An Ounce of Prevention Saves Tons of Lives: Infection in Burns

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Abstract

Background: Modern day burn care continues to wage an uphill battle against an enemy that evolves faster than we can develop weapons. Bacteria (bioburden) are everywhere and can infiltrate anywhere within our susceptible population of burn patients. This is why prevention of infection is key to improving their survival and outcome.

Purpose: To reduce the incidence of infection in the burn patient population.

Materials: Review of pertinent recent literature regarding infection prevention and control in the intensive care unit setting.

Results: We propose that bioburden is one of the central elements in the infectious cycle that is ever-present in burn units. The mechanism of bacterial entry into the unit and subsequent transmission and infection are delineated. Recommendations for mitigating this risk are provided to guide future clinicians in their care of burn patients.

Conclusions: The treatment of infection and sepsis against highly adaptable bacteria is often insurmountable by ill patients. In this process, bioburden needs to be corralled to have any success. Thus, preventing organisms from entering the unit and transferring onto other patients, and eliminating the bacteria dwelling in the unit are all necessary actions in this battle. Ultimately, maintaining a culture that is constantly wary of this risk only can achieve this goal.

OVER THE LAST TWO DECADES, sepsis superseded respiratory failure to account for one-half of deaths [1]. As result of thermal, chemical, or electrical injury, patients lose their natural barriers to bacteria [2]. This exposes the subcutaneous tissue and facilitates bacterial growth by providing the organisms with a nutrient-rich environment. Simultaneously, thrombosis of blood vessels interferes with the transport of essential factors needed to counter the invasion. As the size of injury increases and the immune response weakens due to physiologic stress from the burn, bacteria make the most of the opportunity and proliferate [3,4]. Normally, the body responds vigorously to the attack, but it is unable to in this weakened state and often succumbs. Similarly, the efficacy of the only weapon to counter this offensive, antibiotics, is based on the susceptibility of the invading organism. With the ever-increasing spread of resistant bacteria, controlling and treating this insult becomes more and more difficult or even futile. As risk increases and options decrease, we have to critically assess how we as modern burn care providers can reduce the risk of infections and sepsis by

looking back and evaluating effective and non-effective interventions. This review delineates new and old techniques that may impact the incidence and treatment of infection but ultimately can be summarized into one sentence: Prevention is the best option for patient survival.

Bioburden

What is bioburden? It is the number of bacteria living on a surface prior to sterilization, or the number of bacteria contaminating a surface. Human beings contain between 500–1,000 different organisms in their guts and likely harbor a similarly diverse population on the skin [2]. With nearly 10-fold higher quantity of bacteria compared with human cells, bioburden of all patients is high [4]. Although many of these bacteria are found in the gastrointestinal and urogenital tracts, their effects vary from cellulitis to graft loss to multiple-organ failure and sepsis. Thus, bacteria anywhere on the body can overwhelm the equilibrium after a burn injury and cause an infection. Organisms causing infections commonly are

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Pseudomonas aeruginosa, *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella* spp., *Enterococcus* spp., and *Candida* spp. Although we recognize aerobic organisms commonly, there may be a greater role than perceived that anaerobic organisms play. They are often overlooked as wound cultures are not sent routinely to isolate them. Nearly 40% of burn wounds are colonized with anaerobes [5]. For patients that manifest signs of sepsis without an organism, they may be affected by an anaerobic organism [6]. Debate lingers as to whether an abundance of a particular organism or the presence of multiple opportunistic organisms plays the greatest role in infection development. Regardless, bacteria must be present in an opportunistic host and environment for this to occur. Thus, by minimizing the bioburden and types of bacteria present, risk of infection should decrease.

Route of Transmission of Bacteria

Pathogens are carried into the unit—both on people and equipment. It is the same for the operating room. Between these two vectors, trillions of organisms change places. There is evidence that organisms such as *Clostridium difficile*, vancomycin-resistant enterococci (VRE), and methicillin-resistant *S. aureus* (MRSA) survive on fomites longer than other less problematic bacteria [7]. Thus, controlling the movement of the bioburden is even more imperative.

Methods of Regulating Bioburden in the Environment

This complex approach is a process that takes everyone within the unit, staff and visitors, to adapt to a culture of minimizing the spread of these pathogens. Thus, the first point of prevention begins at admission into a Burn Center. The subsequent steps are actions taken on a daily basis after the patient is admitted and until discharge from the unit.

Admission into burn unit

Patient screening and surveillance swabs. Every patient admitted to the burn unit undergoes a screening questionnaire to determine their precaution status. If they are unable to communicate, then they are placed automatically on full precautions. This clarifies the personal protective equipment (PPE) that all patient contacts will need to utilize for patients on contact, droplet, or airborne precautions and determine the barriers required to minimize transmission between patients. The following questions are used to help determine their status (Table 1).

TABLE 1. QUESTIONS FOR SCREENING PURPOSES

Previously admitted to a hospital (contact precautions until swabs are negative)
Fever or chills? (contact and droplet precautions)
Diarrhea or vomiting? (contact precautions)
Night sweats, hemoptysis, fatigue, weight loss? (airborne precautions)
History of MRSA, ESBL, VRE, or CRE? (contact precautions)
Rash? Check for measles, HSV, VZV, scabies (contact and airborne precautions)

CRE = Carbapenem-resistant Enterobacteriaceae; ESBL = extended-spectrum beta-lactamase; HSV = herpes simplex virus; MRSA = methicillin-resistant *Staphylococcus aureus*; VRE = vancomycin-resistant enterococci; VZV = varicella zoster virus.

Once the patient is placed on these precautions, they remain in place until cleared by health care personnel overseeing these standards in the hospital. By maintaining these strict measures, transmission between patients does decrease [8–10].

All patients undergo surveillance swabs for MRSA and VRE when they are admitted and discharged from the Burn Center. This tactic helps identify patients that are at greatest risk to themselves and the unit [11–15]. Barrier precautions and room cleaning practices for these patients do not change at our facility. Some centers will do a secondary cleaning of the operating room after each use versus a single cleaning as with other patients. For the more virulent strains, patient rooms should undergo a daily terminal clean for 72 h upon patient discharge prior to the admission of another patient [16]. Research shows that gram-negative bacteria decrease nearly five-fold and gram-positive bacteria decrease by only 25% after adequate disinfection [17]. This may be explained by the “stickiness” of MRSA. Routine surveillance cultures are not performed, as our patients do not receive empiric antibiotic prophylaxis to minimize development of resistant organisms [18,19].

Isolation rooms. Each patient is kept in a single-patient room, which is separated from the common area by a door [20]. This setup allows the patient’s bioburden to be confined to the room and decrease the spread to the rest of the unit. The doors are kept closed routinely to minimize transfer of pathogens and especially with dressing changes [21]. In the absence of an anteroom, the patient rooms should be maintained with negative pressure to minimize bacteria escaping when the door opens. The presence of a doorway also acts as a momentary reminder to perform tasks labeled on the door (wearing barrier precautions) and hand washing/cleansing. Another advantage of isolating patients in individual rooms is to allow “cohorting” of patients during an outbreak. Although there is only some evidence that this tactic reduces the number of contacts to exposed patients, it appears highly effective in controlling the spread of bacteria. Also, by corraling the patients with the same pathogen to one part of the unit, there is no need to move them to a separate unit [22]. For burn patients, with high daily care requirements, it makes a large difference in their overall care.

Contact precautions/hand hygiene. For all patients in the unit, full barrier precautions are maintained until they are cleared of their potential antibiotic-resistant organism (ARO) status. Typical barrier devices are gowns, gloves, and masks, depending on the type of isolation. Routine shoe covering is not required, though there is a strict policy to not use anything that has fallen on the floor. These guidelines were created based on the 2007 U.S. Centers for Disease Control and Prevention (CDC) Guideline for Isolation Precautions. After precautions are reduced based on risk clearance, interaction with the patients is still performed with the use of gowns and gloves. Masks and hair covering are donned by the staff for all dressing changes as this activity sheds the greatest bioburden [21]. The amount of bacteria that burn patients can release into the environment is greater than other hospital patients, which is why such standards are maintained. Routine hand hygiene before and after interaction with patients is mandatory. Staff are required to participate in biennial training to maintain

appropriate technique. Additional precautions are taken to maintain trimmed fingernails and prohibit the use of nail enhancements to minimize the spread of bacteria (esp. gram-negative bacteria) [23,24]. All barrier precautions and hand hygiene guidelines apply to visitors as well.

No fomites in unit. All staff and visitors are prohibited from bringing fomites into the unit in an effort to control the risk of spreading pathogens. This would include objects such as ties, laboratory coats, rings, watches, stethoscopes, and cellular communication devices [25,26]. Rings and watches are common culprits as they harbor bacteria and interfere with effective hand hygiene. Cell phones were found to carry *P. aeruginosa* and *K. pneumoniae* strains [27]. White coats act as vectors of MRSA [26]. Evidence for many infection prevention practices in the critical care setting is based on Grade C and D data. Nonetheless, when dealing with the sickest patients, practices that are not unnecessary financial burdens on the system should be followed. Fomites, or potential pathogen carriers, should be left outside of the unit. Strict hand hygiene should be followed with all patient contact as there is ample data supporting this activity. Although barrier precautions may not mitigate the transmission of bacteria according to some authors, the greater bioburden deployed into the environments within the burn unit warrants an extra layer of protection between patients. Similarly, wearing gowns and gloves reminds everyone to adhere to these principles. Surveillance swabs should be performed on admission as it may prepare the staff better to isolate certain patients, use extra caution when in contact with the patient, choose better empiric coverage during an infection, or clean a room more thoroughly.

Burn unit stay

Once a patient is admitted to the unit, the daily practices of infection prevention should continue. However, with each intervention that is performed on these patients, they are at a greater risk for developing infection. This is also a result of the extension to their stay. Thus, the actions of each day should maximize care and minimize risk.

Indwelling devices. The CDC guidelines provide detailed information and the rationale for bundles regarding ventilator-associated pneumonia (VAP), Central-line associated blood stream infection (CLABSI), and urinary tract infections (UTI). These recommendations decrease the infections associated with these indwelling devices [28–30]. Ultimately, the goal is to minimize the duration of each device [31]. Thus, daily assessment is key to achieving success. To minimize the risk of UTI, studies did not show a difference in the rate of infection with different catheters [32,33]. However, limiting the use of Foley catheters to patients that are ventilated or immobilized to protect upper extremity grafts in burn patients should minimize the risk of infection. The placement of a condom catheter is also an option if neurological pathology is present and making it difficult to control incontinence or mobilize reliably. For central venous catheters, there is evidence supporting the use of chlorhexidine-silver sulfadiazine-impregnated catheters for high-risk patients [34,35]. However, for catheters impregnated with rifampin and minocycline, it is less conclusive [36,37]. Although the subclavian site is less prone to infection, the risk of a femoral line colonization may be less severe and

even comparable to a subclavian catheter than once considered [38]. Ideally, a central venous catheter would be placed using sterile full barrier precautions (drape, gown, gloves, cap, and mask) for those in the room. The recommended minimal distance is 25 cm² from a burn with a duration of 3 d [39]. The CDC does not support routine changes of central venous or arterial catheters currently; catheter change is necessary when colonization or infection is suspected [40].

Central venous catheter maintenance is another area of study. Ethanol lock therapy for the catheter showed some benefit, but did have potential risks of central nervous system toxicity, arrhythmias, local venous irritation, and flushing [41]. Results using antimicrobial lock solutions are not much better [42]. Routine dressing changes using chlorhexidine solution do appear to be beneficial.

Adherence to all recommendations is difficult, but removing certain “sticky” bacteria from a unit is even worse. Thus, effective cleaning and prevention better treats certain organisms such as *Acinetobacter baumannii* that can cause recurrent or late-onset VAP [43]. Heat and moisture exchanger (HME) filters and heated humidifier ventilation has not shown a decrease in the development of VAP either, although their use may delay the onset [44]. In addition to the bundling of care guidelines for each of the indwelling devices and ventilator, the training of personnel that perform the procedures and maintain the devices plays a role [45]. Intubations, central line, and Foley placements are all placed by a variety of personnel at different times. Unfortunately, their level of training varies, which includes their understanding of appropriate clean practices of device placement. Although studies have not clearly shown a difference in peripherally inserted central catheters (PICC) causing less infections, the reason that they may cause less infections is that a single team places them and manages them. Thus, achieving this level of knowledge for the ICU team members can also decrease infection rates as shown by multiple studies [46,47].

Wound care

The use of soaks and topical antibacterial products is a fundamental part of burn wound management. Minimizing the bioburden in the wound bed will decrease the likelihood of infection. Thus, appropriate selection of topical solution is needed to achieve effective optimal in controlling bacterial growth (Table 2). These topical solutions are useful pre- and post-excision of the burned tissue. Prior to excision, silver

TABLE 2. TOPICAL TREATMENT OPTIONS FOR BURN WOUND CONTAMINATION OR INFECTION

Topical Antimicrobial	Organisms
Mafenide acetate (5%)	Gram + and Gram –
Silver sulfadiazene	Gram +, Gram –, and yeast
Acetic acid (2%)	Gram + and Gram – (<i>Pseudomonas</i> – 2%)
Sodium hypochlorite solution	Gram +, Gram –, yeast and fungi
Acticoat	Gram +, Gram –, yeast, fungi, MRSA, VRE
Silver nitrate (0.5%)	Gram +, Gram –, yeast, fungi

Anticoat: silver-impregnated antimicrobial barrier dressing, smith & Nephew, London, United Kingdom.

sulfadiazine is used for its broad coverage and cooling effect. Dakin solution is also helpful if the wound requires frequent reassessment as it does not form a pseudoeschar as does silver sulfadiazine, but is less comfortable to the patient. Dressings can be changed frequently depending on the amount of necrotic debris that is present. With each dressing change, the precautions mentioned above should be followed to minimize aerosolization. Patients with partial thickness burns can be successfully treated with Aquacel Ag (ConvaTec, Princeton, NJ) in the inpatient or outpatient setting [48]. This mode of treatment is also comfortable for patients as the dressing separates from the body once the wound has epithelialized.

Ultimately, early excision is the recommended care for burns requiring surgery [49,50]. This will decrease the bioburden substantially [51]. Post-operatively, topical antimicrobials are equally beneficial for managing grafted and donor sites. As the patients continue to be susceptible to infections, dressing changes with the above solutions help control the pathogens. *Pseudomonas* is a common organism that can be treated with dressings of acetic acid 2%. Other silver-based products are available for wound care with similar benefits against gram-positive and -negative organisms, yeast, and fungi as mentioned above [52]. Silver is especially effective against MRSA [53].

Post-operative wound care with a negative-pressure dressing can facilitate controlling the spread of pathogens. These dressings are generally left intact for several days after surgery and fluid drainage is also collected into a container that does not communicate with the environment. In addition to their ability to help minimize dispersal of pathogens, they facilitate wound healing [54]. Thus, by closing a wound sooner, opportunistic organisms are less likely to cause sepsis. There may also be a benefit in using negative-pressure dressings pre-operatively to decrease infection risks. One study in mice demonstrated a decrease in the amount of *Pseudomonas* organisms in a full-thickness eschar through the use of a negative-pressure dressing [55]. This dressing also allows patients to mobilize sooner with less risk of graft shearing, which also indirectly helps decrease infection risk by improving patient physiology. In summary, topical agents are an essential component of burn care to treat or prevent bacterial contamination or infections and a strong recommendation is to use both sulfamylon and acetic acid in an alternating fashion. The addition of negative-pressure dressings to the armamentarium of wound care also shows strong promise for promoting healing, minimizing the spread of bacteria, and facilitating early mobility.

Selective gut decontamination

This practice remains controversial and has not gained much support, as the outcomes of the studies have varied. Decontamination does not appear to conclusively decrease the rate of VAP, antimicrobial resistance, or mortality [56–60]. However, it may have benefits in attenuating the cardio-suppressive effects of burn injury [61]. Certain concerns that are raised with gut decontamination are the cost and potential spread of pathogens from the frequent bowel movements that are induced.

Antibiotic stewardship

Proper monitoring of infectious pathogens and their susceptibilities in the unit improve the ability to treat patients and

minimize spread of infection and resistance. Also, understanding the likely pathogens to cause an infection based on temporal orientation during the hospital stay improves empiric coverage as the patient becomes septic. When a patient demonstrates findings of sepsis, blood, urine, and sputum cultures are routinely sent. Empiric coverage is then initiated until a pathogen and its susceptibilities are identified. Then antibiotic coverage is quickly de-escalated to preserve the broad-spectrum antibiotics for when they are needed most [62].

At our center, early-phase infections (<5 d after admission) are treated with cloxacillin for gram-positive organisms and ceftriaxone for gram-negative infections (or levofloxacin for either if penicillin allergy is documented). However, if the infection is late-phase (>5 d), then cloxacillin may be used for gram-positive bacteria or piperacillin-Tazobactam is used for both, as gram-negative organisms are more likely to cause infection.

Burn ICU-specific equipment

Within the unit, devices that are used frequently to take care of burn patients should not be shared with other parts of the hospital. For our center, fluid warmers, rapid infusers, ECG machine, ultrasound machine, and ventilators were purchased for the sole purpose of minimizing transmission of bacteria to or from the unit. Also, many disposable items (e.g., stethoscope, temperature probes, paper oxygen saturation finger probes) are used to prevent infection [63]. However, not all equipment can be used in solitary units due to fiscal constraints. Thus, it is important that all diagnostic devices that enter patient rooms be thoroughly cleaned and protected to minimize transportation of pathogens. All devices are cleaned with accelerated hydrogen peroxide cleaning agents (Virox Technologies, Oakville, ON, Canada) or Caviwipes XL[®] (Metrex Research, Romulus, MI; contain 17.2% isopropanol, 2-butoxyethanol 1%–5%, and diisobutylphenoxyethoxyethyl dimethyl benzylammonium chloride 0.28% in water) for objects sensitive to the oxidization effect of hydrogen peroxide. If cleaned improperly or used by technicians not following infection control practices, then risk of transmission increases [64].

Daily hydrotherapy

The role of washing wounds on a daily basis is controversial. Some argue that daily washings will clean the wound surface and enhance sloughing, drain pus, and help debride the wound, alter microbial flora to maintain a healthier bioburden, enhance healthy tissue formation, facilitate physical therapy, or simply comfort the patient. This is countered with the risk of aerosolizing more bacteria, creating pain for the patient, inducing greater stress (both physical and emotional), or expose other patients to the bacteria of the patient prior to their hydrotherapy treatment. Another concern is that patients' own bacteria may migrate during the treatment to more susceptible areas and create an infection. To date, there is no strong evidence to support either approach and therefore no evidence-based recommendation. We, based on our experience, suggest that daily hydrotherapy is not necessary and not part of routine care due to the concern of bacterial transmission at our burn center.

Daily room cleaning

It is often difficult to reduce bioburden rapidly once a patient is involved. Thus, an area that can be improved upon

is how rooms are cleaned. This gives the new patient the best chance of not being contaminated by the previous patient's bacteria. As mentioned above, identifying areas that are difficult to clean certainly helps to redirect the cleaning effort. Additional modalities that can reach most areas of the room with relative ease are hydrogen peroxide vapors or ultraviolet decontamination during terminal cleaning. Ultramicrofibers associated with a copper-based biocide may also benefit with the daily cleaning process [65].

All patient rooms undergo cleaning on a daily basis with accelerated hydrogen peroxide cleaner at our center. By regularly disinfecting the surfaces and high-touch areas in the room, bioburden would be kept at a minimal level. Thus, the timing of the cleaning is also coordinated with the dressing change. Once the new dressings are in place, the room is cleaned to account for any bacterial matter that aerosolized during the wound care. As mentioned above, bacteria can be transmitted between patients based on the bioburden that remains in a patient room after discharge [7,8,66]. Although these rooms are cleaned thoroughly each day per hospital guidelines, some pathogens will likely remain [67]. What may help improve the cleanliness and decrease transmission is to identify areas that are harboring bacteria. The unit rooms could be marked using fluorescent targeting to see concentrated areas that may require additional cleaning [68].

Maintaining patient physiology

Bouts of hypotension or hypoxia can suppress immune function. Pain and hypothermia also play a similar role. Minimizing extreme negative physiologic states will improve the physiology of the patient and enable them to fend off pathogens.

Early Detection of Infection

After prevention, early detection and appropriate treatment of an infection/sepsis is paramount to controlling bioburden spread. The American Burn Association (ABA) provides guidelines for identifying sepsis in a burn patient as they vary slightly from the general ICU population. Three of the following criteria need to be present in addition to identifying and infection. This can be a positive culture, pathologic tissue, or response to empiric antibiotics (Table 3).

Similar to Moore et al. [69], a daily screening tool for the early identification of sepsis should be implemented based on the criteria above for burn patients. This enables the medical staff to be prepared better for an impending infection. Often the risk of infection is due to indwelling devices. Thus, it is important to follow the CDC guidelines, as they were created based on strong evidence. The remaining practices listed above are based on weaker evidence. Presently, we do not recommend gut decontamination as it may expose the unit to more bacteria and add an unnecessary cost. This also applies to hydrotherapy on a daily basis. Providing appropriate topical care and antibiotic selection when needed is also important in controlling the bioburden.

New Areas of Infection Prevention and Treatment

Blue light therapy for *Pseudomonas*

An area that warrants exploration for either implementation in patient rooms for wound therapy or cleaning is the use of blue light. Wavelengths of 405 nm and 470 nm appear to

TABLE 3. AMERICAN BURN ASSOCIATION GUIDELINE FOR DIAGNOSIS OF SEPSIS IN A BURN PATIENT

1. Temperature > 39° or < 36.5° C
2. Tachycardia
 - a. Adults > 110 beats/min
 - b. Children > 2 standard deviations above 85% age-adjusted maximum heart rate
3. Thrombocytopenia (applies 3 days after initial resuscitation)
 - a. Adults < 100 k
 - b. Children > 2 standard deviations below normal
4. Tachypnea
 - a. Adults > 25 breaths/min if not ventilated and minute ventilation > 12L/min if ventilated
 - b. Children > 2 standard deviations above 85% age-adjusted maximum respiratory rate
5. Hyperglycemia (non-diabetic patients)
 - a. Untreated glucose (plasma) > 200 mg/dL
 - b. Insulin resistance
 - i. High insulin infusion rates
 - ii. >25% increase in insulin requirements in 24 hours
6. Poor enteral feeding tolerance
 - a. Abdominal distension
 - b. Increased residuals in tube-fed patients
 - c. Profuse diarrhea

have bactericidal effects on *P. aeruginosa* and *S. aureus* in vitro [70]. Blue light is also effective against MRSA in vitro [71]. Although this modality appears ideal as non-pharmaceutical management of these opportunistic pathogens, there is some concern that they may simultaneously enhance the proliferation of other organisms such as *E. coli* [72]. Wound healing also can continue without risk of interference with blue light therapy and may even benefit from the exposure [73,74]. Currently, this therapy does not convey resistance as antibiotic therapy can, even with repeated exposures [75].

Conclusion

In light of increasing incidences of infections and resistant pathogens, we propose to return to the basics and minimize infections by prevention. Preventing infection is the absolute safest thing to do for our patients by a multi-modal approach. Everyone from the housekeeping staff to the medical staff needs to understand how pathogens are transmitted within the ICU, tub room, and operating room, and what we can do to minimize the risks to our patients. Acknowledging this fact only comes through education of all personnel involved in taking care of the unit and its patients, which eventually leads to a belief that these actions make a difference.

Acknowledgments

This study was supported by the National Institutes of Health R01-GM087285-01; CFI Leader's Opportunity Fund: Project #25407, Canadian Institutes of Health Research (CIHR) grant #123336.

Author Disclosure Statement

The authors have no conflicts of interest to declare.

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