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# *The Anesthesiologist's Role in the Prevention of Surgical Site Infections*

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SURGICAL site infections (SSIs) continue to be a substantial source of morbidity and mortality in the surgical patient population. They are the second most common cause of nosocomial infection after urinary tract infections and account for approximately 17% of all hospital-acquired infections.<sup>1</sup> These infections lead to longer hospital and intensive care unit stays, lead to substantially increased mortality, and contribute significantly to healthcare costs.<sup>2</sup> In a 1999 series of cardiac surgery patients, each deep sternal wound infection added an average of \$26,400 in hospital charges and increased the average duration of stay by 16 days.<sup>3</sup>

The incidence of SSI varies for each operative procedure, each surgeon, and each hospital. In addition, each patient presents with his or her own unique risk profile for the development of a SSI. Although sterile surgical technique is extremely important to the prevention of SSIs, there is increasing evidence that anesthesiologists play a prominent yet under appreciated role in the prevention of SSIs. While infections typically present several days postoperatively, the first few hours after bacterial contamination are the critical window for the establishment of infection.<sup>4,5</sup> Therefore, decreasing SSIs hinges on the optimization of perioperative conditions, many of which are controlled by anesthesiologists.

In this review, we will discuss the literature surrounding six perioperative factors over which anesthesiologists have at least partial control and how these factors may influence the risk of postoperative surgical site infection. Although we acknowledge that many anesthesiologists care for patients in the intensive care unit, we limit our discussion here to the immediate perioperative period.

#### Hypothermia

Mild perioperative hypothermia (core body temperature 34°-36°C) is commonly observed in surgical patients. The complications of mild perioperative hypothermia have been studied extensively and include increased duration of hospitalization,<sup>5</sup> increased intraoperative blood loss and transfusion requirements, increased adverse cardiac events, and an increase in patient thermal discomfort in the recovery room.<sup>6</sup> The effects of mild hypothermia on SSI have also been studied.

A series of 200 patients undergoing colorectal surgery were randomized to a hypothermic group  $(34.4^{\circ} \pm$ 0.4°C) or a normothermic group (37°  $\pm$  0.3°C) and followed for 2 weeks postoperatively.<sup>5</sup> The authors had planned to enroll 400 patients; however, the trial was stopped early because of a statistically significant difference in infection between the two groups. The incidence of SSI was 5.8% in the normothermic group and 18.8% in the hypothermic group. The patients who developed SSIs required hospital stays nearly 1 week longer than those who did not develop a SSI, indicating that these were clinically significant complications. The normothermic patients were also found to have significantly more collagen near the wound, had their staples removed a day sooner, and tolerated food earlier.<sup>5</sup> In addition, the authors determined that intraoperative vasoconstriction was present in 74% of the hypothermic patients but only 6% of the normothermic patients. This difference remained statistically significant throughout the 6-h recovery period.<sup>5</sup>

This randomized, double-blind trial suggests hypothermia is a major risk factor for postoperative SSI and that maintenance of perioperative normothermia may reduce the incidence of SSIs. One criticism of this study has focused on the increased allogeneic blood requirement in the hypothermic group ( $0.8 \pm 1.2 \text{ } vs. 0.4 \pm 1.0 \text{ } units$ P = 0.01). Indeed, erythrocyte transfusions have been

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implicated as a risk factor for SSI and will be discussed in detail below. In their discussion, these authors state that "on multivariate regression analysis a requirement for transfusion did not independently contribute to the incidence of wound infection."<sup>5</sup> Further, although the hypothermic patients received more allogenic blood per patient, the number of patients requiring transfusion was not significantly different (P = 0.054).

In 2001, Flores-Maldonado *et al.*<sup>7</sup> reported on a series of 290 consecutive cholecystectomy patients with a 30day follow-up. This series excluded patients that received blood transfusions preoperatively, intraoperatively, or postoperatively. The average temperature in their hypothermic group was  $35.4^{\circ} \pm 0.4^{\circ}$ C *versus*  $36.2^{\circ} \pm 0.2^{\circ}$ C in the normothermic group based on tympanic membrane immediately postoperatively. The incidence of SSI was 11.5% in the hypothermic group and 2% in the normothermic group.<sup>7</sup> This study implicates mild hypothermia as a risk factor for SSI but excludes the possible contribution of perioperative blood transfusion.

Although a few studies have not shown an increased risk of infection in hypothermic patients,<sup>8</sup> most studies, including those reviewed here, implicate mild intraoperative hypothermia as a risk factor for postoperative SSI. Indeed, Kurz et al.<sup>5</sup> performed the only double-blind randomized trial evaluating hypothermia and found a strong correlation between hypothermia and infection. Although the authors acknowledge that this study may not necessarily reflect current practice (in the study, the antibiotics were administered during anesthesia induction and may not have preceded skin incision as is currently recommended, and antibiotics were continued for 4 postoperative days) and that the study only observed patients undergoing colorectal surgery, it is likely that the findings are applicable to other surgical patient populations today. With all that is now known regarding the complications of hypothermia,<sup>6</sup> it should be every clinician's goal to maintain normothermia unless contraindicated.

The major relation between hypothermia and increased SSI is thought to be a decrease in subcutaneous tissue perfusion mediated by vasoconstriction.9 Hopf et al.<sup>10</sup> demonstrated that subcutaneous oxygen tension at a surrogate wound inversely correlated with the risk of SSI. In patients with a subcutaneous oxygen tension greater than 90 mmHg, there were no infections, whereas patients with a subcutaneous oxygen tension of 40-50 mmHg had an infection rate of 43%.<sup>10</sup> This illustrates the critical importance of providing adequate oxygen stores to maintain oxidative killing by neutrophils. Not only does hypothermia decrease perfusion and thus oxygen supply to the wound, it also reduces the production of superoxide radicals for any given oxygen tension. Indeed, bacterial killing by neutrophils is reduced in the face of hypothermia.<sup>6</sup> In addition, animal models have demonstrated that hypothermia induces an antiinflammatory T-cell cytokine profile with increased levels in interleukin 10 and decreased levels of interleukin 2. This profile is similar to that of other "proinfectious" states such as severe burn and hemorrhage. It should also be noted that mild hypothermia increases nitrogen losses and decreases collagen production, which may serve to slow would healing and contribute to the risk of infection.<sup>5,11</sup> These points are summarized in figure 1.

Heat loss during the first hour of anesthesia is typically a result of the redistribution of core to peripheral temperature gradients caused by an anesthetic-induced decrease in vasoconstriction. Actively prewarming patients for 2 h before the induction of either general or regional anesthesia can attenuate this effect.<sup>6</sup> The two most important causes of continued heat loss in the operating room are radiation and convection. The most effective means of preventing these causes of ongoing losses are forced air warming and administration of warmed fluids.<sup>6</sup> Many detailed reviews exist on the causes, treatment, and prevention of perioperative hypothermia.<sup>6,9,12</sup>

## Hyperoxia

In most clinical situations, oxygen delivery is vastly more dependent on the amount of oxygen bound to hemoglobin than the amount of oxygen dissolved in the blood. However, the subcutaneous tissue consumes little oxygen compared with the rest of the body, approximately 0.7 ml/100 ml of blood.<sup>13</sup> This amount of oxygen can be supplied by the plasma alone in a normal perfusion state.<sup>13</sup> In fact, the mean extracellular partial pressure of oxygen in the subcutaneous tissue is around 60 mmHg, a level above the range in which oxygen readily dissociates from hemoglobin. In addition, trauma-induced injury of the microvasculature at the site of the wound increases the diffusion distance required for oxygen, further decreasing the impact of hemoglobin transported oxygen on wound oxygen tension. Adequate wound oxygen tension is important not only for oxygen radical production by neutrophils (fig. 1) but also in the development of collagen and epithelium, instrumental factors in wound healing.13

These facts have led some researchers to hypothesize that providing supplemental oxygen during the perioperative period would lead to higher oxygen tensions in the wound and a decrease in the incidence of SSIs. To date, two randomized, double-blind trials involving 800 patients for elective colorectal surgery have evaluated the effects 80% inspired oxygen *versus* 30% inspired oxygen intraoperatively and for 2 h (500 patients) or 6 h (300 patients) postoperatively. Both of these studies found statistically significant reductions in the rates of SSIs in the 0.8 fraction of inspired oxygen (Fio<sub>2</sub>) group *versus* the 0.3 Fio<sub>2</sub> group.<sup>14,15</sup> Pooling the data from



Fig. 1. Conditions leading to decreased (*A*) and increased (*B*) oxygen tension. Decreases in subcutaneous oxygen increase the incidence of surgical site infection. The maintenance of normothermia and adequate perfusion are important interventions that increase subcutaneous oxygen and help to prevent surgical site infection. The use of increased fractions of inspired oxygen or hyperoxia may also provide significant benefit. NADPH = nicotinamide adenine dinucleotide phosphate;  $O_2 = oxygen$ ; PMN = polymorphonuclear cell; SubQ = subcutaneous.

these two studies yields an absolute risk reduction in SSI of 7% and a relative risk reduction of 45% (P = 0.02).<sup>16</sup> Although halving the rate of SSI after colorectal surgery with a simple maneuver such as increasing the inspired oxygen percentage to 80% would have broad implications, the findings of these authors have not been supported by other studies. Pryor *et al.*<sup>17</sup> reported a study of 160 patients undergoing major abdominal surgery including hemicolectomy, sigmoidectomy, low anterior resection, gastrectomy, and large gynecologic staging or debulking procedures. They randomized patients to either 35% inspired oxygen or 80% inspired oxygen. The assigned oxygen level was also maintained for 2 h postoperatively. This study was terminated at interim analy-

sis secondary to a statistically significant increase in the rate of SSI in the 80% oxygen group.<sup>17</sup>

It is difficult to reconcile the results of these three randomized, double-blind studies with opposing results. An editorial provides a potential explanation of these conflicting results.<sup>16</sup> The study by Pryor *et al.* is limited by its smaller size. In addition, perioperative conditions were not standardized between groups, as they were in the two positive studies. The patient groups in the study of Pryor *et al.* were also not as closely matched, the blinding was less rigorous, and the determination of SSI was retrospective as opposed to the prospective evaluation that was performed in the two positive studies.<sup>16</sup> It would seem from two well-done, randomized trials that high-inspired oxygen levels in the perioperative period

confers some benefit in reducing the incidence of SSIs. Although there is one study with nearly an opposite outcome, this study is likely outweighed by the larger patient populations in two positive trials. While providing 80% inspired oxygen in the operating room is simple and likely without significant risk, the continuation of high  $F_{10_2}$  for 2–6 h postoperatively is not without potential procedural complications and delays in moving patients out of the recovery room. Therefore, the question still remains as to whether high inspired oxygen levels intraoperatively, without continuation into the recovery room, would confer the same benefit.

### **Perioperative Fluid Management**

Although the subcutaneous tissue requires little total oxygen, wound healing and the prevention of infection are critically dependent on adequate perfusion to deliver oxygen.<sup>10</sup> Also important to oxygen delivery is the maintenance of an adequate perfusion state by the preservation of euvolemia.<sup>18</sup> Appropriate fluid management in surgical patients has been studied and debated for decades, and the discussion surrounding SSIs and fluid management is no less unsettled.

Perioperative physicians typically administer intravenous fluids to replace fasting deficits, third space losses, and blood loss with a goal of maintaining adequate cardiac output, blood pressure, and urine output. However, mild to moderate total body hypovolemia is well tolerated by relatively healthy adults as interstitial fluid moves into the intravascular space to help preserve cardiac output. This may result in adequate renal function with preserved urine output and hemodynamic stability while leaving the subcutaneous tissue relatively hypovolemic. By measuring subcutaneous tissue oxygen tensions in postoperative patients, it has been shown that increasing intravascular volume can improve oxygen tensions in previously underperfused patients (fig. 1).<sup>18</sup>

The hypothesis that aggressive fluid administration would better maintain subcutaneous perfusion and wound oxygen tension was tested in a randomized, double-blind trial. Fifty-six patients undergoing elective colon surgery were randomized to receive traditional fluid management (8-10 ml  $\cdot$  kg<sup>-1</sup>  $\cdot$  h<sup>-1</sup> intraoperatively and 1 h postoperatively) or aggressive fluid management (10 ml/kg bolus followed by 16-18 ml  $\cdot$  kg<sup>-1</sup>  $\cdot$  h<sup>-1</sup> intraoperatively and 1 h postoperatively). Additional fluid was given to both groups in a 3:1 ratio to replace blood loss and for urine output less than 1 ml  $\cdot$  kg<sup>-1</sup>  $\cdot$  h<sup>-1</sup> or blood pressure less than 70% of baseline. Although patients in the aggressively hydrated group had statistically significant higher intraoperative and postoperative tissue oxygen tension, no outcome data regarding the incidence of SSIs was presented.<sup>19</sup> This trial was subsequently expanded in a randomized, prospective manner to measure clinical outcomes. The authors could not show a statistically significant difference in the incidence of SSI or wound-healing scores with aggressive *versus* traditional fluid management.<sup>20</sup>

The use of colloids has also been evaluated with regard to improving tissue oxygen tension. Lang *et al.*<sup>21</sup> have shown that using hydroxyethyl starch intraoperatively and postoperatively decreases the amount of crystalloid required to maintain stable hemodynamics and urine output while increasing the tissue oxygen tension. In this study, the colloid group had an increase in tissue oxygen tension of 54%, whereas a group of similar patients who received crystalloid had a 29% decrease in tissue oxygen tension.<sup>21</sup>

Although there is evidence that aggressive fluid management and the use of hydroxyethyl starch improve tissue oxygenation, the only trial that reported on the incidence of SSI with aggressive hydration did not show any statistically significant improvement in the incidence of SSI. In addition, concern over decreased pulmonary function and bowel edema leading to an increase in the time to return of GI function have tempered enthusiasm for aggressive fluid management in general surgical patients. A recent randomized trial has shown that restricting intravenous fluids to patients undergoing major abdominal procedures resulted in fewer complications, improved times to return of gastrointestinal function, decreased wound-healing complications, and shortened the duration of hospital stay by 1 day.<sup>22</sup> At this time, it seems that aggressive fluid resuscitation does not decrease the incidence of SSI, and maintenance of euvolemia is recommended based on clinical parameters.

## Hyperglycemia

It has been well established that patients with diabetes are at increased risk for infections, including SSIs. Even in nondiabetics, hyperglycemia is associated with an increased risk of morbidity and mortality.<sup>23</sup> In one recent trial, the use of insulin infusions to maintain serum glucose at less than 110 mg/dl in critically ill patients decreased the mortality rate from 8.0% to 4.6% regardless of diabetes status. In fact, 87% of the study population had no history of diabetes. The bulk of the reduction in mortality occurred by reducing the incidence of multi-organ system failure with septic focus.<sup>24</sup> Although it is unknown whether this data from the intensive care unit can be extrapolated to the perioperative setting, it has spawned an interest in studying the effects of glucose control on the risk of SSI. The majority of study in this area has taken place in cardiac surgery patients.<sup>3,24-27</sup> However, there is emerging evidence that stringent glucose control may reduce the rates of SSI in a variety of surgical populations.<sup>28</sup>

Several recent studies have now shown a correlation



Fig. 2. Hyperglycemia induces a host of negative effects on the normal immune response in a surgical wound. IgG = immunoglobulin G; PMN = polymorphonuclear cell; WBC = white blood cell.

between hyperglycemia and the risk of SSI (fig. 2).<sup>29–32</sup> The most devastating of these infectious complications in cardiac surgery patients are deep sternal wound infections, potentially leading to mediastinitis, which increases operative mortality twofold to threefold.<sup>3</sup>

Two series from the same institution studied the effects of implementing a continuous insulin infusion to maintain blood glucose levels between 150 and 200 mg/dl in diabetic patients undergoing cardiac surgery. Patients in the continuous insulin infusion groups were matched with historic controls who had received sliding scale insulin every 4 h with a goal of maintaining glucose levels less than 200 mg/dl. These authors noted a 66% reduction in the incidence of deep sternal wound infections in diabetic patients using continuous insulin infusions were continued into the postoperative period during

this study. This indicates the relative importance of optimizing perioperative conditions, not simply isolated intraoperative conditions.

Numerous studies have attempted to elucidate the effects of hyperglycemia on immune function. A glucose challenge in healthy subjects has been shown to induce a transient reduction in leukocyte counts and all lymphocyte subsets. Hyperglycemia also results in the effective deactivation of immunoglobulins by nonenzymatic glycosylation. In addition, the glycosylation of the C3 component of complement blocks binding to bacterial surfaces. As discussed above, neutrophils play an important role in preventing even mildly contaminated wounds from developing infections. Numerous functional deficits have been shown in the neutrophils of diabetic patients. These include impaired chemotaxis, decreased phagocytic ability, and lower bactericidal capacity.<sup>33</sup> In

*in vitro* studies, it has been shown that these functions can be at least partially restored by a normoglycemic environment.<sup>34</sup>

One study examined *in vivo* neutrophil function in cardiac surgery patients whose glucose was aggressively controlled with an insulin infusion and compared them with patients whose glucose was controlled with insulin boluses at a standard level for that institution. These authors found that neutrophil phagocytic function was better preserved at 1 h after separation from cardiopulmonary bypass in the aggressively controlled patients *versus* the standard controls.<sup>27</sup>

Although randomized trials studying the effects of glucose control in the perioperative setting are lacking, a body of evidence is emerging to support tighter glucose control at the time of surgery. The fact that hyperglycemia is associated with increased morbidity and mortality, regardless of diabetic status, underscores the importance of maintaining a low threshold for measuring glucose levels in any patient thought to be at risk of developing increased perioperative glucose levels. Although currently available data do not allow the authors to recommend a specific threshold for the treatment of hyperglycemia, there is ample evidence to suggest that only treating blood glucose greater than 200 mg/dl (as has traditionally been suggested) is inappropriate. Indeed, aggressive treatment of hyperglycemia with insulin and frequent measures of serum glucose levels is quickly becoming an established standard.<sup>35</sup>

## Blood Transfusion and the Risk of Infection

Allogeneic blood transfusions are known to have important immunomodulatory effects.<sup>36,37</sup> More than 100 studies have now been published regarding the transfusion of blood products and the risk of postoperative infection. Unfortunately, small cohorts and retrospective design limit modern interpretation. Further confounding the issue is the fact that early studies often used whole blood, which is rarely used now. In addition, currently produced packed erythrocyte units contain less than 10% plasma and less than 5% leukocytes *versus* units produced in the 1970s. Finally, the hemorrhage that often necessitates transfusion has itself been shown to increase infectious risk.

Regardless, many recent prospective studies have linked perioperative transfusion to infection in multiple surgical populations including cardiac surgery,<sup>38</sup> orthopedic surgery,<sup>39</sup> trauma,<sup>40</sup> and colorectal surgery.<sup>41</sup> Although these studies imply that the transfusion of blood products increases the risk of infection, some studies have not noted an increased risk,<sup>42</sup> and others have argued that the effect of transfusion is minor.<sup>37</sup> Nevertheless, the risk of infection with transfusion can be decreased using autologous blood donation<sup>37</sup> versus allogenic blood. In fact, in most studies, the infection rates with autologous blood approach those of patients who did not have transfusion. This point lends further evidence to the causal relation between allogeneic packed erythrocyte transfusions and the risk of infection.<sup>37</sup>

Most of the discussion in the literature surrounding the immunomodulatory effects of transfusion implicates donor leukocytes.<sup>36,43</sup> To this end, leukoreduction has thought to potentially be helpful. Indeed, some countries have already implemented policies for universal leukocyte reductions and this issue is debated in the United States.<sup>43</sup> Retrospective analysis in 23 centers throughout Canada showed that after adoption of a national leukoreduction program, cardiac surgery, hip fracture, and trauma patients had decreased mortality rates and a decreased incidence of antibiotic therapy, but serious nosocomial infections did not decrease.44 To date, the results of multiple randomized controlled trials have been reported. Meta-analysis of these trials using all randomized patients shows no significant difference in infection rate.<sup>43</sup> However, in some of the trials, patients were included on an intention-to-treat basis, and thus their data were included regardless of whether they received a transfusion. When the pooled data were reanalyzed excluding patients who did not have transfusion, a significant reduction in the risk of wound infection when leukoreduced packed erythrocytes were used. As these authors note, their results should be viewed with caution because intention-to-treat analysis is considered to be the most conservative analytical approach.<sup>43</sup> Another study also did not demonstrate an association between postoperative infections and the use of leukocyte-depleted blood in cardiac surgery patients; however, an increased incidence of postoperative infections was again observed with blood transfusions in general.45

This issue has generated an impressive amount of literature, discussion, and argument. There is no doubt that transfusion has an immunomodulatory effect, but the true clinical impact and the most effective methods of prevention are still hotly debated. At this point, there are not adequate clinical data to support the use of wound infection in the risk-benefit analysis of transfusion.

### **Antimicrobial Prophylaxis**

Perhaps the simplest and most effective role the anesthesiologist can play in the prevention of SSIs is ensuring the administration of appropriate antimicrobial prophylaxis. The goal of perioperative antibiotic administration is to obtain blood and tissue drug levels that exceed the minimum inhibitory concentration of the organisms likely to be encountered.<sup>46</sup> The National Surgical Infection Prevention Project, a project created by the Centers for Medicare and Medicaid Services and the Centers for Disease Control, recently released an advisory statement.<sup>46</sup> Much of the information will be summarized below; however, all perioperative physicians should familiarize themselves with this statement. Indeed, there are significant data indicating that initial physician compliance with advisory statements is poor.<sup>47</sup> There are also data to suggest that compliance is improved when anesthesia teams take responsibility for administration of prophylactic antibiotics.<sup>48</sup>

#### Timing

The first clinical trial in 1969 showed that administering preoperative antibiotics to patients undergoing bowel surgery could decrease the incidence of wound infection and sepsis. This trial also showed that the most effective time period for administration was 1 h before incision. Patients who received the first antibiotic dose postoperatively received almost no benefit in terms of preventing infection.<sup>49</sup>

Multiple studies have since indicated that effective antibiotic administration is dependent on developing adequate blood and tissue drug levels (above minimum inhibitory concentration) *before* incision.<sup>49</sup> Current recommendations state that infusion of the first dose of drug should begin within 60 min of incision. This period can be lengthened to 120 min for drugs such as vancomycin, where high infusion rates have been associated with complications. If a tourniquet is to be used, it is critical that administration of the antibiotic dose be completed before tourniquet inflation.<sup>46</sup> It should be noted that these guidelines are based largely on the retrospective data only.

It should also be noted that due to a lack of benefit and the potential for the selection of resistant organisms, guidelines suggest that antimicrobial prophylaxis should end within  $24 \text{ h.}^{46}$ 

#### Choice of Antibiotic

The ideal perioperative antibiotic prophylaxis focuses therapy at the most commonly encountered organisms. Prophylaxis should not be administered with the goal of covering all possible pathogens, because this may lead to the selection of drug resistant bacteria. For most surgeries not violating chronically colonized organs, the most common pathogens will be skin flora microbes, specifically the *Streptococcus* and *Staphylococcus* species. A first-generation cephalosporin (*i.e.*, cefazolin) adequately covers these organisms in a cost-effective manner. Surgeries involving the bowel necessitate gram-negative and anaerobic coverage for which cefoxitin and cefotetan are appropriate.<sup>46</sup>

Although the routine use of vancomycin for surgical prophylaxis is not supported by any national recommendations, there is some discussion that vancomycin may be the prophylaxis of choice when a "cluster of MRSA [methicillin-resistant *Staphylococcus aureus*] mediastinitis or incisional SSI due to methicillin-resistant, coagulase-negative staphylococci has been detected."<sup>50</sup> Some have suggested that vancomycin should be the prophylaxis of choice at institutions with a high prevalence of MRSA infection; however, there is no evidence that this practice decreases the incidence of MRSA infections.<sup>46</sup>

#### β-Lactam-Allergic Patients

A common problem physicians face is finding the most effective treatment for patients with  $\beta$ -lactam allergies. Ten percent of all patients studied in one series reported that they had a penicillin allergy,<sup>51</sup> and other estimates range from 5% to 20%. Multiple studies, though, have shown that the number of truly allergic patients is much lower.<sup>46,52</sup> Regardless, these patients must be taken at their word when they present for surgery, given the significant morbidity associated with perioperative anaphylaxsis.<sup>53</sup> The question then becomes how best to approach a presumed  $\beta$ -lactam-allergic patient.

Early trials of cephalosporins revealed cross-reactivity in penicillin allergic patients. These patients had a rate of anaphylaxis of approximately 8%.<sup>54</sup> Therefore, the standard of care became the avoidance of cephalosporins in these patients. However, the early cephalosporins contained a side chain similar to the penicillin side chain and were often contaminated with penicillin that was used in the synthetic process. This may have led to these high rates of cross-reactivity. Multiple studies have now shown the relative clinical safety of administering cephalosporins to penicillin allergic patients.<sup>55</sup>

As a result of the above evidence as well as other studies, algorithms are now available for managing these patients. Although skin testing for penicillin allergy has been shown not to be effective in predicting subsequent reactions to cephalosporins,46 skin testing against cephalosporins in any patient who has had a life-threatening reaction to penicillin before administration of a cephalosporin is one potential option.<sup>56</sup> Indeed, a cost-analysis study showed that skin testing of patients with a history of penicillin allergy was more cost-effective than the routine use of vancomycin in these patients.<sup>57</sup> Alternatively, patients with minor reactions to penicillin can be challenged with a cephalosporin.<sup>58</sup> If the potential for allergic reaction to a cephalosporin is deemed high, vancomycin and clindamycin are reasonable alternatives for prophylaxis.<sup>46</sup> Last, it should be noted that patients with a true penicillin allergy are more likely to experience an anaphylactic reaction to other drugs.<sup>59</sup>

### Conclusion

Despite advances in surgical technique and the care of postoperative patients, SSIs remain an important cause of patient morbidity and mortality. There are at least six perioperative factors that may play a role in the prevention of this serious complication.

For some of these factors, there are strong data supporting their implementation. A multitude of studies exist indicating that hypothermia is harmful to many surgical patients on several levels, including an increased risk of SSIs. The timing and selection of antibiotics are important not only in preventing SSIs, but also in decreasing adverse events such as the selection of multidrug-resistant organisms. Although clinical evidence that supports abandoning historic glucose goals (approximately 200 mg/dl) has yet to be shown in multiple studies, there is strong evidence from the critical care literature supplemented by emerging data from the perioperative period that normoglycemia may be an appropriate goal. Optimization of the perioperative environment by the anesthesiologist can have an important affect on the incidence of SSIs.

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