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REVIEW ARTICLE/BRIEF REVIEW

Review article: The anesthesiologist's role in the prevention of surgical site infections

Article de synthèse: Le rôle de l'anesthésiologiste dans la prévention des infections des cicatrices opératoires

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Abstract

Purpose *To highlight the role of anesthesiologists in the prophylaxis of surgical site infections (SSIs) and to recognize the central role they play in quality improvement initiatives for the prevention of SSIs.*

Source *The medical literature was searched with a focus on three interventions affecting the risk of SSIs: preoperative antibiotic administration, perioperative normothermia, and perioperative hyperoxia. The literature was also searched for examples of initiatives in patient safety and quality improvement that highlight the role of anesthesiologists in preventing SSIs.*

Principal findings *The timely administration of preoperative antibiotics and the maintenance of perioperative normothermia have been shown to reduce the risk of SSI significantly. Perioperative hyperoxia in the prevention of SSIs remains controversial but may improve outcomes in specific subsets of the surgical population. Initiatives in quality improvement show the challenges faced by many centres to improve upon these processes of care, but they also highlight the role of anesthesiologists as champions in the multidisciplinary efforts for the prevention of SSIs.*

Conclusions *Anesthesiologists are responsible for many of the processes of care shown to impact the risk for SSIs, and they play an important role in the prevention of SSIs. Their leadership in the multidisciplinary efforts to improve the quality of the surgical patient is of critical importance.*

Résumé

Objectif *Souligner le rôle des anesthésiologistes dans la prophylaxie des infections des cicatrices opératoires (ISS) et reconnaître leur rôle central dans les initiatives d'amélioration de la qualité pour la prévention des ISS.*

Source *Des recherches ont été menées dans la documentation médicale en se concentrant sur trois interventions pouvant modifier le risque d'ISS : l'administration préopératoire d'antibiotiques, la normothermie periopératoire et l'hyperoxie périopératoire. Des exemples d'initiatives en matière de sécurité des patients et d'amélioration de la qualité soulignant le rôle des anesthésiologistes dans la prévention des ISS ont été également recherchés dans les publications.*

Constatations principales *Il a été montré que l'administration d'antibiotiques préopératoires en temps opportun et le maintien d'une normothermie périopératoire diminuaient significativement le risque d'ISS. Le rôle de l'hyperoxie périopératoire pour la prévention des ISS reste controversé mais elle pourrait améliorer l'évolution dans des sous-groupes particuliers de patients chirurgicaux. Les initiatives en matière d'amélioration de la qualité montrent les nombreux défis auxquels sont confrontés beaucoup de centres pour améliorer ces processus de soins; cependant, elles mettent aussi en lumière le rôle primordial des anesthésiologistes dans les efforts multidisciplinaires de prévention des ISS.*

Conclusions *Les anesthésiologistes sont responsables de nombreux processus de soins qui ont un impact démontré sur le risque d'ISS et ils jouent un important rôle dans la prévention de ces infections de la cicatrice opératoire. Leur leadership au sein d'efforts multidisciplinaires pour améliorer la qualité des soins pour les patients chirurgicaux revêt une importance essentielle.*

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Perioperative infections place a significant burden on patients and on the healthcare system. Surgical site infections (SSIs) are the most common perioperative infection, accounting for 38% of all infections in surgical patients and 14-16% of all hospital-acquired infections.[1] The Table provides the definition of SSI by location, as established by the Centers for Disease Control (CDC).[2] In a population-based study of 1.2 million elective in-patient surgeries from Ontario, Canada, 13.5% of all patients developed a SSI.[3] These patients were found to be at an increased risk of readmission to hospital (odds ratio [OR] 6.16; 95% confidence interval [CI] 5.98 to 6.35) and reoperation (OR 2.28; 95% CI 2.11 to 2.48). A matched cohort study found that SSIs were associated with an increased risk of death (relative risk [RR] 2.2; 95% CI 1.1 to 4.5), length of stay (mean 6.5 days; 95% CI 5 to 8),[4] and increased hospital costs measured in the thousands of dollars per patient. The significance of infectious complications, such as SSIs, is not lost on the public, and there is increasing demand for hospitals and physicians to be held accountable. For example, mandatory public reporting of incident infections and the measures taken to prevent them is practice in Ontario, Canada.[5] Among these reported measures includes the use of a Surgical Safety Checklist. Practices for the prevention of SSIs (the administration of antibiotic prophylaxis, glycemic control, use of warming devices) feature prominently among the elements in Ontario's adaptation of the Checklist.

While SSI prevention is a multidisciplinary effort, most prophylactic measures begin and end in the operating room and are influenced directly by the anesthesiologist. Despite this, the role of the anesthesiologist is often understated. The medical literature identifies many areas where the anesthesiologist can affect a patient's risk of infection, including the timing and selection of preoperative antibiotic administration, perioperative normothermia, hyperoxia and normoglycemia, regional anesthesia, smoking cessation, and hand washing. Given the breadth of topics, we selected three that are directly affected by anesthesiologists but also involve the broader multidisciplinary team. Lately, hand washing by anesthesiologists as it pertains to other perioperative infections has also been the subject of research, and we include a brief discussion on the topic. Finally, we highlight the role of anesthesiologists in a discussion on perioperative quality of care and patient safety initiatives.

Perioperative antibiotics

Surgical site infections are commonly the result of skin flora contamination of the wound, including *Staphylococcus* and *Streptococcus* species.[6] Where surgery involves hollow viscera, such as the intestine, gram negative coliforms and anaerobes also become an important source of wound sepsis. The role of antibiotic prophylaxis for the prevention of SSIs was first shown in 1961.[7] Since then, numerous studies have established the importance of timing antibiotic administration with skin incision. Published guidelines direct practitioners to administer antibiotics within 60 min of skin incision to minimize the risk of SSI.[8] The risk of SSI has been shown to increase dramatically when antibiotics are given more than two hours before surgery (OR 6.7; 95% CI 2.9 to 14.7) or after the incision (OR 5.8; 95% CI 2.6 to 12.3).[9] Despite this, population-based studies have shown that timing for antibiotic administration remains poor. Using data from the National Surgical Infection Prevention Project, Bratzler *et al.*[10] found as few as 55.7% of patients in participating hospitals across the United States were receiving preoperative antibiotics in a timely fashion.

The practice of administering antibiotics immediately before the induction of anesthesia can greatly improve antibiotic administration timing. In a recent quality improvement initiative focusing on major colorectal and hepatobiliary surgery, it was found that only five percent of patients were receiving prophylactic antibiotics in a timely fashion when they were administered in the patient holding unit prior to surgery. Delays in patient transfer and the time required for line insertion and patient positioning led to more than 50% of patients receiving their antibiotics more than two hours prior to surgery. Antibiotic timing improved when antibiotic administration was moved into the operating room, with 92.6% of patients receiving their antibiotics in a timely fashion.[11] A similar study mirrored this experience. In a quality improvement study in patients undergoing major cardiac or vascular surgery, Kanter *et al.*[12] identified similar deficiencies in patient care, with only 11% of patients receiving antibiotics in a timely manner when administered in a preoperative holding area. While their changes in process underwent several iterations, it wasn't until anesthesiologists were engaged and identified as the most influential party to improve practice that significant changes were seen. Having anesthesiologists assume responsibility for antibiotic administration, modifying computerized order entry forms, and adding prompts to anesthesiology records have led to a dramatic improvement in patient care. Sustained changes were found, and 97% of patients now receive antibiotics in a timely fashion. Consequently, rates of SSIs have fallen from 3.8% to 1.4%.

Anesthesiologists should also be involved in the selection of appropriate antibiotics. Recommended regimens vary with the type of surgery (cardiovascular, orthopedic, colorectal, etc.) and wound classification (clean, clean-contaminated). Recognizing patients who require modified antibiotic therapy, such as those with a documented

Table CDC definition of SSIs by location (adapted from *Horan TC, et al*. 1992)

Superficial SSI	Deep SSI	Organ Space SSI
Diagnosed within 30 days of operation	Diagnosed within 30 days of operation or within one year if an implanted device/tissue/organ is involved	Diagnosed within 30 days of operation or within one year if an implanted device/tissue/organ is involved
Limited to skin and subcutaneous tissue	Involves fascial/muscle layer	Relates to anatomy opened/manipulated during surgery, excluding the incision
Includes at least one of:	Includes at least one of:	Includes at least one of:
-purulent drainage from incision	-purulent drainage from the deep incision	-purulent drainage from a drain placed into the organ space
-organisms isolated on wound culture	-Spontaneous dehiscence or deliberate opening of fascia by a surgeon when the patient has one of:	-organisms are isolated from fluid/tissues obtained from the organ space
	-temperature > 38°C	-an abscess or other sign of infection is found on direct examination/exploration of the space or on histopathologic or radiologic examination
	-localized pain/tenderness, unless the wound is culture negative	
	-an abscess or other sign of infection based on direct examination/exploration or histopathologic or radiologic examination	-diagnosis of an organ space infection is made by a surgeon or attending physician.
	-diagnosis of a deep SSI by a surgeon or attending physician	
Includes at least one of these signs/symptoms:		
-pain/tenderness		
-localized wound swelling		
-redness		
-diagnosis of a SSI by a surgeon or attending physician		

CDC = Centers for Disease Control; SSI = surgical site infection

penicillin allergy and patients colonized with methicillin resistant *Staphylococcus aureus* (MRSA), is an important part of perioperative care. Patients will often report symptoms attributed to penicillin use that do not represent true allergic reactions.[8] A focused history can help to identify those patients with true allergies who require a modification to their antibiotic regimen. Where gram positive pathogens represent the most common infective agent, substitution of a cephalosporin with vancomycin or clindamycin is recommended.[8] Modification is also required for patients known to be colonized with MRSA. Again, vancomycin is indicated in this case. This is especially true of patients with recent stays in hospital or other institutions, including long-term care.[8,13] While the anesthesiologist may not be the prescriber of prophylactic antibiotics, their role in their administration at the time of surgery warrants their involvement and oversight in drug selection.

Perioperative normothermia

General anesthesia has a dramatic effect on core temperature. On induction of anesthesia, thermoregulatory mechanisms are impaired, and there is a redistribution of core body heat to the periphery.[14] Core temperatures have been shown to fall as much as 1.6 (0.3)°C in the first hour of anesthesia alone. Hypothermia consequently leads to an impairment in immune function by affecting leukocyte migration, neutrophil phagocytosis, and cytokine production and increasing the risk of SSIs.[15] Hypothermia has a myriad of effects on cellular metabolism, which has made it an attractive therapy in the setting of ischemia.[16] Permissive hypothermia does offer significant neuroprotective effects and has become standard management of care for post-cardiac arrest resuscitation.[17,18] Paradoxically, hypothermia may increase the risk of cardiac events in the first 24 hr after surgery.[19] It also decreases platelet function, drug clearance, insulin secretion, and sensitivity to insulin, along with postoperative shivering and a sharply increased metabolic rate in the postanesthesia care unit.[16]

The prevention of perioperative hypothermia has been shown to reduce the incidence of SSIs significantly, perhaps to an even greater extent than antibiotic prophylaxis.[20] A randomized controlled trial of 200 patients undergoing colorectal surgery with active warming strategies in place found the risk of SSI to be significantly less in the warmed

group than in controls (RR 0.31; 95% CI 0.13 to 0.74).[20] A similar effect was seen in patients being warmed while undergoing "clean surgery". Melling *et al.*[21] found that perioperative warming in patients undergoing breast, hernia, or varicose vein surgery resulted in a significantly lower rate of SSIs than in controls (RR 0.42; 95% CI 0.19 to 0.93).

The anesthesiologist's approach to perioperative warming is critical to patient safety. There are many warming solutions on the market today that have varying clinical effect. A recent systematic review of the literature examined the most common patient warming strategies used during abdominal surgery in North America.[22] Level 1 evidence supports the use of both warmed intravenous fluid and forced-air devices for the prevention of perioperative hypothermia. After as little as 30-90 min of anesthesia, differences in core temperatures have been shown with the use of intravenous fluid warmers, differences that are sustained to the end of surgery.[23,24] Heated forced-air has a similar effect when used in either the preoperative or intraoperative setting. In a randomized trial by Camus *et al.*,[25] one hour of preoperative forced-air warming slowed the decrease in intraoperative core temperatures significantly compared with no warming after only 30 min. Intraoperative warming with forced air has similar sustained effects. Lindwall *et al.*[26] randomized patients to receive either intraoperative forced-air warming *vs* warming with blankets. After only 30 min, patient core temperatures differed between the two groups; a difference that was sustained for up to an hour after discontinuing the warming strategy. Forced air has been found favourable to other active warming strategies as well. Leung *et al.*[27] compared forced-air warming with electric blanket warming during laparotomy. Mean temperatures at the end of surgery were 36.2 (0.4)°C and 35.2 (1.0)°C, respectively ($P < 0.01$).

How the anesthesiologist chooses to monitor perioperative temperatures can also influence treatment. Level II evidence supports the use of esophageal thermometry to monitor intraoperative temperatures, given its accuracy and precision compared with the gold standard of pulmonary artery catheter thermometry.[22] The same evidence discourages the use of infrared tympanic thermometry; while relatively easy to use, the accuracy of this device is questionable with as many as 50% of temperature measurements being more than 0.5°C from true core temperature.[28,29] Inaccurate temperature measurement may lead the anesthesiologist or nurse in the recovery room to suspect normothermia is maintained, when in fact it is not. Standardization of the practices for perioperative normothermia has been shown to improve perioperative normothermia rates. A single-institution experience found that introducing a bundle of standardized practices, including raising room temperatures and employing forced-air devices and intravenous fluid warmers for all procedures longer than two hours, significantly maintained normothermia rates at the end of surgery.[11]

Hyperoxia

Oxygen therapy in the perioperative period is managed primarily by the anesthesiologist. The role of hyperoxia in the prevention of SSIs is controversial. *In vitro* studies have previously shown the effects of tissue oxygen tension on the oxidative killing effect of neutrophils.[30] A number of prospective studies have also shown an association between low tissue oxygen tension and SSI. Hopf *et al.*[31] measured tissue oxygen tension for three days in patients undergoing major general surgery procedures determined to be of higher than average risk for SSI. Patients with SSI were found to have a significantly lower subcutaneous tissue oxygen tension than patients without SSI [72 (18) mmHg *vs* 59 (12) mmHg; $P < 0.001$]. There were no infections documented in patients with tissue oxygen tension levels > 90 mmHg. Another study using noninvasive techniques found lower tissue oxygen saturations in patients with SSIs than in those without SSIs[32]; however, this study found differences only when measuring saturation levels at locations remote from the operative site. No association was found between oxygen saturation at the surgical site and SSI.

Despite evidence supporting the theory that increased tissue oxygen levels reduce the risk of SSI, results from randomized controlled trials are conflicting, even showing harm in some cases. Greif *et al.*[33] randomized 500 colorectal surgery patients to receive either 80% or 30% oxygen during surgery and for two hours after surgery. For each arm, the 15-day rate of SSI for positive wound culture was 5.2% *vs* 11.2%, respectively ($P < 0.01$). While not a primary end point of the ENIGMA study, the hyperoxia group did have a lower incidence of wound infections (adjusted OR 0.72; 95% CI 0.52 to 0.98; $P = 0.036$).[34] Conversely, Pryor *et al.*[35] randomized 165 abdominal surgery patients to receive either 80% or 35% inspired oxygen over a similar time period. This study actually found that the rates of SSI were increased in the hyperoxia group (25.0% *vs* 11.3%; $P = 0.03$). The authors suggest a number of cell-level mechanisms to explain this finding; nevertheless, the results have not since been replicated. Five other randomized trials have been reported in the literature,[36-40] and all but one[36] have shown equivalence.

Similarly, a meta-analysis of the seven trials yielded equivalent results.[41] Pooling 2,728 patients (1,358 patients assigned to hyperoxia, 1,370 assigned to controls) failed to show a therapeutic advantage with hyperoxia (OR 0.85;

95% CI 0.52 to 1.38); however, subgroup analyses of patients undergoing colorectal surgery (OR 0.48; 95% CI 0.32 to 0.71) and patients undergoing general anesthesia (OR 0.66; 95% CI 0.46 to 0.93) did suggest that patients receiving hyperoxia were less likely to develop a SSI. The data would suggest then that specific populations may stand to benefit from hyperoxia as a method of SSI prophylaxis, although the role for all surgical patients remains equivocal. The anesthesiologist should weigh patient and procedural factors and consider hyperoxia as part of the perioperative strategy for SSI prevention where appropriate.

Hand washing and venous access infection

Central line-associated bloodstream infections are associated with both an increased length of hospital stay and mortality rates, and infections are most common in central lines inserted by anesthesiologists.[42,43] Several interventions have been described to reduce the risk of central line infections (chlorhexidine skin prep, full barrier precautions, avoiding femoral access, and early removal of unnecessary catheters) and have been shown to reduce infectious complications significantly when bundled together.[44] These efforts, however, do not address the potential for contamination after insertion when the device is being accessed. Stopcock contamination has been found to occur in as many as 11.5% of cases intraoperatively; in 47% of those contaminated cases, the source was found to be bacteria from anesthesia providers' hands through biotyping of collected specimens.[45] It has also been associated with a significant increase in 30-day mortality (OR 58.5; 95% CI 2.23 to 1477).[46] In the latter study, several reservoirs were found for bacterial contamination in the operating room. The anesthesiologist remains an important vector for contamination, and both studies highlight the importance of hand washing and maintenance of sterile technique after line insertion.

Initiatives for patient safety and quality improvement

Prevention of SSIs is part of a broader initiative to maintain perioperative patient safety and improve quality of care, and it features prominently in such initiatives as the Surgical Safety Checklist. In an influential paper published in 2009, the World Health Organization (WHO) reported the results of an international pre- and post-intervention assessment of a 19-item perioperative checklist on patient outcomes.[47] The intention of the WHO Checklist was to raise the awareness of healthcare providers to its components and to improve communication among operating room team members, thereby decreasing the risk of adverse events. There were 7,688 patients enrolled in the study. The post-intervention assessment showed a significant reduction in the rates of 30-day mortality compared with the pre-intervention assessment (1.5% *vs* 0.8%, respectively; $P = 0.003$) and a significant reduction in the number of postoperative complications (11.0% *vs* 7.0%, respectively; $P < 0.001$), including SSI (6.2% *vs* 3.4%, respectively; $P < 0.001$). Of relevance, the appropriate administration of preoperative antibiotics increased from 56.1-82.6% ($P < 0.001$). The Checklist engages all practitioners, including anesthesiologists, to become more aware of the potential for preventable errors (or omissions) that influence patient outcomes. As a result of this study, many jurisdictions around the world have implemented the Surgical Safety Checklist. Legislation in Ontario, Canada has made the use of the Surgical Safety Checklist mandatory for all patients having surgery, with hospitals required to report rates of compliance for public consumption.[5] The impact of this effort on outcomes in Ontario has yet to be measured, but centres in other jurisdictions, including the United States and Europe, have shown a positive impact on patient outcomes with the implementation of a checklist.[48,49]

Voluntary reporting of performance as part of a collaborative effort between participating hospitals has been shown to have a positive impact on SSIs by improving relevant processes of care. Dellinger *et al.*[50] report the results from the National Surgical Infection Prevention Collaborative. Forty-four participating hospitals reported data on over 35,000 surgical procedures over a one-year period. The initiative included quarterly meetings of hospital "champions", commonly surgeons or anesthesiologists, to share insights into barriers to change and successful measures to overcome them. At the end of the one-year project, the rate of SSIs fell 27% from the first to the fourth quarter ($P = 0.0005$). Similarly, tests of trend found continual improvements in all of the processes of care reported.[50]

A number of studies have shown the role of standardized practices for the prevention of SSIs. A pre- and post-intervention study by the authors of this review was conducted over a three-year period.[11] A prospective needs assessment evaluated institutional performance on a number of measures in patients undergoing major abdominal surgery, including selection and timing of preoperative antibiotic administration and rates of perioperative normothermia. Multidisciplinary panels made up of relevant stakeholders, including surgeons, anesthesiologists, nurses, infectious disease specialists, residents, and patient safety specialists, were created. Each aspect of care was carefully scrutinized by the relevant panel, and new protocols were designed, tested for safety and feasibility, and subsequently implemented and put into practice. Changes were disseminated through educational sessions with staff; feedback

was encouraged from those not directly involved with the stakeholder groups, and the responses were used to tailor the changes appropriately. A dramatic improvement resulted, with the number of patients receiving preoperative antibiotics within 60 min of incision increasing from 5.9-92.6% (RR 15.7; 95% CI 6.7 to 36.9), and the rate of normothermia at the end of surgery increased from 60.5-97.6% (RR 1.61; 95% CI 1.34 to 1.94).[11]

A similar study by Kanter *et al*.[12] also shows the value of standardization and highlights the role of the anesthesiologist in the process in patients undergoing cardiac and vascular surgery. At the outset, anesthesiologists and surgeons collaborated to generate an institutional guideline for antibiotic selection and to review local practices. They identified the anesthesiologist as the practitioner most likely to have a positive impact on the timing of antibiotic administration. Practices were streamlined to facilitate the anesthesiologist's role, including prompts on anesthesia records and reminders from nursing staff. An anesthesia "champion" for the process was identified early, and education regarding the process changes was disseminated at grand rounds and OR in-services for all staff. Antibiotic timing improved dramatically after implementation, with 91% of patients receiving antibiotics within 60 min of incision compared with 11% of patients before implementation. The changes have been sustained thanks to an ongoing audit and feedback loop that focuses on educating all practitioners rather than on isolating "bad apples".[12] Engaging all practitioners to change in a "bottom up" approach was a key factor in the success of both of these studies, and this approach should be encouraged as other centres strive to meet both internal and external standards for excellence.

An often unrecognized opportunity is the impact of professional societies on the practice patterns of their members. The current Canadian Anesthesiologists' Society "CAS Guidelines to the Practice of Anesthesia" focus on the importance of having well-trained and qualified staff as well as standards for equipment and monitoring.[51] We would ask the Society to consider including wording about the importance of equipping operating rooms with appropriate patient warming devices as well as articulating the expectation to maintain the patient's temperature in a manner concordant with optimal patient outcome. Given the importance of anesthesiologists' participation in antibiotic prophylaxis, it is time to consider knowledge in this area as a key competency for the specialty and an important construct to incorporate into anesthesia training programs.

Conclusions

Anesthesiology practice can affect a number of factors influencing the patient's risk of infection, including the timing and selection of preoperative antibiotic administration, perioperative normothermia, hyperoxia and normoglycemia, regional anesthesia, smoking cessation, and hand washing.

While individual practice patterns are important, sustained improvement in care needs to include the entire perioperative team (anesthesiologists, surgeons, nurses, and other professionals) involved in the care of this patient population. Anesthesiologists have much to be proud of with respect to their leadership in this area. Ongoing participation and leadership in these activities is an important part of the anesthesiologist's role as a perioperative physician.

Key points

- The timely administration of preoperative antibiotics and the maintenance of perioperative normothermia significantly reduce the risk of surgical site infections (SSIs).
- Perioperative hyperoxia in the prevention of SSIs remains controversial but may improve outcomes in specific subsets of the surgical population.
- The importance of hand hygiene in minimizing transmission of infection should not be underestimated.
- Quality improvement initiatives show the challenges that many centres face to improve upon these processes of care, but they also highlight the role of anesthesiologists as champions in the multidisciplinary efforts for the prevention of SSIs.

Competing interests None declared.

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