

Prevention and Management of Infections Associated With Combat-Related Thoracic and Abdominal Cavity Injuries

Nicholas G. Conger, MD, Michael L. Landrum, MD, Donald H. Jenkins, MD, R. Russell Martin, MD, James R. Dunne, MD, and Erwin F. Hirsch, MD

During wartime, abdominal and thoracic trauma constitutes approximately 20% of combat-related injuries. Rates of infection vary based upon organ of injury with the highest rates noted for trauma to the colon. This review focuses on the management and prevention of infections related to injuries of the thoracic

and abdominal cavity. The evidence upon which these recommendations are based included military and civilian data from prior published guidelines, clinical trials, where available, reviews, and case reports. Areas of focus include antimicrobial therapy, irrigation and debridement, timing of surgical care,

and wound closure. Overall, there are limited data available from the modern battlefield regarding the prevention or treatment of these infections and further efforts are needed to answer best treatment strategies.

Key Words: Combat, Trauma, Abdomen, Thorax, Infection.

J Trauma. 2008;64:S257–S264.

Abdominal injuries are seen in 7% of wartime trauma, and thoracic trauma in 9% to 15% of casualties, 90% of which are penetrating.¹ The nature of these wounds sustained during wartime can be quite different from those that present to civilian trauma centers. Several studies suggest that historically, thoracic trauma from combat injuries pose a higher risk for secondary infection. For example, studies on thoracic injuries from World War II showed an infection rate of 5% to 9%,^{2,3} whereas a comparable civilian study from the same time frame only had a 3% infection rate.⁴ There are several distinct features of wartime trauma, which must be considered, such as the impact from the blast component. It is also not uncommon for the modern wartime medic to see trauma patients with a combination of blunt and penetrating trauma, both high and low velocity, with significant blast

effect and associated burns.^{1,5–7} In addition, injuries sustained during military conflicts may have a more significant delay before definitive surgical care.⁸ Because of these reasons, trauma seen in civilian hospitals may not be comparable to injuries sustained in combat. These factors contribute to the complexity of abdominal and thoracic wartime trauma, and the difficulty in making treatment decisions in an effort to prevent and manage infections associated with them. Specific data from the modern battlefield regarding antimicrobial therapy after abdominal and thoracic trauma and treatment of subsequent infections have not been published. Therefore, we sought to perform a comprehensive review of the civilian trauma literature and combine those results with our clinical expertise in managing wartime injuries to present recommendations, evidence-based whenever possible, to ideally prevent and manage subsequent infections.

Infection after penetrating abdominal trauma has been a common complication during war, with the first detailed reports from World War I during which mortality rates from colon injury ranged from 60% to 75%.^{9,10} During World War II, high rates of intra-abdominal infection and mortality after abdominal trauma, specifically colonic trauma, resulted in the US Surgeon General and others mandating colostomy for the management of such injuries.^{11,12} More recent data from civilian trauma centers revealed the overall rate of postoperative infection after penetrating abdominal trauma to be approximately 30% if antibiotics were administered postoperative, and up to 70% for those with colon injury.^{13,14} Data from the current operations in Iraq and Afghanistan have recently been reported. From September 2003 to December 2004, 3,442 patients were treated at the 31st Combat Support Hospital, of which 175 (5.1%) had colorectal injuries.¹⁵ Penetrating trauma accounted for 168 (96%) of these injuries, and 27 patients (16%) developed sepsis. Patients with colorectal injuries had a mortality of 18%, compared with 8% in those without ($p < 0.001$). In a smaller series of 211 patients

Submitted for publication November 29, 2007.

Accepted for publication November 30, 2007.

Copyright © 2008 by Lippincott Williams & Wilkins

From the Department of Medicine (N.G.C.), Infectious Disease Service, Landstuhl Regional Medical Center, Ramstein Air Force Base, Germany; Infectious Disease Service (M.L.L.), San Antonio Military Medical Center, Fort Sam Houston, Texas; Infectious Disease Clinical Research Program (M.L.L.), Bethesda, Maryland; Department of Surgery (D.H.J.), Wilford Hall Medical Center, Lackland Air Force Base, Texas; Department of Surgery (R.R.M.), Brooke Army Medical Center, Fort Sam Houston, Texas; Trauma/Critical Care Division (J.R.D.), National Naval Medical Center, Bethesda, Maryland; and the Department of Surgery (E.F.H.), Boston University School of Medicine, Boston, Massachusetts.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of the Air Force, Department of the Army, Department of the Navy, Department of Defense or the US Government. This work was prepared as part of their official duties and, as such, there is no copyright to be transferred.

Address for reprints: Nicholas G. Conger, MD, USAF, MC, Infectious Disease Department, Landstuhl Regional Medical Center, CMR 402 Box 1297, APO AE 09180, Germany; email: Nicholas.Conger@amedd.army.mil.

DOI: 10.1097/TA.0b013e318163d2c8

admitted to the USNS Comfort from March to May 2003, 56 patients (27%) were infected, and three (1.4%) died.⁸ Of the 39 patients with abdominal wounds, 17 (43%) became infected. Similar to other reports,¹⁶ the vast majority of bacteria were gram-negative organisms, with *Acinetobacter* spp. accounting for 33%.

Risk factors for secondary infection of the abdominal cavity after trauma depend on both the location of the injury and the condition of the host. Identified risk factors for trauma-related postoperative infection include need for blood transfusion, higher penetrating abdominal trauma index score, and injury to the colon.^{15,17-20} Although isolated colonic injury has long been associated with higher risk for secondary infection, a recent study showed that colonic injuries with concomitant gastric trauma are associated with even higher rates of infection.²¹ In addition, for patients with pancreatic or duodenal trauma, the presence of the pancreatic injury was responsible for the increased risk of infection.²² Lastly, one additional factor unique to modern, urban war-time trauma care, which may impact upon the rate of infection is the potential delay from the time of injury until initial surgical and medical care.⁷

Bacteria responsible for colonization and subsequent infections from abdominal injuries depend on the particular injured organ or viscous structure disrupted.²³ Bacteria that colonize the stomach through the proximal small bowel (including the biliary system) include primarily gram-positive and some gram-negative aerobic and facultative organisms, whereas the distal small bowel has gram-negative aerobic and facultative organisms as well as some anaerobes such as *Bacteroides fragilis*. Colonic commensals include facultative and obligate anaerobes to include streptococci and enterococci. Overall, *Escherichia coli* is the most prominent pathogen in patients with complicated intra-abdominal infection (cIAI).^{23,24} In postoperative patients, the risk of colonization and subsequent peritonitis with nosocomial drug-resistant pathogens, such as *Pseudomonas aeruginosa* increases over time.^{23,25} Therefore, the agents recommended for treatment of postoperative infections are broader spectrum, in general, compared with those used for perioperative prophylaxis.

Thoracic infection within the pleural space after thoracic trauma has been studied in previous conflicts similar to infection after abdominal trauma. As noted above, during World War II, with the advent of antibiotics, empyema was reported to occur in approximately 5% to 10%.^{2,3} During the Vietnam war approximately 2% of patients developed empyema after thoracic trauma.²⁶ More recently, data from Operation Iraqi Freedom (OIF) revealed that injuries to the thorax account for approximately 5% to 10% of wounds.^{5,6,8} In the previously mentioned series of 211 patients admitted to the USNS Comfort, 30 patients (14%) suffered an injury to the chest, seven (23%) of which were associated with an infection, although the specific types of infection (i.e. empyema, pneumonia, bacteremia, extremity wound, etc.) were not reported.⁸

The greatest risk factor for infection of the thoracic space after trauma is retained hemothorax.^{27,28} Studies from the Korean war demonstrated up to 26% of undrained hemothoraces eventually became infected.²⁸ More recent data from civilian trauma centers show approximately 1% to 10% of patients requiring tube thoracostomy develop empyema.^{27,29-31} Other risk factors cited for empyema after chest tube placement include persistent pleural effusion, presence of pulmonary contusion, need for multiple chest tubes in the same hemithorax, higher thoracic acute injury score, and prolonged duration of chest tube use.^{30,32} Mechanism of injury is also an important risk factor, with penetrating injury, especially from a gunshot wound, associated with empyema, and blunt trauma and lung contusion associated with pneumonia.^{29,33,34} Other studies describe patients in shock, unconscious on arrival, or injury sufficient to require splenectomy as risk factors for infection.³⁵ In general, the identified risk factors all point toward a direct relationship between increasing severity of thoracic injury and risk of empyema.

Various bacteria are responsible for infections after thoracic trauma, including gram-positive organisms, anaerobes, and gram-negative pathogens.^{4,29} In most reports, *Staphylococcus aureus* is the most common bacteria found, isolated from 35% to 74% of patients.^{29,30,32} In the case of empyema thoracis, if the infection originates from the initial entry point or local area, then skin organisms, primarily staphylococcal and streptococcal bacteria predominate. If the infection originates from the lungs, pulmonary pathogens, first community acquired and later hospital acquired or ventilator-associated organisms are seen. However, there is not always an obvious source of infection.²⁹ Additionally, the specific nosocomial pathogens may vary from one institution, or intensive care unit, to another. At times, infection may arise because of contamination of bacteria from an adjacent site, most notably the abdominal cavity because of concomitant penetrating abdominal trauma leading to enteric contamination of the thoracic space.³⁰ Flora associated with the hollow viscus that is damaged, as discussed above, should then be considered.

Prevention of Infection After Abdominal Trauma Antimicrobial Prophylaxis

The use of antimicrobials in preventing intra-abdominal infection (IAI) after operation for penetrating abdominal trauma has changed little in several decades. In 1972, Fullen et al.¹³ provided the seminal argument for the use of preoperative antibiotics before surgical intervention for penetrating abdominal injury, demonstrating that patients whose antibiotics were delivered preoperatively had a much lower (7%) rate of secondary infection than those who received antibiotics intraoperatively (33%) or postoperatively (30%).¹³ Subsequently, Thadepalli et al.¹⁴ showed that kanamycin paired with clindamycin was more effective than when paired with cephalothin, demonstrating the role for anaerobic coverage in preventing secondary infection. Thus, from the early 1970s it was shown that antibiotics, particularly a regimen that in-

cludes anaerobic coverage as well as aerobic coverage decreases subsequent infection. No placebo-controlled trials have been performed since, with most trials focusing on what is the most effective antimicrobial regimen.

Numerous studies in the subsequent years have evaluated different antibiotic agents and the optimal duration of therapy after abdominal trauma. Prospective, randomized trials have investigated penicillin, cephalosporins, clindamycin, aminoglycosides, doxycycline, and others, all in various combinations.^{36–41} Study sample sizes have varied from approximately 50 to 300 patients, with postoperative infection rates ranging from 2% to 36%. No one antibiotic agent or combination has been consistently proven to have superior efficacy as long as the spectrum of activity of the drug or combination covers the bacterial flora of the gastrointestinal tract. No study has clearly demonstrated decreased rates of postoperative infection with courses of therapy extended beyond 24 hours postoperation. In the largest prospective randomized trial evaluating the optimal duration of therapy, Fabian et al.⁴² showed no benefit to administering 5 days of cefoxitin or cefotetan compared with 24 hours. However, some argue that because this trial only included 111 patients with colon injuries the study was not able to definitively address the issue of prolonged antibiotic prophylaxis in those with the highest risk of infection. But other studies have also failed to demonstrate any benefit from prolonged therapy.^{43–45}

More recent investigations have yielded similar results. Sims et al.⁴⁰ randomized 291 patients to receive cefoperazone alone, ceftriaxone with metronidazole, or metronidazole with gentamicin and ampicillin for 1 to >5 days depending on the type of injury. Overall, postoperative infections developed in 15 patients, only two of which developed in patients randomized to ceftriaxone with metronidazole. Although there was no statistical difference between groups regarding the primary outcome, the study was underpowered, did not report differences in surgical management, and was confounded by varying lengths of therapy, so conclusions from the study are limited. Tyburski et al.²⁰ more recently compared metronidazole with either ciprofloxacin or gentamicin in 68 patients treated for 24 to 96 hours depending on the type of injury. Again, no difference was found in the rate of postoperative trauma-related infections, but the study was underpowered.

At least three recent randomized, prospective studies have evaluated the impact of duration of prophylaxis on postoperative infection rates. Investigators have reported no difference in efficacy of ampicillin/sulbactam¹⁸ or cefoxitin^{17,46} whether given for 24 hours or 5 days. In the trial comparing 1 versus 5 days of ampicillin/sulbactam, 317 patients were randomized, of which 162 had colon injuries.¹⁸ Twenty-nine patients (9%) developed surgical site infections, which were equally distributed between groups, despite the fact that patients randomized to only 1 day of prophylaxis had significantly more patients with multiple hollow viscus injuries. Cornwell et al.⁴⁶ studied cefoxitin for 1 versus 5 days in abdominal trauma patients at high risk of postoperative infection. To be eligible,

patients had to have full-thickness injuries to the colon with one of the following: penetrating abdominal trauma index >25, transfusion of six or more units of packed red blood cells, or be more than 4 hours from injury to operation. Similar to other studies, no reduction in risk of trauma-related postoperative infection was seen with prolonged prophylaxis. Unfortunately, because of the inclusion criteria, the study was small with only 63 patients and was underpowered by the authors' estimates.

Despite the Eastern Association for the Surgery of Trauma (EAST) guidelines and the available evidence, which does not support the prolonged use of prophylactic antibiotics after abdominal trauma, clinicians continue to prescribe perioperative antibiotics for more than 24 hours.¹⁹ This is particularly true in patients with colon or other hollow viscus injuries.^{17–19,46} However, there is now some evidence that in addition to lacking benefit, prolonged presumptive antibiotic therapy may be associated with harm.^{47,48} In a retrospective study of 151 trauma patients with nosocomial pneumonia, Hoth et al.⁴⁸ reported those with presumptive antibiotic therapy for more than 48 hours were more likely to have gram-negative organisms causing the first pneumonia, and more likely to have resistant organisms causing the first or second pneumonia. Similarly, in a prospective, observational study of 250 patients, Velmahos et al.⁴⁷ showed patients receiving prophylactic antibiotics for more than 24 hours were more likely to have a drug-resistant infection. These reports are concerning, but the data are not sufficient to support a definitive statement regarding the possible harm of prescribing a prolonged course of perioperative antibiotics for this guideline. However, clinicians should consider the potential risks and benefits of such a course of therapy before its administration.

It is difficult to form conclusions from the trials of perioperative antibiotic use after abdominal trauma because of the lack of uniformity in regard to mechanism and severity of injury, surgical intervention, antibiotic regimens, dosages, and duration. Furthermore, standard definitions of postoperative infections and degree of peritoneal contamination have not been used, and the majority of studies have been underpowered. A review in the late 1980s and another in 2000 concluded that although preoperative antibiotics are beneficial, there can be no definitive recommendation for a preferred prophylactic antimicrobial regimen for penetrating abdominal injuries.^{36,49} Our literature review found no evidence since 1996 that adds significantly to those conclusions. In the military trauma system, the initial site of surgical care (Level IIb or III facility) will likely perform the first laparotomy. In respect to antimicrobial therapy, we recommend the following for patients with penetrating abdominal trauma: presumptive antibiotic therapy preoperatively alone or perioperatively started preoperatively and extended no more than 24 hours with sufficient gram-negative enteric and anaerobic coverage for patients with hollow viscus injury (AI) (grading outlined in this supplement of *Journal of Trauma*: "Guidelines for the Prevention of Infection After Combat-Related Injuries"). Antibiotics should not be extended beyond this time as prolonged duration does not add

benefit (BI). Recommendations for intratheater antibiotics include cefoxitin (if available), or moxifloxacin 400 mg i.v. × 1 as a single agent, or levofloxacin in combination with metronidazole or ciprofloxacin in combination with metronidazole (AI). It is recommended that carbapenems not be used at this level as these drugs and their drug classes should be saved to treat potential future drug-resistant organisms (CIII).

Surgical Management

The optimal surgical approach to the management of penetrating abdominal trauma is beyond the scope of this guideline. Many lessons have been learned by our surgeons performing surgery in Level IIB/III facilities to stabilize patients for further and more definitive surgical care at a Level IV or V facility. First, the standard of care should be followed, such as the appropriate debridement of all nonviable and heavily contaminated tissue, and the use of copious irrigation. At least 6 L of irrigation is recommended (BIII) as recent prophylactic antibiotic trials for patients with abdominal trauma have used 6 L or more of saline irrigation before closing the abdomen.^{18,46} In addition, early primary repair of complex or destructive colonic injuries is not recommended (BII), especially if associated with massive blood transfusion, ongoing hypotension, hypoxia, reperfusion injury, multiple other injuries, high-velocity injury, or extensive local tissue damage.¹ However, simple, isolated colon injuries may be repaired primarily (AI).^{1,15,50,51} In one series of 175 colorectal injuries from OIF, primary repair was used for 55 patients (34%), and resection with anastomosis was used for 31 patients (19%). Of the 86 patients managed without stoma placement, 11 (13%) developed a leak, but on multivariate analysis this had no impact upon sepsis or mortality. Skin should not be closed if there is a colon injury or extensive devitalized tissue because of excessive infectious complications (BIII). Wound vacuums should be utilized in theater and placed to closed suction (CIII); however, the safety of the use of suction devices in flight is currently under investigation.

Immunization After Splenectomy

Overwhelming sepsis is a well-recognized risk for patients with splenectomy after abdominal trauma. Although the lifetime incidence has been estimated to be <2%, the associated mortality is higher than 50%.^{52,53} Therefore, despite limited data regarding efficacy, surgeons have, in general, advocated immunization for these patients. Guidelines for vaccination after traumatic injury were recently published by the Surgical Infection Society.⁵⁴ Because of the risk of overwhelming infection all patients who have undergone splenectomy after traumatic injury should be immunized with 23-valent pneumococcal polysaccharide vaccine (CIII), meningococcal conjugate vaccine (CIII), and *Haemophilus influenzae* type b conjugate vaccine (CIII) all within 2 weeks of splenectomy. The optimal timing of vaccination is not clear and highly debated. One study reported improved opsonophagocytic antibody function in those immunized with pneu-

mococcal vaccine at 14 days after surgery, compared with either 1 or 7 days after surgery.⁵⁵ Unfortunately, nonspecific cross-reactive antibodies were not removed as part of the protocol, and in a follow-up study by the same group antibody responses were similar to healthy controls after removing cross-reactive antibodies regardless of whether the vaccine was administered at 14 or 28 days after surgery.⁵⁶

Prevention of Infection After Thoracic Trauma

Surgical management to prevent infection from thoracic trauma involves prompt lung expansion usually via tube thoracostomy as soon as safely possible. Because of risk of infection with retained hemothorax, prompt placement of a chest tube is recommended for any large or suspicious fluid collections. Tube thoracostomy is recommended for management of thoracic trauma for many indications other than just infection prevention.¹ Strict infection control techniques to include preparation of the site, and use of sterile gloves and equipment should be used for tube placement. One recent study looked at chest tubes placed in the field versus within the emergency department, with trained physicians performing thoracostomies at both sites; no statistical difference in subsequent infection was found.⁵⁷ This suggests that a chest tube placed in the field by a trained individual can be life saving without significant additional infectious risk.

The use of antibiotics before, during, or after tube thoracostomy after thoracic trauma is controversial, and has been addressed in guidelines⁴ and in a recent meta-analysis.³¹ An older review from 1985 found a significant decrease in thoracic infections after tube thoracostomy when prophylactic antibiotics were used.³⁵ However, since that time, the majority of published studies have not found a protective effect. In addition, the studies have varied in antibiotics used, timing of dose, and duration of therapy. A total of six randomized, placebo-controlled trials have been published.^{30,58–62} None were able to show a statistically lower rate of empyema in those receiving antibiotics, compared with placebo. In the most recent of these trials, Maxwell et al.³⁰ randomized 224 patients to cefazolin until removal of the chest tube, cefazolin for the first 24 hours after placement, or placebo. Four patients (5.6%) developed empyema in the placebo group, two (2.5%) in those receiving cefazolin for 1 day, and none in those receiving cefazolin until the chest tube was removed. These differences were not statistically significant. Unfortunately, the study only enrolled 20% of the subjects needed per the power analysis because of the difficulties with enrollment. Of the other infections seen during the study, the authors also observed more antibiotic resistance with increasing exposure to cefazolin. More recently, a meta-analysis of five of the randomized, prospective trials mentioned above was performed.³¹ In that report, antibiotic administration for 24 hours or until removal of the chest tube was associated with a reduced risk of empyema, and the magnitude of reduction did not vary between a short or long duration of therapy.

Conflicting prospective randomized and observational studies lead us to conclude that a first-generation cephalosporin may be used at chest tube insertion. As with prophylaxis after abdominal trauma, there is no evidence supporting a prolonged duration of therapy and some evidence that prolonging therapy only selects for more drug-resistant bacteria should an infection occur. Therefore, we make the following recommendation: when performing tube thoracostomy consider preprocedure single dose of i.v. cefazolin (CII). The presence of a chest tube alone does not require use of antimicrobials.

Diagnosis of Infection

Abdominal Trauma

Patients with fever, elevated white blood cell (WBC) count, and systemic inflammatory response syndrome should be evaluated for infection from any source. Evidence pointing to cIAI includes peritonitis, changing abdominal examination or failure to regain normal gut function, or purulent exudates from inflamed tissue. Cultures should be taken intraoperatively or percutaneously if there is suspicion for infection. Infection can then be confirmed by findings of operative or percutaneous drainage to include presence of exudates, and positive Gram's stains and culture.

In general, blood cultures do not provide additional information to properly collected intra-abdominal specimens.^{23,25} An adequate intra-abdominal specimen is at least 0.5 mL of fluid or tissue, representative of the material associated with infection, that is expeditiously transported to the lab in anaerobic conditions (if anaerobic culture is available).²³ Swabs are not adequate. Gram stains of specimens may be helpful for nosocomial or postoperative cases when gram-positive pathogens, such as *S. aureus* or *Enterococcus* spp., may be seen, which would alter empiric therapy. Yeasts are rarely seen on Gram's stain even if true pathogens.²⁵

Thoracic Trauma

Likewise, patients postthoracic trauma should be evaluated for infection when they demonstrate evidence of a systemic inflammatory response to include fever, elevated WBC count, and hemodynamic instability. Empyema may present as localized pain, purulent drainage from existing wounds, or persistent, undrained fluid in the chest. In addition, patients may present with pneumonia, often ventilator associated, with subsequent parapneumonic effusion or empyema. Suspicions for infection can also be confirmed by findings of operative or percutaneous drainage and Gram's stain and culture. Cell count, pH, lactate dehydrogenase, and serum to pleural albumin gradient can all help differentiate between empyema and simple parapneumonic effusion. If there is any question, prompt drainage with tube thoracostomy should be performed.

Treatment of Infection

Abdominal Trauma

Guidelines endorsed by the Infectious Diseases Society of America, the Surgical Infection Society, the American Society for Microbiology, and the Society of Infectious Disease Pharmacists for the treatment of complicated intra-abdominal (cIAI) infection have been published recently.²³ Similar to the literature regarding perioperative antibiotics after abdominal trauma, there is lack of standardization in antibiotic treatment for cIAI regarding antibiotic agents, doses, and duration of therapy. Many studies have compared single agent with combination regimens using various drugs, such as flouroquinolones with or without metronidazole, β -lactam/ β -lactamase inhibitors, cephalosporins, aminoglycosides, and carbapenems, all with comparable efficacy.²³ However, data regarding the optimal antibiotic regimen after postoperative intra-abdominal infection have not been published, and the trials investigating therapy for cIAI typically have enrolled few, if any, postoperative or trauma patients. Recent trials have even excluded patients with severe abdominal trauma.^{63,64} These differences in study populations, in addition to unique features of wartime trauma, make application of the currently published literature regarding cIAI treatment very difficult. With no particular regimen clearly superior to others in the literature, appropriate empiric therapy should be dictated by the local antibiogram.

In general, trauma patients who develop postoperative cIAI after appropriate prophylaxis should be empirically covered for nosocomial pathogens particular to that institution. Two studies have described increased risk of antimicrobial failure and recurrent infection in those with >48 hours of preoperative antimicrobial therapy.^{65,66} Although not explicitly described, this implies antibacterial resistance may be responsible, in part, for treatment failure. This hypothesis is supported by the largest study to date on postoperative cIAI, which showed that antibiotic resistance is common in patients after elective surgery and that inappropriate initial therapy adversely impacts outcome.²⁵ In their series of 100 patients with postoperative peritonitis after elective surgery, Montravers et al.²⁵ reported that 70 had resistant pathogens isolated at the time of reoperation. Of these, 37 patients had multiply resistant bacteria, including *P. aeruginosa*, *Klebsiella pneumoniae*, *E. coli*, *Serratia marcescens*, and *Acinetobacter baumannii*. In addition, *Candida* spp. were isolated from 23 patients. Anaerobes were only found in 14 patients. More troubling, empirical therapy was inadequate for 54 patients, and inadequate therapy was significantly associated with increased length of stay, increased number of subsequent reoperations, and higher mortality. Twenty-seven (50%) of those treated with an inadequate regimen died within 7 days of the initial reoperation for peritonitis.

In considering the above data, regimens used to treat cIAI should be selected after considering the likelihood of nosocomial pathogens and the clinical stability of the patient. Nosocomial organisms are more likely to be isolated from

patients >48 hours after initial operation or in patients that have previously received >48 hours of antibiotics after penetrating abdominal trauma. Therefore, for cIAI in nonseptic patients within 48 hours of initial surgery, who have not received more than 48 hours of antibiotics, we recommend empiric therapy to cover drug susceptible enteric and anaerobic bacteria to include *Bacteroides fragilis* (AII). Empiric choices may include fluoroquinolone (ciprofloxacin or levofloxacin) + metronidazole, third-generation cephalosporin (cefotaxime or ceftriaxone) + metronidazole, ticarcillin/clavulanic acid, or moxifloxacin alone (AI). In all patients with sepsis or those that have received >48 hours of antibiotics or that are >48 hours after initial surgery, nosocomial organisms with drug resistance are more common, and the empiric regimen should target nosocomial pathogens particular to your institution (BII). Potential empiric regimens include piperacillin/tazobactam, imipenem/cilastatin, meropenem, third- or fourth-generation cephalosporin (ceftazidime or cefepime) + metronidazole, or aztreonam + metronidazole. Because of the increasing antibacterial resistance of *B. fragilis*, and unavailability of anaerobic susceptibility testing, clindamycin and the cefamycins (cefoxitin and cefotetan) should not be used to treat cIAI in any setting (AIII).^{23,67,68} Antibiotics should be appropriately narrowed after culture and sensitivity data become available (CIII).

The roles of antifungal and antienterococcal therapy in penetrating abdominal trauma patients with cIAI are not clear. These organisms are typically isolated in polymicrobial infections in postoperative patients, so their direct role in pathogenesis and outcome are not known.²⁵ However, fungal peritonitis was associated with increased mortality in one report,²⁵ and may play a role in patients with recurrent or postoperative intra-abdominal infection.^{23,25,69} Therefore, if identified from culture, therapy for *Enterococcus* spp. and *Candida* spp. should be given to patients with cIAI occurring >48 hours after initial surgery (BIII). For *Candida albicans*, fluconazole is the agent of choice, and for nonalbicans *Candida* spp. treatment will be based upon local availability of antifungal agents.

Surgical management includes computed tomography-guided percutaneous or operative drainage. Computed tomography scans or other imaging modalities should be used when available to ensure adequate drainage if patients are not improving as expected. One recently published study reported that patients with intra-abdominal abscesses >6.5 cm in diameter or temperature >101.2°F were more likely to fail conservative therapy with antibiotics alone and require percutaneous drainage.⁷⁰ There are no data regarding the appropriate duration of antimicrobial therapy. In recent clinical trials in patients with community-acquired cIAI, clinical response rates were approximately 80% with the duration of therapy ranging from 4 to 14 days.^{24,63,64} Therefore, we recommend, in agreement with other experts,²³ continuing antibiotics until resolution of infection as evidenced by improvement in symptoms, normalization of temperature and

WBC count, and resolution of systemic inflammatory response syndrome (BIII).

Thoracic Trauma

As discussed above, the organisms causing empyema will change depending on the cause of the infection, and so appropriate antibiotic therapy will as well. Therefore, one must ascertain the source of the empyema. For all empyemas, appropriate drainage of fluid is indicated (AI). For empyemas associated with either trauma itself or tube thoracostomy, appropriate antibiotics should target gram-positives and skin flora. We recommend a first-generation cephalosporin such as cefazolin (BIII). gram-negative coverage would only be necessary for a positive Gram's stain or if the infection was diagnosed >48 hours into a hospital course. Empyemas because of enteric contamination should be covered with antibiotics appropriate for cIAI depending upon the duration of hospitalization and previous exposure to antimicrobial therapy (see above). Empyemas because of pneumonia, particularly ventilator-associated pneumonia (VAP), should be covered for nosocomial organisms. Similar to cIAI occurring after 48 hours of hospitalization, empiric therapy for empyema occurring >48 hours after hospitalization should be chosen based upon the institution's antibiogram (BIII). Appropriate antibiotics for VAP are beyond the scope of this article but guidelines published by the American Thoracic Society/Infectious Disease Society of America are available.

There are no good studies delineating proper duration of therapy. Chest tubes placed to drain empyema can be removed once output has decreased to minimal levels, typically <100 to 200 mL/d, with improvement in local symptoms, temperature, and WBC count, and antibiotics can generally be stopped at that time (CIII).

Several studies in recent literature have validated the use of video-assisted thoracic surgery as a less invasive alternative to open thoracotomy for persistent empyema.⁷¹⁻⁷³ If drainage proves difficult or impossible to drain via tube thoracostomy alone, video-assisted thoracic surgery is a viable alternative to thoracotomy for patients presenting with a nonimproving empyema post tube thoracostomy.

SUMMARY

In most cases recommendations have been made by extrapolating data from the literature regarding civilian trauma. Because of this, these guidelines should be interpreted as such, and clinicians will need to continue considering the specific aspects of each patient before providing treatment. In general, decisions regarding the appropriate antibiotic prophylaxis or treatment are guided by knowledge of the most likely microorganisms to be encountered. Prolonged antibiotic prophylaxis after either penetrating abdominal or thoracic trauma has not been proven to improve outcomes. As wounding patterns change because of advances

in protection and weaponry, surgical techniques will need to adapt as well.

Although the care of combat casualties continues to improve, many issues involving abdominal and thoracic injuries and infection to include incidence, bacteriology, appropriate therapy and outcomes, and prevention strategies are targets for future study. A description of the rates and pathogens associated with these infections from the current military conflict will be helpful in guiding physicians in future conflicts. In addition, the duration of antibiotic therapy with placement of a chest tube may be elucidated given the sheer numbers of chest tubes that have been placed during OIF. However, the number of injuries at other sites and therefore need for antibiotics for other reasons may make this type of study difficult. In regards to treatment, ascertaining which antibiotic regimen leads to best clinical outcomes would be ideal and highly desirable, but may also prove elusive as it is difficult to standardize surgical practice. In addition, results may be specific to the pathogens at individual institutions and may not be generalized. Nevertheless, we owe it to those who will take care of wounded warriors after us to describe, to the best of our ability, through observation and research, the best way to prudently use antibiotics with surgical techniques to maximally prevent and optimally treat infections due to abdominal and thoracic trauma.

REFERENCES

- Burriss DG, FitzHarris JB, Holcomb JB, et al. *Emergency War Surgery: Third United States Revision*. Washington, DC: Borden Institute; 2004.
- Johnson J. Battle wounds of the thoracic cavity. *Ann Surg*. 1946; 123:321–342.
- Montgomery H, Halberslend D, Carr FP. Puncture wounds of the chest. *J Thor Surg*. 1947;47:407–415.
- Luchette FA, Barie PS, Oswanski MF, et al. Practice management guidelines for prophylactic antibiotic use in tube thoracostomy for traumatic hemothorax: The EAST practice management guidelines work group. *J Trauma*. 2000;48:753–759.
- Zouris JM, Walker GJ, Dye J, Galarneau M. Wounding patterns for U.S. marines and sailors during Operation Iraqi Freedom, major combat phase. *Mil Med*. 2006;171:246–252.
- Cho JM, Jatoi I, Alarcon AS, Morton TM. Operation Iraqi Freedom: surgical experience of the 212th mobile army surgical hospital. *Mil Med*. 2005;170:268–272.
- Mabry RL, Holcomb JB, Baker AM, et al. United States army rangers in Somalia: an analysis of combat casualties on an urban battlefield. *J Trauma*. 2000;49:515–529.
- Peterson K, Riddle MS, Danko JR, et al. Trauma-related infections in battlefield casualties from Iraq. *Ann Surg*. 2007;245:803–811.
- Wallace C. A study of 1,200 cases of gunshot wounds of the abdomen. *BMJ*. 1916;4:679.
- Fraser J, Drummond H. Three hundred perforating wounds of the abdomen. *BMJ*. 1917;X:321.
- Ogilvie WH. Abdominal wounds in the western desert. *Surg Gynecol Obstet*. 1944;78:225.
- Imes PR. War surgery of the abdomen. *Surg Gynecol Obstet*. 1945; 81:608–616.
- Fullen WD, Hunt J, Altemeier WA, et al. Prophylactic antibiotics in penetrating wounds of the abdomen. *J Trauma*. 1972;137:270–276.
- Thadepalli H, Gorbach SL, Broido PW, et al. Abdominal trauma, anaerobes, and antibiotics. *Surg Gynecol Obstet*. 1973;137:270–276.
- Steele SR, Wolcott KE, Mullenix PS, et al. Colon and rectal injuries during Operation Iraqi Freedom: are there any changing trends in management outcome? *Dis Colon Rectum*. 2007;50:870–877.
- Yun HC, Murray CK, Roop SA, et al. Bacteria recovered from patients admitted to a deployed U.S. military hospital in Baghdad, Iraq. *Mil Med*. 2006;171:821–825.
- Bozorgzadeh A, Pizzi WF, Barie PS, et al. The duration of antibiotic administration in penetrating abdominal trauma. *Am J Surg*. 1999; 177:125–131.
- Kirton OC, O'Neill PA, Kestner MM, Tortella BJ. Perioperative antibiotic use in high-risk penetrating hollow viscus injury: a prospective randomized, double-blind, placebo-control trial of 24 hours versus 5 days. *J Trauma*. 2000;49:822–832.
- Delgado G, Barletta JF, Kanji S, et al. Characteristics of prophylactic antibiotic strategies after penetrating abdominal trauma at a level I urban trauma center: a comparison with the EAST guidelines. *J Trauma*. 2002;53:673–678.
- Tyburnski JG, Wilson RF, Warsow KM, McCreadie S. A trial of ciprofloxacin and metronidazole vs gentamicin and metronidazole for penetrating abdominal trauma. *Arch Surg*. 1998;133:1289–1296.
- O'Neill PA, Kirton OC, Dresner LS, et al. Analysis of 162 colon injuries in patients with penetrating abdominal trauma: concomitant stomach injury results in a higher rate of infection. *J Trauma*. 2004; 56:304–313.
- Tyburnski JG, Dente CJ, Wilson RF, et al. Infectious complications following duodenal and/or pancreatic trauma. *Am Surg*. 2001; 67:227–230.
- Solomkin JS, Mazuski JE, Baron EJ, et al. Guidelines for the selection of anti-infective agents for complicated intra-abdominal infections. *Clin Infect Dis*. 2003;37:997–1005.
- Babinchak T, Ellis-Grosse E, Dartois N, et al. The efficacy and safety of tigecycline for the treatment of complicated intra-abdominal infections: analysis of pooled clinical trial data. *Clin Infect Dis*. 2005;41:s354–s367.
- Montravers P, Gauzit R, Muller C, et al. Emergence of antibiotic-resistant bacteria in cases of peritonitis after intraabdominal surgery affects the efficacy of empirical antimicrobial therapy. *Clin Infect Dis*. 1996;23:486–494.
- Virgilio RW. Intrathoracic wounds in battle casualties. *Surg Gynecol Obstet*. 1970;130:609–615.
- Coselli JS, Mattox KL, Beal AC. Reevaluation of early evacuation of clotted hemothorax. *Am J Surg*. 1984;148:786–790.
- Valle AR. An analysis of 2811 chest casualties of the Korean conflict. *Chest*. 1954;26:623–633.
- Mandal AK, Thadepalli H, Mandal AK, Chettipalli U. Posttraumatic empyema thoracis: a 24-year experience at a major trauma center. *J Trauma*. 1997;43:764–771.
- Maxwell RA, Campbell DJ, Fabian TC, et al. Use of presumptive antibiotics following tube thoracostomy for traumatic hemothorax in the prevention of empyema and pneumonia—a multi-center trial. *J Trauma*. 2004;57:742–749.
- Sanabria A, Valdivieso E, Gomez G, Echeverry G. Prophylactic antibiotics in chest trauma: a meta-analysis of high-quality studies. *World J Surg*. 2006;30:1843–1847.
- Aguilar MM, Battistella FD, Owings JT, Su T. Posttraumatic empyema: risk factor analysis. *Arch Surg*. 1997;132:647–651.
- Antonelli M, Moro ML, Capelli O, et al. Risk factors for early onset pneumonia in trauma patients. *Chest*. 1994;105:224–228.
- Hoff SJ, Shotts SD, Eddy VA, et al. Outcome of isolated pulmonary contusion in blunt trauma patients. *Am Surg*. 1994;60:138–142.
- Walker WE, Kapelanski DP, Weiland AP, et al. Patterns of infection and mortality in thoracic trauma. *Ann Surg*. 1985;201:752–757.

36. Luchette FA, Borzotta AP, Croce MA, et al. Practice management guidelines for prophylactic antibiotic use in penetrating abdominal trauma: the EAST practice management guidelines work group. *J Trauma*. 2000;48:501–513.
37. Fabian TC, Hess MM, Croce MA, et al. Superiority of aztreonam/clindamycin compared with gentamicin/clindamycin in patients with penetrating abdominal trauma. *Am J Surg*. 1994;167:291–296.
38. Fabian TC, Hoefling SJ, Strom PR, Stone HH. Use of antibiotic prophylaxis in penetrating abdominal trauma. *Clin Ther*. 1982;5:38–47.
39. Jones RC, Thal ER, Johnson NA, Gollihar LN. Evaluation of antibiotic therapy following penetrating abdominal trauma. *Ann Surg*. 1985;201:576–585.
40. Sims EH, Thadepalli H, Ganesan K, Mandal AK. How many antibiotics are necessary to treat abdominal trauma victims? *Am Surg*. 1997;63:525–535.
41. Nichols RL, Smith JW, Klein DB, et al. Risk of infection after penetrating abdominal trauma. *N Engl J Med*. 1984;311:1065–1070.
42. Fabian TC, Croce MA, Payne LW, et al. Duration of antibiotic therapy for penetrating abdominal trauma: a prospective trial. *Surg Gynecol Obstet*. 1992;112:788–795.
43. Lou MA, Thadepalli H, Mandal AK. Safety and efficacy of mezlocillin: a single-drug therapy for penetrating abdominal trauma. *J Trauma*. 1988;28:1541–1547.
44. Ericsson CD, Fischer RP, Rowlands BJ, et al. Prophylactic antibiotics in trauma: the hazards of underdosing. *J Trauma*. 1989;29:1356–1361.
45. Moore FA, Moore EE, Ammons LA, McCroskey BL. Presumptive antibiotics for penetrating abdominal wounds. *Surg Gynecol Obstet*. 1989;169:99–103.
46. Cornwell EE, Dougherty WR, Berne TV, et al. Duration of antibiotic prophylaxis in high-risk patients with penetrating abdominal trauma: a prospective randomized trial. *J Gastrointest Surg*. 1999;3:648–653.
47. Velmahos G, Toutouzas KG, Sarkisyan G, et al. Severe trauma is not an excuse for prolonged antibiotic prophylaxis. *Arch Surg*. 2002;137:537–542.
48. Hoth JJ, Franklin GA, Stassen NA, et al. Prophylactic antibiotics adversely affect nosocomial pneumonia in trauma patients. *J Trauma*. 2003;55:249–254.
49. Dellinger EP. Antibiotic prophylaxis in trauma: penetrating abdominal injuries and open fractures. *Rev Infect Dis*. 1991;13:s847–s857.
50. Maxwell RA, Fabian TC. Current management of colon trauma. *World J Surg*. 2003;27:632–639.
51. Cayten CG, Fabian TC, Garcia VF, et al. EAST patient management guidelines for penetrating intraperitoneal colon injuries. *J Trauma*. 1998;44:941–956.
52. Malangoni MA, Dillon LD, Klamer TW, Condon RE. Factors influencing the risk of early and late serious infection in adults after splenectomy for trauma. *Surgery*. 1984;96:775–783.
53. Brigden ML, Pattullo AL. Prevention and management of overwhelming postsplenectomy infection—an update. *Crit Care Med*. 1999;27:836–842.
54. Howdieshell TR, Heffernan D, DiPiro JT. Surgical infection society guidelines for vaccination after traumatic injury. *Surg Infect*. 2006;7:275–303.
55. Schatz DV, Schinsky MF, Pais LB, et al. Immune responses of splenectomized trauma patients to the 23-valent pneumococcal polysaccharide vaccine at 1 versus 7 versus 14 days after splenectomy. *J Trauma*. 1998;44:760–766.
56. Schatz DV, Romero-Steiner S, Elie CM, et al. Antibody responses in postsplenectomy trauma patients receiving the 23-valent pneumococcal polysaccharide vaccine at 14 versus 28 days postoperatively. *J Trauma*. 2002;53:1037–1042.
57. Spanjersberg W, Ringberg A, Bergs B, et al. Prehospital chest tube thoracostomy: effective treatment or additional trauma. *J Trauma*. 2005;59:96–101.
58. Grover FL, Richardson JD, Fewel JG, et al. Prophylactic antibiotics in the treatment of penetrating chest wounds. A prospective double-blind study. *J Thorac Cardiovasc Surg*. 1977;74:975–977.
59. Stone HH, Symbas PN, Hooper CA. Cefamandole for prophylaxis against infection in closed thoracostomy. *J Trauma*. 1981;21:975–977.
60. Cant PJ, Smyth S, Smart DO. Antibiotic prophylaxis is indicated for chest stab wounds requiring closed thoracostomy. *Br J Surg*. 1993;80:464–466.
61. Nichols RL, Smith JW, Muzik AC, et al. Preventive antibiotic usage in traumatic thoracic injuries requiring closed thoracostomy. *Chest*. 1994;106:1493–1498.
62. Gonzalez RP, Holevar MR. Role of prophylactic antibiotics for tube thoracostomy in chest trauma. *Am Surg*. 1998;64:617–621.
63. Malangoni MA, Song J, Herrington J, et al. Randomized controlled trial of moxifloxacin compared with piperacillin-tazobactam and amoxicillin-clavulanate for the treatment of complicated intra-abdominal infections. *Ann Surg*. 2006;244:204–211.
64. Solomkin JS, Yellin AE, Rotstein OD, et al. Ertapenem versus piperacillin/tazobactam in the treatment of complicated intraabdominal infections: results of a double-blind, randomized comparative phase III trial. *Ann Surg*. 2003;237:235–245.
65. Solomkin JS, Reinhart HH, Dellinger EP, et al. Results of a randomized trial comparing sequential intravenous/oral treatment with ciprofloxacin plus metronidazole to imipenem/cilastatin for intra-abdominal infections. *Ann Surg*. 1996;223:303–315.
66. Solomkin JS, Wilson SE, Christou NV, et al. Results of a clinical trial of clinafloxacin versus imipenem/cilastatin for intraabdominal infections. *Ann Surg*. 2001;233:79–87.
67. Aldredge KE, O'Brien M. In vitro susceptibilities of the *Bacteroides fragilis* group species: change in isolation rates significantly affects overall susceptibility data. *J Clin Microbiol*. 2002;40:4349–4352.
68. Snyderman DR, Jacobus NV, McDermott LA, et al. Multicenter study of in vitro susceptibility of the *Bacteroides fragilis* group, 1995 to 1996, with comparison of resistance trends from 1990 to 1996. *Antimicrob Agents Chemother*. 1999;43:2417–2422.
69. Calandra T, Bille J, Schneider R, et al. Clinical significance of candida isolated from peritoneum in surgical patients. *Lancet*. 1989;2:1437–1439.
70. Kumar RR, Kim JT, Haukoos JS, et al. Factors affecting the successful management of intra-abdominal abscesses with antibiotics and the need for percutaneous drainage. *Dis Colon Rectum*. 2006;49:183–189.
71. Lawrence DR, Ohri SK, Moxon RE, et al. Thoracoscopic debridement of empyema thoracis. *Ann Thorac Surg*. 1997;64:1448–1450.
72. Navsaria PH, Vogel RJ, Nicol AJ. Thoracoscopic evacuation of retained posttraumatic hemothorax. *Ann Thorac Surg*. 2004;78:282–285.
73. Wurnig PN, Wittmer V, Prindun NS, et al. Video-assisted thoracic surgery for pleural empyema. *Ann Thorac Surg*. 2006;81:309–313.