

Infection Prevention and Control in Deployed Military Medical Treatment Facilities

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Abstract: Infections have complicated the care of combat casualties throughout history and were at one time considered part of the natural history of combat trauma. Personnel who survived to reach medical care were expected to develop and possibly succumb to infections during their care in military hospitals. Initial care of war wounds continues to focus on rapid surgical care with debridement and irrigation, aimed at preventing local infection and sepsis with bacteria from the environment (e.g., clostridial gangrene) or the casualty's own flora. Over the past 150 years, with the revelation that pathogens can be spread from patient to patient and from healthcare providers to patients (including via unwashed hands of healthcare workers, the hospital environment and fomites), a focus on infection prevention and control aimed at decreasing transmission of pathogens and prevention of these infections has developed. Infections associated with combat-related injuries in the recent operations in Iraq and Afghanistan have predominantly been secondary to multidrug-resistant pathogens, likely acquired within the military healthcare system. These healthcare-associated infections seem to originate throughout the system, from deployed medical treatment facilities through the chain of care outside of the combat zone. Emphasis on infection prevention and control, including hand hygiene, isolation, cohorting, and antibiotic control measures, in deployed medical treatment facilities is essential to reducing these healthcare-associated infections. This review was produced to support the *Guidelines for the Prevention of Infections Associated With Combat-Related Injuries: 2011 Update* contained in this supplement of *Journal of Trauma*.

Key Words: Infection control, Infection prevention, Combat, Trauma, Military.

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Modern technology, doctrine, and training have resulted in improved survival of personnel injured on the battlefield, including those with severe combat-related injuries. In addition to body armor, immediate life-saving techniques such as tourniquet and hemostatic bandage use, field cricothyroidotomy, and rapid evacuation from the battlefield using aircraft, medical treatment facilities (MTFs) are positioned throughout the combat zone to allow rapid surgical stabilization and ultimately transportation of the injured back to their home nations. Care of the wounded is initiated at the point of injury by self-aid, buddy aid, combat lifesavers, and/or combat medics/corpsmen. Wounded personnel are then transported to increasingly higher levels of care (Table 1) until they reach definitive and rehabilitative care back in their home nation. Transportation of patients between levels (Roles) of care is dependent on combat activities, location, transportation assets, weather, terrain, and military control of ground or air. In the current conflicts, most casualties are transported from point of injury to Role 2 or 3 care via helicopters. Once stabilized, most patients will then need to be transported again to a Role 3 hospital from which aeromedical evacuation out of the combat zone is possible. For wounded US personnel in the current conflicts, next is a long distance aeromedical evacuation to Germany (Role 4, Landstuhl) and then to continental US military medical centers (Role 5), most commonly by C-17 aircraft. This complex chain of care, by its nature, requires multiple physical and care management handoffs over a short period of time, typically 3 days to 7 days from point of injury to care in a medical facility in the patient's home country.

The focus of this review is care within combat zone MTFs. This care is often provided in less than ideal environmental conditions by staff who, by the nature of military deployments, are transient members of the MTF. Challenges to provision of care have been previously described and include high personnel turnover rates, provision of care to local nationals and non-US personnel, physical structure of MTFs, environmental conditions, and the logistical support chain (Table 2).^{1–3} These challenges all make the effective practice of infection prevention and control difficult in deployed MTFs. In this article, we review the history and challenges of healthcare-associated infections (HAIs) in deployed MTFs as they pertain to caring for combat-injured

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TABLE 1. Care and Resources Available Across the Various Strata of Medical Support for Patients Injured in Combat Operations

Designation*	MTF or Site of Care	Care Provided/Resources
Role 1/Level I	Point-of-injury (field care)	Self-aid, buddy aid, combat lifesaver, combat medic/corpsman care
	MTF: battalion aid station (US Army), shock trauma platoon (USMC)	Physician/physician assistant care, no patient holding capacity
Role 2/Level II	MTF: medical company (includes forward support medical company, main support medical company, and area support medical company, US Army), expeditionary medical support (USAF)	72-h patient holding capacity, basic blood transfusion, radiography and laboratory support
Role 2b/Level IIb	MTF supplemented with surgical assets: forward surgical team (US Army), mobile field surgical team (USAF), forward resuscitative surgical system (USMC)	Forward resuscitative and stabilization surgical care
Role 3/Level III	MTF: combat support hospital (US Army), Air Force theater hospital, (USAF), casualty receiving ships (USN)	Full inpatient capacity with intensive care units and operating rooms
Role 4/Level IV	MTF: regional hospital (Landstuhl Regional Medical Center, Germany) or USNS hospital ships (USN), typically outside of the combat zone	General and specialized inpatient medical and surgical care
Role 5/Level V	MTF: military care facilities within United States, typically tertiary care medical centers	General and specialized inpatient medical and surgical care, rehabilitative care

MTF, medical treatment facility; USMC, US Marine Corps; USAF, US Air Force; USN, US Navy; USNS, US Naval Ship.

* Level or echelon are considered equivalent terms to Role.

personnel. We also review the history and current practice strategies available to decrease or prevent these infections.

BACTERIOLOGY OF WAR WOUNDS

Before the use of rapid surgical management, early debridement and irrigation, and adjunctive postinjury systemic antimicrobials, most infections associated with combat-related injuries occurred soon after wounding and were secondary to bacteria that contaminated wounds at the point of injury.⁴ These included *Clostridium perfringens*, the cause of gangrene, from the soil, and aerobic gram-positive cocci of the skin, including *Streptococcus pyogenes* and *Staphylococcus aureus*. If wounding resulted in the breaching of the gastrointestinal (GI) tract, the bacteria that constitute the GI

TABLE 2. Challenges in Deployed Medical Treatment Facilities That Potentially Impact Infection Prevention and Control Efforts

Challenge	Impact or Potential Impact
High personnel turnover rate	Limit institutional memory. Hospital personnel, including leadership, change at rates higher than permanent US facilities influencing any/all long-term programs.
Provision of care to local nationals and non-US personnel	Prolonged hospital stays. Options to transfer these patients to lower levels of care once stabilized may be limited by resources available in the community and risks to the individual patients in the local community.
Physical structure of medical treatment facilities	Use of preexisting structures not designed as modern hospitals results in space constraints including crowding, limited numbers of private rooms, and less than ideal configurations for optimizing infection control practice. Deployable structures (e.g., tentage) may make infection control challenging.
Environmental	Extremes of hot or cold temperatures, rain, snow, dust, and dust storms challenge design and operation of deployed facilities. Hostile environment add physical and operation challenges.
Logistical support chain	Receipt of supplies via a long supply chain which passes through hostile territory can result in temporary shortages of items or substitution with available but not identical items.

Adapted with permission from *J Trauma*.¹

flora could also contaminate wounds. Patients who survived past this initial insult were subsequently at risk for HAIs in hospitals established in, and outside of, the combat zone. The introduction of antimicrobials to help ameliorate these infections has been associated with the selection of bacterial pathogens resistant to these antimicrobials.

Natural History

In World War I, Sir Alexander Fleming described three stages of wound bacterial flora/infection. The first stage (days 1–7) is characterized by foul-smelling, watery discharge and predominantly sporulating anaerobes (likely clostridia) and streptococci. The second stage (days 8–20) is characterized by purulence and pyogenic cocci. The third stage (>20 days from wounding) is oftentimes identified with simple infection by streptococci or staphylococci.⁵ This was verified and further defined by studies of war wound bacteriology in World War II. Studies during that war found that although pyogenic organisms (*S. pyogenes* and *S. aureus*) were only rarely (5–6%) recovered from wounds at hospital admission, those bacteria were common causes of wound infection, infecting >50% of wounds, after 1 week, and increased up to 70% to 90% thereafter.⁶

Influence of Antimicrobials

With the institution of topical and later systemic postinjury antimicrobial therapy (prophylaxis) during and after World War II (in addition to early surgical debridement and

irrigation), bacteria resistant to these antimicrobials, especially gram-negative bacteria, have filled the niche previously occupied by soil anaerobes and skin streptococci and staphylococci. The postinjury use of penicillin and streptomycin during the Korean War was associated with 83% and 85% resistance, respectively to these antimicrobials, in bacteria recovered from infections diagnosed upon transfer to the US military hospital in Japan.⁷ A study conducted during the Vietnam War documented a transition of wound bacteria from those typically found on skin to predominantly gram-negative bacteria, most commonly *Pseudomonas aeruginosa*, by day 5 after injury.⁸

Multidrug-Resistant Bacteria Colonization and Infection of Wounds

Numerous reports have documented the epidemiology of colonization and infections associated with the recent conflicts in Iraq and Afghanistan.^{9–12} Multidrug-resistant (MDR) gram-negative bacilli, including *Acinetobacter baumannii-calcoaceticus* complex, extended-spectrum β -lactamase (ESBL)-producing Enterobacteriaceae (e.g., *Escherichia coli* and *Klebsiella pneumoniae*), *P. aeruginosa*, and methicillin-resistant *S. aureus* (MRSA), have most commonly been reported as the cause of these infections.^{12–14} Over the past decade, carbapenem susceptibility has dramatically declined in *Acinetobacter* isolates recovered from those personnel injured in combat in Iraq and Afghanistan.^{12,15} Accumulated data support nosocomial spread of these MDR bacteria within deployed MTFs and likely throughout the military healthcare system (Fig. 1). With the exception of MRSA, it does not appear that US personnel are colonized with these bacteria before injury. Colonization with community-associated MRSA has been documented in healthy military personnel and is a potential source of later infection.^{16–18} Preinjury colonization by resistant gram-negative bacteria in military personnel, specifically *Acinetobacter*, has not been found in small studies of de-

ployed and never (pre-) deployed troops.^{19–21} MDR bacteria have also not been found contaminating wounds at the time of admission to these deployed facilities.²² Introduction of resistant bacteria into deployed MTFs through care provided to host nation and other non-US patients is a concern and likely source of colonization leading to later infection of our combat-injured personnel. Studies conducted in deployed MTFs have found associations between MDR bacteria and host nation patients as well as associations between duration of host nation patient intensive care unit stay.^{23,24} Two studies conducted to specifically examine the possibility that local nationals were a source of MDR pathogens documented MDR colonization or infection of both Iraqi²⁵ and Afghan²⁶ patients around the time of admission to US military MTFs.

Globally, reports of the spread of ESBL organisms and more recently, carbapenem-resistant organism, like the New Delhi Metallo- β -lactamase-1 strains originating in the Indian subcontinent, have raised grave concerns of the expansion of resistance among gram-negative bacteria and spread of these MDR bacteria outside of the healthcare setting and into the community at large.²⁷ Indeed, a New Delhi Metallo- β -lactamase-1 strain has been recently recovered at the US military Role 3 hospital in Bagram, Afghanistan, in an Afghan patient admitted with burn injuries.²⁸ Asymptomatic carriage in the GI tract by healthy persons is also a potential source of MDR pathogens. A recent study of asymptomatic travelers from Sweden found GI tract colonization with ESBL bacteria in an unexpectedly large number (24%).²⁹

HEALTHCARE-ASSOCIATED INFECTIONS IN MILITARY HOSPITALS

In the late 1700s and early 1800s, hospitals were known for their malodorous stench from infected wounds and dead bodies. Wounds from both trauma and surgery were all expected to become purulent. The production of pus was

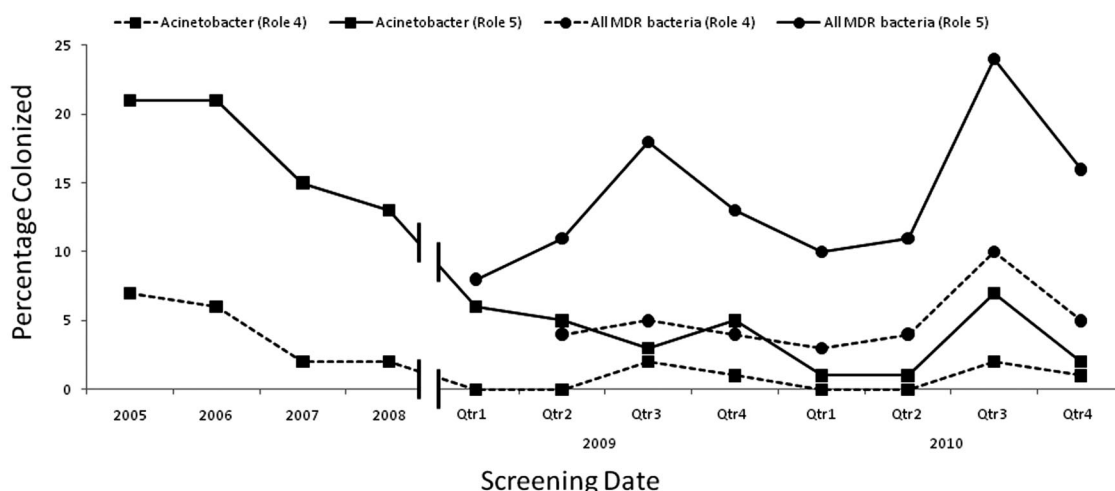


Figure 1. Colonization of injured US personnel upon arrival to Landstuhl Regional Medical Center (Role 4) from the combat zone and at three continental US medical centers (Role 5; Brooke Army Medical Center, National Naval Medical Center, and Walter Reed Army Medical Center) after transportation from Germany. Note: admitted personnel were only screening for *Acinetobacter* carriage from 2005 to 2008. Thereafter, admitted personnel were screened for all multidrug-resistant (MDR) bacteria.

considered an essential part of the healing process. This idea of “laudable pus” had been around since the time of Galen (circa 130–200 AD).³⁰ Hospitals around the turn of the 18th century commonly had open wards with large beds that were occupied by multiple patients.³¹ Bandages were reused, and the wounds of multiple patients were “cleaned” with the same sponge and water. HAIs have been recognized for >150 years. Described as “hospital infections”, “added infections”, and more recently, “nosocomial infections”, Sir James Simpson used the term “hospitalism” in his 1867 publication.³² Detailing the serious infections that plagued hospitalized patients of the time, Simpson reported data comparing the mortality in hospitalized and nonhospitalized patients. An example of these data is his report of 41% mortality following amputations performed in hospitals versus a noted 11% mortality with the same procedure performed in “country practice.” During the American Civil War, most injured personnel who survived to hospital care died of infection, including tetanus, hospital gangrene, erysipelas, and pyemia.³³ Hospital gangrene and erysipelas were recognized at that time as contagious, and recommendations were made for cleanliness, ventilation, and against overcrowding. Both hospital gangrene and erysipelas are now postulated to be secondary to streptococcal infection.

In 1940, Miles et al.³⁴ described the epidemiology of microbiology of war wounds in hospitalized patients. Their description of “hospital infection—infection of the tissues with pathogenic microbes derived from the hospital environment” was supported by studies of serial wound cultures that documented changes in wound colonization/infection over time.^{34,35} They identified colonization of hospital personnel with *S. aureus* in the nose and *S. pyogenes* in the nose and throat as likely sources of hospital wound infections. They also showed that wound pathogens (chiefly staphylococci and streptococci) could be found in the air of wards full of wounded soldiers, which they postulated were from cleaning, changing sheets, and wound care (dressing changes).³⁶ In addition to the hospital air, they identified fingers, instruments, dressings, baths, bed-pans, and urine bottles as likely sources of hospital infection.

RESPONSE TO HEALTHCARE-ASSOCIATED INFECTIONS: HISTORY OF INFECTION PREVENTION AND CONTROL PRACTICES

Hand Hygiene

Although Hippocrates provided comment on the proper length of a surgeon’s fingernails, neither too long nor too short,³⁷ it was Ignaz Semmelweis (1818–1865) who is credited with proving a direct connection between hand hygiene and HAIs. After noting the large difference in mortality rates of women dying from puerperal sepsis when delivered by physicians and medical students compared with midwives, Semmelweis deduced this might be because the groups differed in that the physicians and medical students performed the autopsies on the women who died of this complication.³² Introduction (and enforcement) of hand cleansing with a hypochlorite solution (chloride of lime) after performing

autopsies dramatically decreased mortality from puerperal sepsis in women delivered by physicians and medical students, comparable to the rate of midwives. Although the importance of hand hygiene became accepted before his death in 1865, strict adherence to hand hygiene remains a difficult goal to achieve even in modern hospitals in the 21st century.

Environment (Hospital) Hygiene/Sanitation/Outcome Data Monitoring

Although not a believer in the germ theory, or that infection could be passed on the hands of healthcare providers, Florence Nightingale is held in the greatest esteem by the infection prevention and control community for her efforts in both hospital hygiene/sanitation reform and meticulous record keeping and application of statistics to support interventions. Sent by the British Army to Crimea in 1854, Nightingale’s work to improve sanitation at the Scutari Hospital led to a drop in the hospital’s mortality rate from 42% to 2%, between February and June 1855. This included environmental cleaning, provision of adequate food (i.e., improving patient nutrition), clothing, and bedding, and insistence on the maintenance of nursing staff personal hygiene.³² She is quoted as saying, “Every nurse ought to be careful to wash her hands very frequently during the day. If her face too, so much the better.”³² Nightingale dedicated her life to sanitary reforms in the British military and United Kingdom.

The US Sanitary Commission was established in 1861, at the start of the American Civil War, to improve medical conditions within the military hospitals of the time.³³ It was recognized by that time that hospital cleanliness was necessary to allow recovery and wound healing. In addition to trying to maintain high standards of cleanliness/sanitation/hygiene, the use of bromide spraying into the air to stop erysipelas outbreaks was employed. After major outbreaks of hospital gangrene in 1862 to 1864, use of immediate patient isolation and basic sanitary precautions (dedicated patient sponge, toiletry items, and eating utensils) resulted in no further outbreaks of this infectious disease.³³ Use of individual patient sponges and basic sanitary conditions were suggested to decrease the incidence of pyemia (wound sepsis). Despite these efforts by the Sanitary Commission, it is interesting to note that surgeons during the American Civil War did not regularly wash their hands or surgical instruments.

Antisepsis and Asepsis

Joseph Lister (1827–1912) advanced the idea of antisepsis to surgery in 1867.³¹ Supported by the discoveries of Louis Pasteur (in the 1850s–1860s) that germs (bacteria) were the cause of putrefaction (pus production), Lister promoted the use of carbolic acid solutions to improve surgical safety. During the American Civil War, three studies conducted using antiseptics (bromide, turpentine, and nitric acid) showed reduction of mortality from hospital gangrene. Specifically, one study reported <3% mortality in 308 patients treated with bromide for hospital gangrene (compared with 43% mortality in 30 untreated patients).³⁸ Before the Listerian era, surgical instruments were not even routinely cleaned, often simply wiped off between uses.³¹ Suture was

often carried in the surgeon's pocket. Antiseptic surgery became virtually universal between 1870 and 1890. Heat sterilization of surgical instruments was introduced by Ernst von Bergmann in 1891.³⁰ In 1915, Keen reported, "Instead of hospitals reeking with pus and emptied by death, ... we have hospitals of immaculate whiteness and emptied by quick recovery."³⁹

Surgical Attire and Personal Protective Equipment

Sterile surgical caps and gowns were introduced in 1883 by Neuber and masks in 1897 by Mikulicz.³⁰ Gloves, initially used to protect the surgical nurse's hands from the antiseptic chemicals used in surgery, were adopted around the turn of the century (1890s–1900s) when it was noted that their use was also associated with lower rates of postsurgical infections (Fig. 2).⁴⁰ To interrupt the spread of infection among the war wounded, Miles et al.³⁶ espoused use of masks, dressing of wounds with clean dry hands and using sterile instruments, removal of dressings and plasters with minimum disturbance, and care of the hospital environment to minimize dust and disinfect key surfaces (e.g., baths). McKissock et al.⁴¹ reduced infections in head wounds from 30% to 2% with use of aseptic dressing changes and dedication and disinfection of patient personal and care items.

Isolation and Cohorting

Cohorting of patients with similar infectious processes was used during the American Civil War to prevent spread of disease such as erysipelas to other patients. Miles reported that the risk of infections associated with wounds was greatly reduced by the practice of antiseptics and asepsis and of the segregation of grossly infected cases.^{34,35}

Mobile Surgical Hospitals and Deployed Research Laboratories

In World War I, Antoine Depage (1862–1925) helped advance combat wound management through reintroduction

of debridement, use of delayed wound closure based on microbiology sampling, and organization of mobile surgical units.^{42,43} Alexander Fleming performed microbiologic studies of the war wounded in laboratories associated with Depage's hospital. This idea of a deployed research cell to support the advancement of combat casualty care was used by the United States during the Vietnam War and most recently in Iraq and Afghanistan.

INFECTION PREVENTION AND CONTROL IN THE DEPLOYED SETTING

The effective practice of infection prevention and control in the deployed setting holds all the challenges that are present in fixed Western hospitals, but also must meet the unique challenges of the combat zone. The challenges unique to the deployed setting have been described in recent reviews, including in conjunction with specific combat zone reviews of infection control practice and challenges conducted in 2008 and 2009.^{1–3} From these reviews, specific areas for improvement have been identified (Table 3).

Emphasis on Infection Prevention and Control Basics

Success of an effective infection prevention and control program in a deployed hospital hinges on the same factors as

TABLE 3. Specific Infection Control Areas Identified for Improvement in Deployed Hospitals and Recommendations

Area Identified for Improvement	Recommendations for Improvement
IC expertise	• Provide improved predeployment ICO training through use of AMEDD C&S short course or other established courses • Establish theater-level IC consultant • Use outside experts to assist via electronic (teleconferencing, email) and in-theater reviews • Require facilities to develop annual IC plans and summaries
Emphasis on basic IC measures	• Establish hand hygiene programs with command emphasis and compliance monitoring • Apply transmission-based (isolation) precautions when MDRO colonization or infection is suspected or proven • Use patient cohorting to separate short-term and long-term patients
Use of standardized procedures and guidelines	• Establish theater-level IC SOPs • Apply national (US) guidelines to prevent and treat HAIs • Monitor guideline compliance
Antimicrobial control	• Emplace antibiotic control programs • Use national (US) and other guidelines to limit duration and overuse of broad spectrum antibiotics • Continue to expand in-theater microbiology capabilities and establish antibiograms for individual facilities

IC, infection control; AMEDD C&S, Army Medical Department Center and School; MDRO, multidrug-resistant organisms; SOPs, standard operating procedures. Adapted with permission from *J Trauma*.^{1,3}

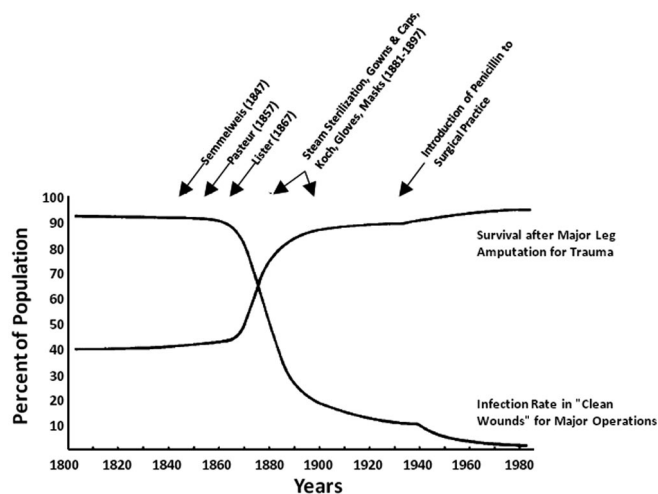


Figure 2. Impact of aseptic surgery and other infection prevention and control practices on postsurgical infections and survival. Reproduced with permission from *Ann Surg*.³¹

in modern fixed facilities anywhere. These include emphasis by all personnel, education and reeducation of healthcare providers, and emphasis and oversight by the MTF leadership. Standard precautions should be used to prevent the transmission of pathogens from both recognized and unrecognized sources. The major component of standard precautions is hand hygiene (i.e., washing or cleansing hands before and after every patient interaction). Other components include the use of personal protective equipment (gloves, gowns, masks, and eye protection) when indicated. Although the importance of hand hygiene has been stressed for more than 100 years, maintaining high levels of compliance in even modern, well-funded Western hospitals has continually proven difficult.⁴⁴ In the deployed setting, with less than ideal

facilities and sometimes limited resources, hand hygiene compliance is an even bigger challenge. With the recent emergence of waterless hand sanitizers, lack of or limited availability of water should no longer prevent the performance of hand hygiene. As with all infection prevention and control, the key to success in promotion of this essential keystone is emphasis, education, and leadership. Hand hygiene programs with compliance monitoring should be established in all deployed MTFs.

Another fundamental infection prevention and control tenet, use of transmission-based (isolation) precautions, must also be used in all deployed MTFs. Using contact, droplet, and airborne precautions in the deployed setting can pose a much greater challenge than that of basic hand hygiene

TABLE 4. Isolation Precautions to Prevent Transmission of Infections in Deployed Hospitals

Isolation Category	Patient Placement	Provider PPE
Contact—infection transmitted by direct contact with the patient or indirect contact with environmental surfaces or patient care items. Examples include MDR bacteria and diarrheal disease	Best: private room	Best: disposable gown and gloves for all interactions that may involve contact with the patient or potentially contaminated areas in the patient's environment. Changing PPE and hand hygiene between patients
	Good: bed separated from other patients by >3 feet	Good: gloves with removal and handwashing after each patient contact
Droplet—infection transmitted by droplets (can be generated by cough, sneeze, talking, or the performance of procedures). As these pathogens do not remain infectious over long distances special air handling and ventilation are not required. Transmitted via conjunctiva, nasal and oral mucosa. Examples include meningococcus, diphtheria, mumps, pertussis, influenza, and adenovirus	Best: private room	Best: surgical mask when entering room
	Good: cohort with other patients with same symptoms. Spatial separation of >3 feet with curtain between patient beds. If no curtains, consider keeping the patient 6–10 feet away from other patients	Good: surgical mask within 6–10 feet of the patient Note: Patient should wear surgical mask during transport. Request patients to cough/sneeze into tissue
Airborne—infection transmitted by airborne nuclei or small-particles of the size that can be deeply inspired. These particles can remain infective over time and distance (can be dispersed widely by air currents within a room or over a long distance). Examples include TB, varicella virus (chickenpox and disseminated shingles), smallpox, and rubeola (measles)	Best: private room with negative-air pressure, discharge of air to the outdoors or through high-efficiency filtration before recirculation. The door to the room must remain shut	Best: wear of N95 respirator at all time when in patient room or immediate environment. Personnel should be fit tested using the brand/model N95 respirator used at the facility
	Good: private room with a fan exhausting outward. The door to the room must remain shut Note: If no private room available, place patient as far as possible away from other patients in a well ventilated room with a physical barrier around the patient. Make sure patient is not near air intakes. Ideally, these patients should not be admitted to facilities without a negative pressure rooms. Consider housing them in private quarters outside the hospital and examining them outside in the sunlight	Good: wear of N95 respirator as above without fit testing Note: Patient should wear surgical mask (not N95 respirator) during transport
Cohorting—when individual patient rooms are not available, patients with the same infection or presumed infection/colonization pattern can be housed in the same room or grouped in the same area of an open ward (if airborne pathogens are not suspected). Examples include influenza and varicella virus (chickenpox). In the deployed setting, this can be applied to patients with presumed MDR bacterial colonization based on duration of hospitalization. An arbitrary time of 72 h has been promoted by this group.	Use above based on expected pathogen(s)	Use of above based on expected pathogen(s)

PPE, personal protective equipment.

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(Table 4). Patient segregation may be limited by the size and design of the buildings, portable hospital modules, or tentage used by any individual MTF. Lack of private rooms should not prevent the use of contact or droplet precautions. Physical barriers (e.g., empty beds) or markers (e.g., red duct tape delineation or construction cones on the floor) can be used to ensure adequate separation of patients. Use of airborne precautions in the deployed setting without properly engineered rooms poses the most difficult isolation challenge. Use of a private room with a strong fan pulling air to the outside is a potential work around within the MTF.⁴⁵ Establishing a patient care area outside the main MTF structure in a tent or isolated building/housing unit may provide more protection for other patients and staff.

As was done in the American Civil War, cohorting of patients presumed to have the same infection is a viable option during outbreaks (e.g., diarrhea, dysentery, and influenza). As described in previous articles, cohorting can also be used to separate patients at high risk for colonization with MDR pathogens from recent admissions unlikely to be carrying these bacteria. Therefore, it is suggested that newly admitted patients, especially those with open wounds, be separated (physically and by assigning designated nursing and other care team staff) from those patients who have been admitted for >72 hours.

The simple system described by Spaulding⁴⁶ in 1968 continues to underlie the practice of disinfecting and sterilizing hospital equipment and surfaces. Using this system, patient care and contact items are divided into critical, semicritical, and noncritical. Critical items include those that enter sterile tissue or the vasculature. These items should be purchased sterile or steam sterilized if possible. Semicritical items are those that come into contact with mucous membranes or nonintact skin. These items require high-level disinfection using US Food and Drug Administration (FDA) cleared chemical disinfectants. FDA-cleared high-level disinfectants include glutaraldehyde (e.g., Cidex), ortho-phthalaldehyde (e.g., Cidex OPA), hydrogen peroxide (e.g., Sporox), and peracetic acid (e.g., STERIS 20) based products. All other items fall under the category noncritical. These items can (and in the United States must) be cleaned with US Environmental Protection Agency (EPA) registered products. Low level EPA-registered products include quaternary ammonium, phenolic, and iodophor-based products, including Wexcidex, Cavicide wipes, and Chlorox. Disinfection and sterilization should be performed based on national and professional society guidelines.⁴⁷

Enhancing Deployment Infection Control Expertise

Because of the transient nature of staffing in deployed MTF, maintenance of an effective infection prevention and control program can be difficult. Personnel inexperience in the deployed setting and the lack of available trained infection control personnel can also pose challenges. With the large scale and duration of the US efforts in Iraq and Afghanistan, the need for infection control officers (ICOs) has been much greater than their availability. Reviews of deployed MTF in both 2008 and 2009 found this shortage of ICOs to

be one of the most significant deficiencies.^{1,3} Because of this identified issue, a 5-day infection control in the deployed setting course was established to provide basic training to personnel identified to serve as ICOs.⁴⁸ In the fall of 2010, assignment of an adequately trained ICO was made a US Army requirement for each deployed Role 3 location. In addition to the development of this short course, a universal standard operating procedure template was developed for use in the deployed MTF and supporting electronic resources produced.³ These electronic resources include an Army Knowledge Online teleconsultation service that is monitored by US military infection control experts and internet resources (www.afids.org/links3.htm), which include links to key infection prevention and control and HAI management documents.

Antimicrobial Stewardship

Because of the association between the use of broad-spectrum antimicrobials and the development/selection of bacterial resistance, antimicrobial stewardship is also a key in decreasing colonization and infection with MDR bacteria. Limiting the use (and duration) of overly broad-spectrum antimicrobial agents can be encouraged by the use of treatment and prevention guidelines and through the availability of clinical microbiology. The timely availability of culture results, including antimicrobial susceptibility, is essential in tailoring antimicrobial usage (i.e., decreasing use of overly broad-spectrum empirical coverage) in deployed MTFs. Without the availability of clinical microbiology support, de-escalation of empirical broad-spectrum antimicrobial coverage is not possible. Use of guidelines and locally derived antibiograms are also important adjuncts to guide the appropriate use of antimicrobials. Stewardship programs can also include use of admission order overprints with specific antimicrobial selections, drug utilization evaluations, and antibiotic use approval programs.

Improvement of Epidemiology of Colonization and Infection

Wounded US military personnel are currently screened for colonization with MDR bacteria at admission to Role 4 and 5 MTFs (Fig. 1).¹⁰ This testing provides data on the epidemiology of MDR colonization of wounded personnel as they arrive from the combat zone and after transportation to the continental US. The Multidrug-resistant Organism Repository and Surveillance Network was established in 2009 to further evaluate MDR bacteria and their associated epidemiology.^{49,50} Both these programs can provide feedback to medical leaders in the combat zone on new and ongoing MDR threats.

RESEARCH GAPS

Many areas of research are greatly needed to further reduce the rates of infections in deployed hospitals. These include research into the epidemiology of the pathogens that cause HAI in this setting, pathogen detection, patient decolonization, and environmental disinfection. To further direct preventive measures, data are needed to better delineate the epidemiology of the pathogens involved in combat-injury-

related infections, specifically the role of cross-contamination with these organisms within deployed MTFs and during the transportation of the injured between facilities. Colonization screening within deployed MTFs would use valuable resources but is worth exploring. Admission and interval screening of local national patients, especially those transferred from other healthcare facilities, may be the best place to start. More rapid detection, identification, and analysis of antimicrobial susceptibility could help guide antimicrobial selection and infection prevention measures, as well as limit broad-spectrum antimicrobial use. The usefulness and effectiveness of patient cleansing/decolonization merits further study. Patient cleansing with chlorhexidine cloths is currently recommended in US military theater guidelines.⁵¹ The impact of this intervention in decreasing MDR colonization and later infections has not been analyzed and published. The use of chlorhexidine in similar settings in civilian practice has produced mixed results;^{52,53} more research is needed. Evaluation of selective oral and digestive decontamination is also an area that merits further research in this setting. Although hospital cleaning programs, with approved disinfectants, have long been established, there are many novel technologies (e.g., vaporized hydrogen peroxide and ultraviolet light) that continue to be developed which could potentially be adopted to disinfect the sometimes unique structures of the deployed MTF. Studies on the effectiveness of most of these technologies are not readily available, and no studies of their use in the setting of the deployed MTF have been conducted.

CONCLUSIONS

Although numerous challenges are present in the deployed setting, practice of infection prevention and control should mirror that performed in hospitals outside the combat zone whenever possible. Practice should follow US and international guidelines and standards, although some modifications may be necessary based on local facility design, logistical challenges, personnel availability and skills, security, and environmental concerns.

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