



ELSEVIER

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Practice forum

Surgical wound irrigation: A call for evidence-based standardization of practice

Sue Barnes RN, BSN, CIC^a, Maureen Spencer RN, MEd, CIC^b, Denise Graham^c, Helen Boehm Johnson MD^{d,*}^a Infection Prevention and Control, Quality and Safety Department, Program Office, Kaiser Permanente, Oakland, CA^b UHS of Delaware, a subsidiary of Universal Health Services, King of Prussia, PA^c DDG Associates, Alexandria, VA^d Independent medical writer, Vero Beach, FL

Key Words:

Surgical irrigation
Infection prevention
Infection control
Surgical site infection

Surgical wound irrigation has long been debated as a potentially critical intraoperative measure taken to prevent the development of surgical site infection (SSI). Unlike many other SSI prevention efforts, there are no official practice guidelines or recommendations from any major medical group for the practice of surgical irrigation. As a result, practitioner implementation of the 3 major irrigation variables (delivery method, volume, and solution additives) can differ significantly. A focus group of key thought leaders in infection prevention and epidemiology convened recently to address the implications of different surgical irrigation practices. They identified an urgent need for well-designed clinical trials investigating surgical irrigation practices, improved collaboration between surgical personnel and infection preventionists, and examination of existing evidence to standardize irrigation practices. The group agreed that current published data are sufficient to support the elimination of antibiotic solutions for surgical irrigation; the avoidance of surfactants for surgical irrigation; and the use of sterile normal saline, sterile water, and 1 medical device containing a sterile 0.05% chlorhexidine gluconate solution followed by sterile saline. Given the current lack of sufficient evidence identifying ideal delivery method and volume choices, expert opinion must be relied on to guide best practice.

© 2014 Published by Elsevier Inc. on behalf of the Association for Professionals in Infection Control and Epidemiology, Inc.

Surgical site infections (SSI) continue to be one of the most significant burdens on the health care system, both in the United States and abroad. Despite extensive scrutiny, multiple collaborative efforts, and significant advances in infection prevention practices, approximately 500,000 SSIs with an associated cost estimated at \$10 billion occur annually in the United States alone.¹ The consequences of these SSIs are well-known: increased hospital lengths of stay, increased morbidity rates, increased mortality rates, loss of productive life costs, as well as intangibles such as psychologic disability, pain, and suffering.^{2,3} Great attention has been placed on identifying risk factors for SSIs and developing practice guidelines and surveillance systems aimed at both preventing and identifying these complications.

* Address correspondence to Helen Boehm Johnson, MD, 616 Flamevine Lane, Vero Beach, FL 32963.

E-mail address: HBoehm705@aol.com (H.B. Johnson).

Conflicts of interest: None to report.

Although practitioner implementation can vary significantly, many intraoperative practices aimed at infection prevention are relatively standardized across surgical fields. A growing consensus, supported in part by the National Surgical Quality Improvement Project and Surgical Care Improvement Project and by recommendations from numerous organizations such as the Association for Professionals in Infection Control and Epidemiology, the Association of Perioperative Registered Nurses, The American College of Surgeons, Surgical Infection Society, and the American Society of Health System Pharmacists, exists for practices ranging from antibiotic prophylaxis to preoperative hair removal at the surgical site.⁴ Interestingly, no such consensus and, in fact, no formal recommendations from any major medical organization exist for one integral part of the operative process: surgical irrigation. The fact that an SSI almost always occurs as a result of contamination of the surgical site during the interval between operative incision and closure^{5,6} warrants taking a closer look at irrigation practices and developing some standardized guidance.

SURGICAL IRRIGATION

Surgical irrigation is a critical part of the intraoperative process aimed at reducing the risk of SSI. As Dr Charles Edmiston said in his 2013 American Journal of Infection Control article, "Reducing the risk of surgical site infections: Does chlorhexidine gluconate provide a risk reduction benefit?", "The view that 'the solution to pollution is dilution' has been the driving force behind the widespread application of intraoperative irrigation across the spectrum of surgical services." Dr Donald Fry, surgeon and executive vice president for Clinical Outcomes Management at Michael Pines Associates, states that "While there is variability among surgeons, there is a general consensus with respect to standardized practices for many of the other pre-, intra-, and postoperative measures (antibiotic prophylaxis, surgical site hair removal, sterilization of barriers and instruments, and others) that are employed to reduce the possibility of SSI. There is very little evidence and no consensus for the use of surgical irrigation to prevent SSI." In fact, at this time, there are no official recommendations from any health care organization regarding surgical irrigation practices and a paucity of well-designed clinical trials addressing the issue.⁷

At the 2013 annual Association for Professionals in Infection Control and Epidemiology conference, a focus group of key thought leaders in infection prevention and epidemiology, including epidemiologists, surgeons, and infection prevention directors for major health care systems, convened to address the implications of different surgical irrigation practices. The group agreed that, in an era where health care-associated infections rank as the fifth leading cause of death² and carry an attributable per patient cost ranging from \$80,000 to \$110,000,^{8,9} closer investigation of surgical irrigation practices as an integral part of the infection prevention process is warranted. With a better understanding of the broad range of irrigation methods currently employed and the data both supporting and refuting them, surgeons, perioperative nurses, and infection preventionists could collaborate to establish consensus regarding surgical irrigation practices in their fight against SSI.

There are 3 critical variables in the surgical irrigation process: delivery, volume, and solution additives. In the absence of formal guidelines, anecdotal evidence suggests that a wide variety of practices are used with regard to each of these three variables.

Delivery

Surgical irrigation delivery includes choosing delivery method, pressure (the American College of Surgeons [ACS] defines high pressure as 15 to 35 psi and low pressure as 1 to 15 psi,¹⁰ and continuous or pulsatile flow. Neither the ACS nor the Association of periOperative Registered Nurses (AORN) has published practice recommendations on surgical irrigation delivery.

Delivery method choice appears to be driven largely by pressure limitations associated with the different options and user preference. Powered/mechanical lavage, pressure canisters, and piston syringes are capable of producing higher pressures, and bulb syringes and plastic containers with pour caps or nozzles or simply the practice of pouring from a kidney basin are generally associated with lower pressures. It is worth noting that equipment choices can have a notable impact on infection prevention with regard to the splatter effect. Surgical irrigation is capable of generating significant splatter and aerosolized contamination over a considerable distance, potentially exposing health care professionals and patients to contaminants. Whereas many assume perioperative professionals fully engage in wearing protective apparel, the number of professionals who fail to don eye protection is startling. Jagger et al conducted a multicenter study of operating room personnel and noted that 45.3% of all skin or mucous membrane exposures

occurred in the eye.¹¹ Of those with these eye exposures, 74.4% were not wearing eye protection, with the remainder wearing inadequate protection¹¹ despite federal mandates.¹² Although the overall risk of disease transmission is relatively low with mucous membrane exposure (as low as 0.09% with HIV),¹² cases of HIV and hepatitis C virus acquisition in operating room (OR) professionals via splash to the conjunctiva have been well documented.¹³⁻¹⁷

A number of studies have been performed to evaluate optimal pressures for wound irrigation. The majority of these have shown high-pressure irrigation to be most effective in bacteria and foreign material removal; however, high-pressure irrigation has also been associated with impairment of the local immune response, tissue damage, and propagation of bacteria deeper into tissue or bone.¹⁸ These negative effects suggest that high-pressure lavage should be limited to conditions where contamination is severe and the anticipated difficulty in bacterial removal outweighs the potential of propagation of bacteria.¹⁸ Whereas no official guidelines exist for optimal pressures, recommendations have suggested utilizing pressures of 8 to 12 psi in traumatic wounds in an effort to overcome the adhesive forces of bacteria.¹⁹

The data on pulsatile lavage versus continuous lavage are inconclusive,^{18,20} and there are no published recommendations from the ACS or AORN. Madden et al showed pulsatile flow to be less effective in bacterial removal than continuous flow in their study of *Staphylococcus aureus*-contaminated rabbit wounds,²¹ whereas Rodeheaver et al showed no significant difference in soil removal from soil-contaminated guinea pig wounds at equal pressures with the 2 types of flow.²² A 2004 study published in *JAMA* described an outbreak of multidrug-resistant *Acinetobacter baumannii* associated with pulsatile wound lavage.²³ Kalteis et al showed that, compared with flush and bulb-syringe lavage, both high- and low-pressure pulsatile lavage resulted in significantly ($P < .001$) higher rates of deep bacterial seeding in bone.²⁴

Volume

Similar to the lack of data on delivery of surgical irrigation, there are no official recommendations on irrigant fluid volumes.¹⁸ Additionally, there are no published human studies. Animal studies have indicated that increasing volume improves bacteria and foreign material removal to a point, but optimal volumes remain undefined.^{18,20} Commonly accepted parameters from wound care studies (and not surgical wound bed studies) are 50 to 100 mL per centimeter of laceration length or square centimeter of a wound^{25,26}; however, degree of wound contamination and surgical wound type should certainly be taken into consideration when determining irrigant volumes.

Additives

Perhaps the most controversial aspect of surgical irrigation is the enhancement of irrigant fluids with additives. Normal saline lavage has been a widely accepted practice in the OR for years, and a recent survey of OR nurses at the 2013 AORN congress suggests that it is still the most common form of irrigation used.²⁷ Over the years, however, a variety of different additives, commonly grouped into the categories of antibiotics, surfactants, and antiseptics, have been combined with irrigation fluids in an attempt to optimize infection prevention. Unfortunately, there are few well-designed clinical trials looking at these practices and, hence, no established clinical guidelines.⁷ In fact, currently, the Food and Drug Administration (FDA) has only approved the use of sterile normal saline and sterile water and cleared a medical device containing a 2-step wound debridement and irrigation system using a 0.05% chlorhexidine gluconate (CHG) solution followed by a normal saline rinse for irrigation.

Antibiotics

Antibiotics appear to be the most commonly used additives in surgical irrigation fluids,¹⁸ despite a shortage of evidence supporting their usage and a growing body of evidence suggesting their usage can have deleterious consequences.^{7,18,28} In the 1980s, 2 separate reviews of human studies looking at irrigation with antibiotics revealed no clear benefit.^{29,30} A relatively recent large retrospective study comparing antibiotic irrigation (bacitracin/neomycin) versus normal saline irrigation in pacemaker insertions, coronary artery bypass procedures, and laminectomies found no significant difference in SSI outcomes among the patients receiving the different irrigation fluids.³¹ Two recent published orthopedic papers suggest that, even in cases of irrigating known infected wounds, antibiotic usage in irrigation fluids does not appear to significantly improve clinical outcomes.^{32,33} The lack of efficacy seen when using antibiotics in irrigation fluids is not surprising when the mechanism by which antibiotics successfully function is considered. As described by Dr Fry, "The bioactivity of antibiotics against bacteria requires an interval of time for binding to target sites on the pathogen. The amount of time for transient contact of the topical antibiotic and the microorganism afforded by irrigation makes it highly unlikely that antimicrobial benefit will be achieved." Some evidence suggests that antibiotics in irrigation fluid not only lack efficacy but pose significant threats. Reported cases of severe anaphylaxis following the use of irrigation fluids containing bacitracin have been seen in certain cardiac, neurosurgical, general, and orthopedic cases.³⁴ The use of neomycin in irrigation fluids has been associated with cases of "systemic absorption and toxicity."¹⁸ Vancomycin powder that has been reconstituted with sterile water and used in irrigation has been linked with tissue irritation. Perhaps most concerning is the possibility that the "indiscriminate or inadequate" use of antibiotics in irrigation fluids could contribute to the development of resistant strains of bacteria.¹⁸ In the absence of compelling evidence supporting such usage, it is hard to argue that these risks are worth taking.

Some surgeons will mix their irrigant solutions in the OR, which is generally more cost-effective but results in concentration variability, whereas others will have them mixed by the hospital pharmacy, certainly leading to increased cost. Compounding one's own formulations has inherent risk including consistency in concentration and sterility, among other factors. One only has to think back to the alcohol wipe debacle in 2011³⁵ and the epidural steroid injection fiasco in 2012.³⁶

One final consideration in the use of antibiotics in irrigation fluids is that of cost. Anglen estimates that the cost of the most commonly used dosage of bacitracin per liter (100,000 U) is more than \$50.¹⁸ If 10 L of irrigation fluid is used per wound irrigation procedure, that translates into a cost of more than \$500 for antibiotic alone.¹⁸ In light of the spiraling costs of health care in the United States today, these are not inconsequential numbers.

Surfactants

Surfactants are additives designed to help flush bacteria from wounds by interfering with their ability to adhere to surfaces. The surfactants surround the bacteria in micelles, which can then be rinsed from the wound during the irrigation process.¹⁸ Among commonly used surfactants are castile soap (an anionic surfactant) and benzalkonium chloride (a cationic surfactant).¹⁸ Surfactants have been used for decades in wound cleansing, particularly in the preantibiotic era. They have been shown to have efficacy in removing bacteria from a number of surfaces, including steel, bone, and titanium; however, this efficacy has been brought into question by studies comparing them with other additives.^{37,38} In their 2009

study, Owens et al looked at bacterial counts in *Pseudomonas aeruginosa*-contaminated complex musculoskeletal wounds in goats irrigated with normal saline, castile soap, bacitracin, and benzalkonium chloride and found normal saline to be the most effective irrigant in reducing bacterial counts at 48 hours after injury.³⁸ Burd et al compared benzalkonium chloride, castile soap, castile soap followed by benzalkonium chloride, triple antibiotic, CHG, and CHG/triple antibiotic in beef, cadaveric human, and fresh human Achilles tendon-calcaneus allografts with polymicrobial inoculums and found that only the 4% CHG and 4% CHG/triple antibiotic irrigation solutions resulted in complete disinfection of all tissues.³⁷ Other studies have revealed a number of negative effects associated with the use of surfactants at varying concentrations. Red blood cell hemolysis, impaired clotting mechanisms, skin irritation, and impaired healing are among a number of these effects.¹⁸ Additionally, there appear to be very specific interactions between certain surfactants and bacteria. One group of researchers showed in a rat model that benzalkonium chloride was very effective in removing staphylococci from inoculated wounds but caused significant wound breakdown when used in *Pseudomonas*-inoculated wounds,^{39,40} suggesting that benzalkonium irrigation should be used judiciously.

Antiseptics

Antiseptic additives exert their bactericidal effect by damaging bacterial cell walls or membranes. Povidone-iodine is perhaps the most commonly used antiseptic, despite inconclusive evidence supporting its efficacy¹⁸ and lack of FDA clearance for use on open wounds.⁴¹ Povidone-iodine has been shown to be toxic to host cells and to delay or weaken wound healing, particularly at higher concentrations.^{7,42} Similar findings have been seen in a concentration-dependant manner with other antiseptics, including hydrogen peroxide, CHG, sodium hypochlorite, and parachloroxylenol.¹⁸ Cell and tissue culture studies with povidone-iodine and sodium hypochlorite have shown that they can be diluted sufficiently to mitigate the tissue toxicity effects without eliminating their bactericidal activity; however, these diluted concentrations were significantly lower than is typically used in clinical practice.¹⁸ Similar dilutional studies with hydrogen peroxide and acetic acid have shown that they lose their bactericidal activity before they lose their tissue toxicity.¹⁸ It is notable that the only antiseptic currently with FDA clearance for debriding and cleansing wounds is an irrigant fluid containing sterile water and 0.05% CHG in a medical device. Anecdotal evidence suggests that there is ongoing use of a variety of non-FDA-approved antiseptics in surgical irrigation fluids with a surprising lack of consistency in methodology.

A recent study of the use of 0.05% CHG with sterile water as an irrigation solution against selective gram-positive and gram-negative surgical isolates, including methicillin-resistant *Staphylococcus aureus*, revealed a 5- to 6-log reduction in bacteria recovery at 1 and 5 minutes.⁷ Additionally, significant reductions (*P* values ranging from < .05 to < .01) in bacterial recovery from the surface of 4 different biomedical devices were seen when exposed to the same irrigation solution.⁷ Given the high susceptibility of implant devices to bacterial contamination, irrigation with this combination prior to wound closure could have a significant impact on the risk reduction for SSI in both implant and nonimplant procedures.⁷

AIRBORNE CONTAMINATION

The etiology of SSI has historically been attributed to hematologic seeding, contamination from the patient's own skin or nasopharyngeal flora, or to a break in the aseptic barrier in the surgical field.⁴³ A number of studies over the past 50 years, however, have

identified the airborne route as a significant source for intraoperative surgical wound contamination.⁴³⁻⁴⁵ In fact, in their 1982 study of hip and knee joint replacement procedures, Whyte et al demonstrated that 98% of bacteria found in the wound washout from the procedures performed in conventionally ventilated ORs originated from the air.⁴⁴ Lidwell et al similarly found that 95% of bacteria found in intraoperative wound washouts came from the air in their 1983 study of total joint replacements.⁴⁵ Additionally, they identified a “good correlation between the air contamination and joint sepsis rate.”⁴⁵ A 2005 study of microbial populations collected in air sampling units placed at different locations throughout the OR in 70 vascular procedures revealed the recovery of gram-positive staphylococcal isolates (the most common pathogens implicated in vascular graft infections) in the majority of procedures.⁴³ Interestingly, these isolates were more frequently found in the air sampling units located closest to the surgical wound, and a number of the isolates were found through pulse-field gel electrophoresis to have clonality with gram-positive staphylococcal isolates collected from the anterior nares of the OR personnel.⁴³

Whereas data such as this has guided the surgical field toward the use of ultraclean air ventilation systems, other sources of airborne contamination remain. Surgical procedures involving electrocautery, laser ablation of tissue, or ultrasonic scalpels contribute additional airborne contamination by creating gaseous byproducts called surgical plume or smoke. This surgical smoke has been shown to be toxic to human tissues and to contain viable cellular material, including HIV, hepatitis B virus, and human papillomavirus.⁴⁶ Brown et al identified significantly increased bacterial air counts during skin preparation and draping in total hip and knee arthroplasties than during the operation itself, despite the use of ultraclean air, suggesting the potential for surgical instrument contamination if the instrument packs are opened prior to preparation/draping.⁴⁷

A number of strategies aimed at mitigating the risk of airborne contamination have been identified, including utilizing ultraclean or laminar air flow ventilation systems in the OR, limiting the number of individuals in the OR, using OR garments designed to limit bacterial dispersal such as body exhaust suits or rotecno occlusive clothing, employing efficient evacuation systems to capture the surgical smoke created during laser tissue ablation or electrocautery procedures, considering the use of conductive warming over forced air warming to maintain intraoperative normothermia, and limiting exposure of surgical implants to OR air.^{43,45,47-49} The argument could be made that surgical irrigation would play a similarly important role in this risk reduction. Copious irrigation, in addition to an effective antiseptic solution, just prior to wound closure may play a part in reducing the airborne-derived bacterial load in a surgical wound, potentially leading to a reduction in SSIs.

IMPLICATIONS

Surgeons clearly have many choices when it comes to the practice of surgical irrigation. It is interesting that, in an era of both heightened awareness regarding SSI prevention and health care cost containment, this practice has not been subjected to greater scrutiny by infection prevention teams and surgical teams alike. Anecdotal surveys of OR nurses, infection prevention personnel, and surgeons suggest not only a lack of institutional policy regarding surgical irrigation practice but also a lack of communication and collaboration between surgical staff and infection prevention staff. Standardized practices, regular review of institutional data regarding SSI, data dissemination to all involved parties, and interdepartmental cooperation are all key elements in successful surgical infection prevention.

The potential for surgical irrigation to play a key role in not only significantly reducing the risk of SSI but also in mitigating the risk of bacterial resistance, avoiding the need for more aggressive post-SSI interventions (eg, implant removal, peripherally inserted central catheter line placement for additional antibiotic administration, and others), and containing overall health care costs (eg, fewer procedures, shortened hospital stays) is undeniable.

At the conclusion of the key thought leader meeting, the following consensus statements were identified as key in the evaluation of surgical irrigation:

- Surgeons, perioperative nurses, and infection preventionists must partner to deliver exceptional infection prevention results.
- Infection preventionists need to know more about what happens “behind the red line” and how they can support practice changes that deliver real results.
- There is currently an absence of evidence-based science addressing surgical irrigation. As a result, there is a lack of guidance and standardization in perioperative practice. Standardization must address irrigation solution type(s), volume(s), and method(s) of delivery.
- Existing published evidence is sufficient to support:
 - Elimination of antibiotic solution for surgical irrigation;
 - avoidance of surfactants for surgical irrigation
- Current existing published evidence is not sufficient to guide delivery method and volume. Expert opinion could instead be used to guide best practice.

Albert Einstein once stated that the definition of insanity was “doing the same thing over and over again and expecting different results.” If reduced SSI rates are the “different results” the surgical world is pursuing, it is time for health care professionals to use science to support standardization of, and changes to, intraoperative irrigation as a critical step forward.

References

1. Anderson DJ, Kaye KS, Classen D, Arias KM, Podgorny K, Burstin H, et al. Strategies to prevent surgical site infections in acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29:551-61.
2. Stone PW. Economic burden of healthcare-associated infections: an American perspective. *Expert Rev Pharmacoeconomics Outcomes Res* 2009;9:417-22.
3. Dohmen PM. Economic burden of surgical site infections in cardiac surgery. *J Med Microb Diagn* 2013;2:e120.
4. Fry D. Fifty ways to cause surgical site infections. *Surg Infect* 2011;12:497-500.
5. Burke JF. The effective period of preventive antibiotic action in experimental incisions and dermal lesions. *Surgery* 1961;50:161-8.
6. DiPiro JT, Cheung R, Bowden TA, Mansberger JA. Single dose systemic antibiotic prophylaxis of surgical wound infections. *Am J Surg* 1986;152:552-9.
7. Edmiston CE, Bruden B, Rucinski MC, Henen C, Graham MB, Lewis BL. Reducing the risk of surgical site infections: does chlorhexidine gluconate provide a risk reduction benefit? *Am J Infect Control* 2013;41:549-55.
8. Tubaki VR, Rajasekaran S, Shetty AP. Effects of using intravenous antibiotic only versus local intrawound vancomycin antibiotic powder application in addition to intravenous antibiotics on postoperative infection in spine surgery in 907 patients. *Spine* 2013;38:2149-55.
9. Greco G, Shi W, Michler R, Blackstone E, Kron I, Moquete E, et al. The economic impact of healthcare associated infections in cardiac surgery. 2013. Available from: <http://www.abstractsonline.com/Plan/ViewAbstract.aspx?sKey=b9193dbe-c752-450f-9b49-f41fdf2be1c0&cKey=8fc06889-f397-4701-b7df-b7ae743b307f&mKey=951e351e-429c-4b2e-84d0-8da73b00de45>. Accessed December 30, 2013.
10. Prucz RB, Sullivan SR, Klein MB. *Acute wound care*. ACS surgery: principles and practice. Ontario, Canada: Decker Intellectual Properties; 2012.
11. Jagger J, Bentley M, Tereskerz P. Patterns and prevention of blood exposure in operating room personnel: a multi-center study. *Adv Exp Prev* 1998;3: 61-71.
12. Mohebbati A, Davis JM, Fry D. Current risks of occupational blood-borne viral infection. *Surg Infect* 2010;11:1-7.
13. Fry DE. The ABC's of hepatitis. *Advances in surgery*, Vol 33. Maryland Heights [MO]: Mosby, Inc; 1999.

14. Beltrami EM, Williams IT, Shapiro CN, Chamberland ME. Risk and management of blood-borne infections in health care workers. *Clin Microbiol Rev* 2000;13:385-407.
15. Gioannini P, Sinicco A, Cariti G, Lucchini A, Paggi G, Giachino O. HIV infection acquired by a nurse. *Eur J Epidemiol* 1988;4:119-20.
16. Hosoglu S, Celen MK, Akalin S, Geyik MF, Soyoral Y, Kara IH. Transmission of hepatitis C by blood splash into conjunctiva in a nurse. *Am J Infect Control* 2003;31:502-4.
17. Sartorti M, La Terra G, Aglietta M, Manzin A, Navino C, Verzetti G. Transmission of hepatitis C via blood splash into conjunctiva. *Scand J Infect Dis* 1993;25:270-1.
18. Anglen JO. Wound irrigation in musculoskeletal injury. *J Am Acad Orthop Surg* 2001;9:219-26.
19. Hays EP. Wound care: from door to discharge. Proceedings of the Boston Scientific Assembly; October 6, 2009; Boston, MA.
20. Gabriel A, Schraga E, Windle ML. Wound irrigation. 2011. Available from: www.emedicine.medscape.com/article/1895071. Accessed July 20, 2013.
21. Madden J, Edlich RF, Schauerhamer R, Prusak M, Borner J, Wangenstein OH. Application of principles of fluid dynamics to surgical wound irrigation. *Curr Topics Surg Res* 1971;3:85-93.
22. Rodeheaver GT, Peltry D, Thacker JG, Edgerton MT, Edlich RF. Wound cleansing by high pressure irrigation. *Surg Gynecol Obstet* 1975;141:357-62.
23. Maragakis LL, Cosgrove SE, Song XE, Kim D, Rosenbaum P, Ciesla N, et al. An outbreak of multi-drug resistant *Acinetobacter baumannii* associated with pulsatile lavage wound treatment. *JAMA* 2004;292:3006-11.
24. Kalteis T, Lehn N, Schroeder HJ, Schubert T, Zysk S, Handel M, et al. Contaminant seeding in bone by different irrigation methods: an experimental study. *J Orthop Trauma* 2005;19:591-6.
25. Chisholm CD, Cordell WH, Rogers K, Word JR. Comparison of a new pressurized saline canister versus syringe irrigation for laceration cleansing in the emergency department. *Ann Emerg Med* 1992;21:1364-7.
26. Lammers RL, Hudson DL, Seaman ME. Predictors of traumatic wound infection with a neural network-derived decision model. *Am J Emerg Med* 2003;21:1-7.
27. Business Wire (Internet). Survey conducted at AORN congress reveals need for new and better surgical site infection prevention strategies; c2013 [updated 2013 March 11]. Available from: <http://www.businesswire.com/news/home/20130311005412/en/Survey-Conducted-AORN-Congress-Reveals-Surgical-Site>. Accessed September 27, 2013.
28. CDC. Recommendations for preventing the spread of vancomycin resistance: recommendations of the Hospital Infection Control Practices Advisory Committee (HICPAC); September 22, 1995/44 (RR12); 1-13. Available from: <http://www.cdc.gov/mmwr/PDF/RR/RR4412.PDF>. Accessed July 10, 2013.
29. Golightly LK, Branigan T. Surgical antibiotic irrigations. *Hosp Pharm* 1989;24:116-9.
30. Roth RM, Gleckman RA, Gantz NM, Kelly N. Antibiotic irrigations: a plea for controlled clinical trials. *Pharmacotherapy* 1985;5:222-7.
31. Michels M, Aggers WA. Prophylactic use of topical antibiotic irrigation for clean surgical wounds. *Gundersen Lutheran Med J* 2003;2:31-3.
32. Crowley DJ, Kanakaris NK, Giammoudis PV. Irrigation of the wounds in open fractures. *J Bone Joint Surg* 2007;89B:580-5.
33. Koyonos L, Zmstowski B, Della-Valle CJ, Parvizi J. Infection control rate of irrigation and debridement of periprosthetic joint infection. *Clin Orthop Relat Res* 2011;469:3043-8.
34. Damm S. Intraoperative anaphylaxis associated with bacitracin irrigation. *Am J Health-Syst Pharm* 2011;68:323-7.
35. US Food and Drug Administration. Silver Spring [MD]: Trial alcohol prep pads, alcohol swabs, and alcohol swabsticks: recall due to potential microbial contamination; c2011 [updated 2011 June 15]. Available from: <http://www.fda.gov/Safety/MedWatch/SafetyInformation/SafetyAlertsforHumanMedicalProducts/ucm239319.htm>. Accessed September 26, 2013.
36. Centers for Disease Control and Prevention. Atlanta [GA]: Multistate fungal meningitis outbreak investigation; c2012 [updated 2013 September 6]. Available from: <http://www.cdc.gov/hai/outbreaks/meningitis.html>. Accessed September 26, 2013.
37. Burd T, Conroy BP, Meyer SC, Allen WC. The effects of chlorhexidine irrigation solution on contaminated bone-tendon allografts. *Am J Sports Med* 2000;28:241-4.
38. Owens BD, White DW, Wenke JC. Comparison of irrigation solutions and devices in a contaminated musculoskeletal wound survival model. *J Bone Joint Surg Am* 2009;91:92-8.
39. Tarbox BB, Conroy BP, Malicky ES, Moussa FW, Hockman DE, Anglen JO, et al. Benzalkonium chloride: a potential disinfecting irrigation solution for orthopedic wounds. *Clin Orthop* 1998;346:255-61.
40. Conroy BP, Anglen JO, Simpson WA, et al. Comparison of castile soap, benzalkonium chloride, and bacitracin as irrigation solutions for complex contaminated wounds. *J Orthop Trauma* 1999;13:332-7.
41. Daily Med (2011). Povidone iodine; c2011. Available from: <http://dailymed.nlm.nih.gov/dailymed/lookup.cfm?setid=095c47d5-9fe0-45ed-93eb-a2ac3961db59>. Accessed September 27, 2013.
42. Fletcher N, Sofianos D, Berkes MM, Obremesky WT. Prevention of perioperative infection. *J Bone Joint Surg* 2007;89:1605-18.
43. Edmiston CE, Seabrook GR, Cambria RA, Brown KR, Lewis BD, Sommers JR, et al. Molecular epidemiology of microbial contamination in the operating room environment: is there a risk for infection? Presented at the 62nd Annual Meeting of the Central Surgical Association, Tucson, AZ, March 10-12, 2005.
44. Whyte W, Hodgson R, Tinkler J. The importance of airborne bacterial contamination of wounds. *J Hosp Infect* 1982;3:123-35.
45. Lidwell OM, Lowbury EJJ, Whyte W, Blowers R, Stanley SJ, Lowe D. Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. *J Hosp Infect* 1983;4:111-31.
46. Alp E, Bijl D, Bleichrodt RP, Hansson B, Voss A. Surgical smoke and infection control. *J Hosp Infect* 2006;62:1-5.
47. Brown AR, Taylor GJS, Gregg PJ. Air contamination during skin preparation and draping in joint replacement surgery. *J Bone Joint Surg Br* 1996;78:92-4.
48. McGovern PD, Albrecht M, Belani KG, Nachtsheim C, Partington PF, Carluke I, Reed MR. Forced-air warming and ultra-clean ventilation do not mix. *J Bone Joint Surg Br* 2011;93:1537-44.
49. Tavitian JD, Ong SM, Taub NA, Taylor GJS. Body-exhaust suit versus occlusive clothing. *J Bone Joint Surg Br* 2003;85:490-4.