event. Stress-induced hyperglycemia is relatively common, with as many as 40% of patients manifesting hyperglycemia at the time of surgery without a documented history of Type I or Type II diabetes mellitus. Although reducing hyperglycemia has obvious mechanistic benefits from both a post-operative infection-prevention and wound-healing perspective, conventional glycemic control with a target range of 140–180 mg/dL appears to be adequate for most surgical patients. The original SCIP INF 4 core initiative did not mandate tight glycemic control, but the process has morphed beyond expectations.

The SCIP core measure INF-1 specifies that patients receive antibiotic prophylaxis within one hour prior to surgical incision (2 h if the patient is to receive vancomycin). This specific measure has created some confusion, especially as this time interval appears to be variable. As pointed out in the Hawn editorial [7], the 60-min time window has never been tested in a randomized manner and tends to treat all antibiotics except vancomycin as equivalent pharmacokinetically. As a general rule, we indicate to our surgical teams that the drug should be infused at least 30 to 45 min prior to incision, but again, no prospective trial has validated this approach. From a pragmatic perspective, the likelihood of achieving the maximum tissue concentration at 30–45 min prior to incision is greater than if the drug (usually a cephalosporin) is "pushed" 5–10 min prior to incision.

A secondary issue that has arisen during our study is the variability of the "wheels in to cut" time among the surgical services. Table 1 documents this time for 13 services at Freodtert Hospital, Milwaukee. For 10 services, the mean time is less than 45 min (in 6 of the 13, less than 30 min), suggesting it is unlikely, given the operational flow of the events following patient arrival, that maximum tissue drug concentrations will be achieved at the time of incision when the preparatory time is so short. However, based on our institutional experience, in those surgical services where the "wheels in to cut" time falls below 30 minutes, antimicrobial prophylaxis can be initiated prior to patient arrival and the timing still fall within the SCIP-mandated 60-minute window.

A tertiary issue that has emerged regarding the peri-operative timing of antimicrobial prophylaxis is the "up time," or tourniquet application on services such as plastic, orthopedic, vascular, and trauma surgery. Table 2 documents tourniquet placement and timing of antimicrobial prophylaxis in ran-

Table 1. Mean "Wheels in to Cut" Time for 13 Surgical Services, February 2007 to December 2007[a]

Surgical service	*Mean "wheels in to cut" time (min)*
Cardiac	80.1
Cardiothoracic	75.1
Otolaryngology	36.3
General	29.8
Gynecology	26.1
Neurosurgery	45.9
Ophthalmology	21.1
Oral	34.6
Orthopedics	33.7
Plastic	29.6
Transplant	25.2
Trauma	25.8
Vascular	37.9

[a]Data from audit of surgical services at Froedtert Hospital, clinical affiliate of Medical College of Wisconsin, Milwaukee.

Table 2. Tourniquet Placement ("Up-Time") and Timing of Antimicrobial Prophylaxis in Orthopedic and Plastic Surgical Cases Selected Randomly Over a Six-Month Interval[a]

Surgical service	*Cases*	*No. (%) with tourniquet prior to antibiotic*
Orthopedic[b]	135	37 (27.4)
Plastic[c]	128	43 (33.5)
Total	263	80 (30.4)

[a]Data from audit of surgical services at Froedtert Hospital, clinical affiliate of Medical College of Wisconsin, Milwaukee.
[b]Six infections documented on postoperative surveillance (four patients had body mass index >40 kg/m^2).
[c]Five infections documented on postoperative surveillance (four patients had body mass index >40 kg/m^2).

domly selected plastic and orthopedic surgical cases over a 6-mo period. In 27.4% (37/135) of total joint replacements and 33.5% (43/128) of plastic surgery cases where a tourniquet was applied, antimicrobial prophylaxis was started during or after the tourniquet was inflated, ensuring that little or no antibiotic was present in the wound bed at the time of incision. From a SCIP perspective, all of these cases were timed appropriately; however, from a risk assessment perspective, these patients would be viewed as vulnerable. A total of 11 SSIs (nine superficial; two deep incisional) were noted in this population over the 6-mo interval, and eight of these patients had a body mass index (BMI) greater than 40 kg/m^2. These findings emphasize the importance of starting antimicrobial prophylaxis prior to operating room entry.

Two additional considerations that impact the effectiveness of the SCIP initiative, and should be factored into the delivery of Twenty-First Century surgical care, are: (1) The role of BMI as a sentinel risk factor for SSIs; and (2) the diminished susceptibility of traditional surgical pathogens to the first-generation cephalosporins. Whereas the SCIP antimicrobial prophylaxis process addresses timing, correct drug utilization, and discontinuation within 24 h, no consideration is given to dosing, especially in the obese population. Body mass index or percent body fat has emerged as a major risk factor for postoperative SSI on virtually all surgical services [13–21]. A pharmacokinetic study conducted in our institution in bariatric patients (BMI >40 kg/m^2) revealed that the traditional 2-g dose of cefazolin, followed by re-dosing at 3 h, was insufficient to achieve therapeutic tissue concentrations in the majority of patients undergoing Roux-en-Y gastric bypass. Intraoperative therapeutic tissue concentrations were achieved in 48.1%, 28.6%, and 10.2% of patients with BMIs 40–49, 50–59, and ≥60 kg/m^2, respectively [22]. A subsequent analysis suggested that a 3-g loading dose may increase overall intraoperative tissue concentrations 2–3-fold (unpublished data), depending on the BMI. Microdialysis in six patients with BMIs ranging from 44–53 kg/m^2 given a single intravenous (IV) dose (1.5 g) of cefuroxime found that a single such dose may be adequate to provide therapeutic tissue concentrations for methicillin-sensitive *Staphylococcus aureus* (MSSA). However, tissue concentrations based on therapeutic breakpoints would most likely be inadequate for gram-negative microorganisms (*Enterobacteriaceae*) [23]. Anaya and Dellinger suggested that obese patients require a larger loading dose to provide consistent tissue concentrations over the duration of the surgical procedure [24].

Finally, Table 3 documents the evolving susceptibility of staphylococcal and selected gram-negative isolates to first-generation cephalosporins, whereas Table 4 presents the change in the Clinical and Laboratory Standards Institute (CLSI) breakpoints for the *Enterobacteriaceae*. At first glance, it would appear that *Klebsiella pneumoniae* has displayed relatively stable susceptibility to the first-generation cephalosporin agents over the past decade. However, *Escherichia coli* demonstrated diminished responsiveness to cephalothin over the same time interval, returning to 89% susceptibility when cefazolin was substituted for cephalothin in 2008 (see Table 3). These values may be misleading, however, because the current breakpoints for the *Enterobacteriaceae* were revised in January 2010, and these changes may not be reflective in the hospitals 2011 antibiograms. Those gram-negative isolates that were fully sensitive at ≤8 mcg/mL are now considered fully resistant at ≥4 mcg/mL, a major change that likely will influence tissue therapeutic activity following the usual 1- or 2-g prophylactic antimicrobial dosing (Table 4). It should be noted that in 2011, gram-negative breakpoints for the carbapenems also were shifted downward, altering the perceived therapeutic activity of an important class of antibacterial agents. Over the same time interval, in vitro activity of the first-generation agents against staphylococci has ranged from the high 20th to the 30th percentile for coagulase-negative strains, whereas coagulase-positive isolate susceptibility has fluctuated between the low 60th and high 50th percentile.

Evolutionary changes in patterns of antimicrobial susceptibility and the emergence of multi-drug-resistant gram-positive and -negative strains associated with SSIs portends the questionable utility of current agents for antimicrobial prophylaxis. Clinical guidelines, although updated periodically, continue to rely on data that are 20–30 years old. Falagas et al. called for the development of properly designed, randomized trials to assess the effectiveness of standard and

Table 3. Froedtert Hospital In-Vitro Susceptibility (%) of Staphylococcal and Selected Gram-Negative Clinical Isolates, 2001–2009 Against First-Generation Cephalosporins[a]

	2001	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Escherichia coli	81	77	78	80	80	25	27	89	89
Klebsiella pneumoniae	83	86	86	96	90	80	83	92	93
Staphylococcus epidermidis	27	29	34	35	31	38	NR	NR	NR
S. aureus	63	64	61	57	54	55	NR	NR	NR

[a]2001–2007, cephalothin was test agent; 2008 onward, cefazolin was test agent.
NR = not reported.

Table 4. Old and Revised[a] Therapeutic Breakpoints (Broth Dilution) for First-, Second-, and Third-Generation Cephalosporins against *Enterobacteriaceae*[b]

	Old (M100-S19)			*Revised (M100S-20)*		
	S[c]	*Int*	*R*	*S*	*Int*	*R*
Cefazolin	≤8	16	≥32	≤1	2	≥4
Cefotaxime	≤8	16–32	≥64	≤1	2	≥4
Cefizoxime	≤8	16–32	≥64	≤1	2	≥4
Ceftriaxone	≤8	16–32	≥64	≤1	2	≥4
Ceftazidime	≤8	16	≥32	≤4	8	≥16
Aztreonam	≤8	16	≥32	≤4	8	≥16

[a]Clinical and Laboratory Standards Institute (CLSI) revised 2010 breakpoints.
[b]No change in breakpoints for cefuroxime, cefepime, cefoxitin (S = ≤8; Int = 16; S = ≥32) or cefotetan (S = ≤16; Int 32; R = ≥64).
[c]S = susceptible; Int = intermediate; R = resistant.

innovative antimicrobial prophylactic strategies in selected surgical settings, especially where the risk of acquiring antimicrobial-resistant strains is considerable [26].

Embracing a "SCIP-Plus" Perspective to Reduce the Risk of Surgical Site Infections

Whereas the SCIP process has considerable shortcomings as a stand-alone interventional strategy, as documented in the previous section, it does represent the largest surgical patient safety and surgical infection reduction initiative in U.S. history [26]. Therefore, at best, it should be viewed as a baseline to which other adjunctive evidence-based strategies are added to create a total risk-reduction package. Four adjunctive evidence-based interventions that warrant consideration are pre-admission antiseptic showering or cleansing, adoption of a state-of-the-art peri-operative skin antisepsis regimen, use of antimicrobial suture technology at wound closure, and adoption of an institutional screening strategy to detect *S. aureus* before elective surgical procedures.

Preadmission antiseptic shower

More than 20 years ago, Kaiser et al. and Garibaldi et al. demonstrated, in separate randomized trials of surgical patients, that bathing with 4% chlorhexidine gluconate (CHG) was more effective at reducing staphylococcal skin colonization than was povidine-iodine (PI) or antiseptic bar soap [27,28]. However, these studies were at best surrogate observations; they did not document reductions in SSI. A Cochrane collaborative publication in 2006 reviewed seven clinical trials, involving 10,157 patients, in which patients bathed preoperatively with chlorhexidine (4%), placebo, or bar soap or used no preoperative bath (cleansing). These studies were published over a 26-year period, from 1983–2009. The conclusion of this meta-analysis was that preoperative bathing (cleansing) with chlorhexidine did not significantly reduce infection in clean surgical procedures (Class I). However, in the discussion, the authors stated, "One of the limitations of this review was the quality of some of the studies" [29]. Among the potential shortcomings of the studies cited by the Cochrane investigators, one fundamental flaw was the lack of a standardized process for applying the skin antiseptic agent. In a study conducted in our institution and published in 2008, using a standardized application (2×) of 4% CHG, it was possible to achieve skin surface concentrations 25-fold greater than the minimal inhibitory concentration $(MIC)_{90}$ for staphylococcal surgical isolates (5 mcg/mL). Alternatively, in individuals who cleansed twice using a 2% CHG polyester cloth, skin surface concentrations approached 350×the MIC_{90} for staphylococcal skin isolates [30]. Several recent clinical trials support the use of skin surface cleansing with CHG to reduce the risk of selected healthcare-associated infections, including SSIs [31–34]. The U.S. Centers for Disease Control and Prevention and the Association of periOperative Registered Nurses (AORN) have endorsed the concept of the preadmission shower or skin cleansing, with both organizations recommending CHG as the antiseptic agent [35,36] Furthermore, AORN and other peri-operative practitioners recommend a minimum of two CHG applications prior to hospital admission [36,37].

Peri-operative skin antisepsis

There are several options for peri-operative skin antisepsis, including 10% PI paint, aqueous CHG (2–4%), PI in isopropyl alcohol (70%), 2% CHG in 70% isopropyl alcohol, and iodine povacrylate (0.7% available iodine) in isopropyl alcohol (74%). However, until recently, there were no clinical trials comparing these agents. A study of 3,209 patients conducted at the University of Virginia by Swenson et al. compared three regimens: PI/70% alcohol followed by a final PI paint; 2% CHG/70% isopropyl alcohol; and iodine povacrylate/isopropyl alcohol. A sequential design was used in which each agent was evaluated for six months before switching to the next regimen. Patients were followed for 30 days post-operatively, and the SSI rate was calculated. The rate was significantly lower with the iodophor agents (4.8%; $p < 0.001$) than with the CHG/alcohol combination (8.4%) [38]. In 2010, Darouiche et al. published a prospective, randomized, multicenter clinical trial comparing PI with 2% CHG/70% alcohol in over 800 patients undergoing clean-contaminated surgical procedures. As in the Swenson et al. study, the patients were monitored for 30 days; the overall infection rate was 16.1% in the PI group and 9.5% in the CHG/alcohol group ($p < 0.004$). The CHG/alcohol agent was superior to the PI paint in presenting both superficial incisional ($p < 0.008$) and deep incisional ($p < 0.05$) SSIs. In both studies, there were no differences in the likelihood of adverse skin reactions [39].

Although one could debate the relative merits of these two studies, the conflicting outcomes will continue to generate partisan debate. Nevertheless, CHG does have several mechanistic advantages over iodine-based agents: (1) CHG binds to the skin surface, providing residual antiseptic activity; (2) unlike PI, CHG is not inactivated by blood or tissue proteins; and (3) in the presence of 70% alcohol, CHG exhibits rapid, sustainable antiseptic activity on the skin [40].

Antimicrobial technology

The use of antimicrobial-coated devices to reduce the risk of certain healthcare-associated infections has been a mainstay in medical/critical care patient populations for more than 15 years [41,42]. Historically, antimicrobial technology has had little appeal to the surgical practitioner as a risk reduction strategy. However, for more than 30 years, orthopedic surgeons have used antimicrobial-impregnated polymethyl-

methacrylate bone cement for revision arthroplasty after infection or aseptic loosening of the device [43]. Recently, two studies documented the risk-reduction benefit of an antimicrobial-impregnated technology in selected surgical patients. Carson reviewed the clinical efficacy of antibiotic-impregnated inflatable penile prostheses ($n = 2,261$) compared with standard devices ($n = 1,944$) and found a significant difference in the infection rates. The group with the antimicrobial devices had an infection rate 82.4% lower ($p = 0.0034$) than that of the control patients at 60 days post-insertion and 57.8% lower ($p = 0.0047$) after 180 days [44]. In part because of the catastrophic risk of infectious complications after implantation of these devices, the antimicrobial penile prosthesis now is considered the standard of care. In a second investigation, 2,000 cardiac surgery patients were randomized to either standard antimicrobial prophylaxis or standard prophylaxis plus insertion of a collagen sponge containing gentamicin 260 mg prior to wound closure. Use of the gentamicin-impregnated sponge resulted in a significant reduction in sternal SSI ($p < 0.001$). However, the sponge was associated with more early reoperations for bleeding ($p < 0.03$) [45].

In 2003, a triclosan-coated suture was introduced. The concept that a braided antimicrobial suture could reduce the risk of SSI was met with skepticism by both surgical and nonsurgical healthcare professionals. However, two classic studies published more than 50 years ago by Elek and Cohen and James and Macleod demonstrated clearly that the presence of a suture (foreign body) in a clean incision was sufficient to lower the inoculum required to produce an SSI [46,47]. Katz et al. reported wide variability in bacterial adherence to various types of suture material [48], concluding that "bacterial adherence to sutures plays a significant role in the induction of surgical infection." Recent in vitro studies documented that micro-organisms associated commonly with SSIs were inhibited from adhering to the surface of triclosan-coated polyglactin 910-braided sutures [49, 50]. The antimicrobial activity persisted (96 h) even in the presence of tissue protein, suggesting a protective benefit during wound re-epithelialization [50]. The intrinsic safety of this implantable technology was evaluated by Ford et al. in a pediatric population, finding that the presence of triclosan did not lead to suture rejection or any adverse tissue reactions compared with non-antimicrobial control sutures [51].

The clinical efficacy of this technology has been evaluated in several independent clinical trials involving cardiothoracic, pediatric neurosurgical, vascular, and general surgical patient populations [52–55]. In a case-control trial ($n = 479$), Fleck et al. found that the use of triclosan-coated sutures resulted in a significant ($p < 0.008$) reduction in sternal SSI compared with non-antimicrobial closure technology [52]. In a randomized clinical trial ($n = 61$), Rozzelle et al. documented that use of antimicrobial-braided sutures was safe and effective for closure in cerebrospinal fluid shunt surgery (pediatric), resulting in a significant ($p = 0.038$) reduction of SSI [53]. In a Chinese randomized study ($n = 456$) involving general surgical patients, use of triclosan-coated sutures reduced the risk of SSI significantly ($p < 0.01$) compared with non-antimicrobial monofilament/braided devices and silk suture [54]. The largest study, involving 2,088 midline laparotomy procedures, compared a non-antimicrobial monofilament device with a triclosan-coated braided suture for closure in a before–after quasi-experimental design, controlling for antimicrobial prophylaxis, normothermia, and co-morbidities. Use of the antimicrobial-coated suture resulted in a significant ($p < 0.001$) reduction of SSI (4.9% vs. 10.8%) compared with closure using non-antimicrobial monofilament sutures [55]. In a cost-benefit analysis of the original study of Rozzelle et al., Stone et al. documented a significant ($p = 0.038$) cost savings associated with the prevention of postoperative shunt infections in the triclosan-coated suture group compared with the control group (non-antimicrobial closure technology) [56]. It thus appears, on the basis of mounting evidence, that antimicrobial-coated sutures do reduce the risk of SSI in diverse surgical patient populations.

Preoperative surveillance for S. aureus

Rapid identification of surgical patients colonized with *S. aureus* (methicillin-sensitive [MSSA] or methicillin-resistant [MRSA]) may prevent nosocomial dissemination or allow the practitioner to direct appropriate therapy [57]. However, universal screening of asymptomatic patients for *S. aureus* or MRSA colonization remains controversial despite governmental mandates [58–61]. Selecting an appropriate population for screening, the method of screening, the body site screened, and compliance with infection control practices can influence the potential for reduction of *S. aureus*/MRSA carriage/infections.

Traditional methods employed to identify *S. aureus* or MRSA include standard bacteriological culture utilizing selective or differential media. Although these methods are the least expensive screening techniques, they result in delayed turnaround because of the requirement for confirmation of positive results. Newer culture methods for MRSA detection include the chromogenic agar media, which incorporate a substrate that reacts with an enzyme in *S. aureus*, causing the colony to change color. The chromogen coupled with an antimicrobial agent in the medium provides a sensitive and specific method to screen for MRSA. Studies evaluating chromogenic medium compared with traditional culture demonstrate excellent sensitivity and specificity, with a final result available within 24–48 h at a cost marginally higher than that of traditional culture [63].

Other methods used for MRSA detection, including conventional polymerase chain reaction (PCR) technology, amplify DNA obtained from clinical isolates by targeting the MRSA-specific *mecA* gene and an *S. aureus*-specific marker (i.e., *nuc* gene). Conventional PCR requires extensive and meticulous technique that can be prone to contamination because of the need for post-PCR processing [64]. Real-time PCR (RT-PCR) is an excellent method for the rapid detection of MRSA [65]. With quick turnaround and exceptional accuracy, RT-PCR has proven to be an ideal testing strategy within a clinical setting of moderate MRSA endemicity where large numbers of screens need to be processed daily. However, implementation of RT-PCR in a setting of low endemicity, such as community hospitals, may be unfeasible because of the limited work space (separate rooms are needed for pre-PCR, PCR, and post-PCR work to prevent amplicon contamination), up-front costs, and cost per test.

Proponents suggest that detection and eradication of MRSA has measureable benefits in reducing the risk of SSI in some surgical populations. Beginning in 2007, Pofahl et al. screened all patients for MRSA who were scheduled for elective surgical

procedures. Patients who were positive were treated for five days with 2% mupirocin topically BID in the nares and showered with 4% CHG on days 1, 3, and 5 of mupirocin treatment. Appropriate antibiotic prophylaxis also was given. The rate of MRSA SSIs decreased significantly ($p < 0.04$) after institution of universal screening [66]. Bode et al. conducted a randomized, double-blind, placebo-controlled, multi-center trial and demonstrated that rapid detection of *S. aureus* by RT-PCR, followed immediately by nasal decolonization with mupirocin and CHG (extra-nasal sites), resulted in a significant reduction in SSI, especially deep incisional SSI (0.9% vs. 4.4%; relative risk 0.21; 95% confidence interval [CI] 0.07–0.62) [67]. This study did not discriminate between MSSA and MRSA but rather viewed both as microbial risks for post-operative SSI. A study by Kim et al. in 7,019 patients undergoing elective orthopedic surgery used similar tactics for screening for MSSA and MRSA. Patients colonized with either were treated with topical muprirocin and CHG showers. Patients who were MRSA-positive were re-screened by PCR to confirm eradication. A significant (60%) reduction in MRSA infections and a 50% reduction in MSSA infections were observed ($p < 0.0093$) [68]. Whereas real-time staphylococcal surveillance can be associated with high institutional (capital equipment and labor) cost, so are the fiscal and personal adverse events that have been well-documented for SSIs caused by *S. aureus* [69].

Thinking about risk reduction outside the box

Two final issues are worthy of consideration. First, the incidence of biomedical device implantation has increased substantially in all surgical disciplines over the past 20 years. This trend has resulted in a shifting of the "window of discovery" of SSIs by conventional post-operative surveillance strategies. Experience suggested that anywhere between 80–85% of post-operative infections were "discoverable" within a 30-day period, with an additional 15% appearing beyond that 30-day window. Trending patterns observed at the hospital affiliate of the Medical College of Wisconsin suggest that in an era of widespread device implantation, there has been a shift toward more infections occurring beyond the traditional 30-day period. Over the past seven years, we have observed an increase in the number of device-associated infections appearing after 30 days, such that the number of post-operative infections occurring beyond 30 days approaches 40% (unpublished data). Whereas infection preventionists routinely monitor certain procedures involving device insertion (e.g., total joint replacements) for as long as 12 months post-operatively, the sheer volume of current device implantation on all surgical services makes this task daunting. Therefore, effort should be placed on "risk prevention" on the front end. This involves an understanding of both the traditional and non-traditional pathways of incision or device contamination.

A 2005 study from our institution documented the role of intraoperative nasopharyngeal shedding as a risk factor for postoperative vascular graft contamination and infection. Using a molecular technique called pulsed-field gel electrophoresis (PFGE), a clonal connection was made between shedding of staphylococci from the nasopharyngeal sites of members of the vascular surgery team and incision/device contamination [70]. Additional molecular evidence supporting the nasopharyngeal etiology has been reported in both the orthopedic and the cardiothoracic literature [71,72], incriminating microbial shedding as a risk factor for device-related infection. In light of this emerging evidence, care should be taken to reduce the risk of device contamination prior to and during implantation. A pragmatic solution might be to cover the device on the sterile field with a small non-linting drape if there appears to be a delay in device insertion, which often happens when complications (e.g., bleeding) occur in the surgical field. Future tactics to limit or reduce the risk of microbial shedding involve the development of a new generation of surgical masks, which (a) incorporating an active antimicrobial agents, or (b) are modeled after the N-95 respirator technology into its construction but providing a more comfortable fit while preventing the release of nasopharyngeal flora into the operative field.

A final etiologic mechanism associated with SSI is micro-perforation of surgical gloves, allowing bacteria from the operator's hands to be deposited in the incision. Recent literature documents that glove perforation occurs at rates ranging from 19% in major elective gynecologic surgery to 78% during selective emergency procedures [73,74]. During surgery, manipulation of abrasive and cutting objects in association with mechanical stress threatens the integrity of the glove barrier allowing bacterial migration across the composite layers of the glove [75]. Because of the perceived rate of unnoticed glove perforation, some surgeons recommend routine glove changes on a 2-h cycle [76]. A recent study of more than 4,000 general, vascular, and trauma surgical patients found that glove perforation was associated with a higher likelihood of SSI, and that failure to administer timely, appropriate antimicrobial prophylaxis was an important risk co-factor, leading to contamination and infection [77]. This study clearly documents a crucial relation between glove integrity and SSI.

A recent study of the benefits of an innovative tri-layer antimicrobial glove technology demonstrated a reduced risk of microbial passage in a model of gross wound contamination. There was a significant ($p < 0.005$) reduction in bacterial transit following glove micro-perforation for staff members wearing the innovative antimicrobial gloves compared with individuals wearing single- or double-layer latex gloves [78]. The antimicrobial component is sequestered in a middle layer composed of a blend of chlorhexidine digluconate, didecyl dimethyl ammonium chloride salt, and benzalkonium chloride salt in a polyethylene glycol diluent, which is effective against gram-positive and -negative bacteria and some viruses. Whereas glove perforation as a risk factor in the development of SSI represents a new and possibly controversial etiology, it may in fact play a crucial role in the development of late-onset post-operative infection via device contamination through the handling process at the time of insertion.

Final Considerations

The SCIP initiative has captured the attention of surgeons, infection preventionists, hospital administrators, and other healthcare professionals. Unfortunately, this process has not resulted in a significant improvement in either the morbidity or the mortality rate from SSIs. The complexity and co-morbidities observed among current surgical patients render the "one-size-fits-all" process initiative simplistic, if not naïve. Efforts to reduce the risk of SSI henceforth will require three focused commitments: (1) Collegiality—a process that involves all interested parties to invoke a team commitment;

(2) commitment to evidence-based initiatives involving valid documented interventions that are above and beyond the current SCIP mandate, embracing new and innovative risk reduction strategies (SCIP Plus); and (3) passion and patient advocacy—the desire to improve a process that should always be patient-centric.

Author Disclosure Statement

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