

Prophylactic antibiotic use in penetrating abdominal trauma: An Eastern Association for the Surgery of Trauma practice management guideline

Stephanie R. Goldberg, MD, Rahul J. Anand, MD, John J. Como, MD, Tracey Dechert, MD, Christopher Dente, MD, Fred A. Luchette, MD, Rao R. Ivatury, MD, and Therese M. Duane, MD

BACKGROUND: The use of prophylactic antibiotics in penetrating abdominal trauma has resulted in decreased infection rates. The Eastern Association for the Surgery of Trauma (EAST) first published its practice management guidelines (PMGs) for the use of prophylactic antibiotics in penetrating abdominal trauma in 1998. During the next decade, several new prospective studies were published on this topic. In addition, the practice of damage control laparotomy became widely used, and additional questions arose as to the role of prophylactic antibiotics in this setting. Thus, the EAST Practice Management Guidelines Committee set out to update the original PMG.

METHODS: A search of the National Library of Medicine and the National Institutes of Health MEDLINE databases was performed using PubMed (www.pubmed.gov) and specific key words. The search retrieved English language articles regarding the use of antibiotics in penetrating abdominal trauma published from 1973 to 2011. The topics investigated were the need for perioperative antibiotics, the duration of antibiotic therapy, the dose of antibiotics in patients presenting in hemorrhagic shock, and the appropriate duration of antibiotic therapy in the setting of damage control laparotomy.

RESULTS: Forty-four articles were identified for inclusion in this review.

CONCLUSION: There is evidence to support a Level I recommendation that prophylactic antibiotics should only be administered for 24 hours in the presence of a hollow viscus injury. In addition, there are no data to support continuing prophylactic antibiotics longer than 24 hours in damage control laparotomy. (*J Trauma Acute Care Surg.* 2012;73: S321–S325. Copyright © 2012 by Lippincott Williams & Wilkins)

KEY WORDS: Penetrating abdominal trauma; antibiotics; prophylaxis; infection.

STATEMENT OF THE PROBLEM

Preoperative antibiotics for elective abdominal operations are essential in decreasing surgical site infections (SSIs) such that the timely and appropriate administration of antimicrobials is a quality benchmark measure. However, their role in emergent surgery for intestinal perforation is controversial. In the preantibiotic era, penetrating abdominal trauma was associated with a mortality rate as high as 65% to 70%.^{1,2} With the development of antimicrobials and their use in injured patients, SSIs and thus patient morbidity were reduced. However, the specific antibiotic choice and the duration of treatment in patients with hollow viscus injuries were topics of debate and clinical study. In 1998, the Eastern Association

for the Surgery of Trauma (EAST) Practice Management Guidelines (PMGs) Committee reviewed the existing literature to define the role of prophylactic (preemptive) antibiotics in abdominal penetrating injuries. This resulted in the publication of a guideline identifying the lack of Class I studies to allow a definitive answer for the standard of care (Level I recommendation).³ However, the literature at that time did support a single dose of preoperative prophylactic antibiotics with broad-spectrum aerobic and anaerobic coverage continued for 24 hours as a Level II recommendation for trauma patients sustaining penetrating abdominal wounds with an intestinal injury. It was also recommended that in the absence of a hollow viscus injury, no additional doses of antimicrobials were warranted. Finally, there was insufficient data supporting the modification of antibiotic dosing for patients with ongoing hemorrhage and shock.

The purpose of this review is to evaluate studies published since 1998 and to update the previous EAST PMG. Specific questions addressed by the PMG Committee include the following:

- What is the appropriate use of preoperative antibiotics in penetrating abdominal trauma?
- What is the appropriate duration of postoperative antibiotics in penetrating abdominal trauma?
- Should perioperative antibiotic use be altered in the absence of hollow viscus injury at the time of laparotomy?
- Is it necessary to redose antibiotics in the setting of hemorrhage?

Submitted: March 15, 2012, Revised: August 8, 2012, Accepted: August 8, 2012.

From the Division of Trauma, Critical Care, and Emergency General Surgery (S.R.G., R.J.A., T.M.D., R.R.I.), Virginia Commonwealth University Medical Center, Richmond, Virginia; Department of Surgery (J.J.C.), Case Western Reserve University School of Medicine, Cleveland, Ohio; Trauma Surgery & Critical Care (T.D.), Boston University School of Medicine, Boston, Massachusetts; Division of Surgical Critical Care (C.D.), Emory University School of Medicine, Atlanta, Georgia; Division of General Trauma Surgery and Critical Care (F.A.L.), Loyola University Medical Center, Maywood, Illinois.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for reprints: Stephanie R. Goldberg, MD, Division of Trauma, Critical Care, and Emergency General Surgery, P.O. Box 980454, Richmond, VA 23298; email: sgoldberg@mcvh-vcu.edu.

DOI: 10.1097/TA.0b013e3182701902

J Trauma Acute Care Surg
Volume 73, Number 5, Supplement 4

S321

- What is the duration of therapy with antimicrobials for patients with damage control laparotomy and an open abdomen?

PROCESS

Identification of References

Using a search methodology similar to that used by Luchette et al.,³ a MEDLINE search was performed to identify publications from 1973 to 2011 using the key words “antibiotic prophylaxis,” “penetrating abdominal injuries,” “abdominal injuries,” “complications,” “peritonitis,” “wound infection prevention and control,” “open abdomen,” “damage control laparotomy” (DCL), “pharmacokinetics,” and “trauma.” In addition, references included among the initial 1998 EAST guidelines were included.

Forty-four English language articles were included in this analysis; letters to the editor, case reports, and review articles were omitted. The bibliography of each article was also reviewed to identify additional publications that may not have been identified in the original MEDLINE query. The articles were reviewed by seven surgeons with expertise in trauma surgery, critical care, and acute care surgery who then collaborated to update the recommendations. This guideline was presented to the EAST membership for discussion and review at the annual EAST meeting in 2012.

Quality of the References

Each article was reviewed and classified according to the methodology established by the Agency for Health Care Policy and Research of the US Department of Health and Human Services. Additional criteria and specifications were used for Class I articles as described by Oxman et al.⁴ This process is similar to that performed for the original PMG.³

Thus, the articles were classified as follows:

Class I: Prospective, randomized, double-blind study.

Class II: Prospective, randomized, nonblinded trial.

Class III: Retrospective series of patients or meta-analysis.

RECOMMENDATIONS

Level 1

1. A single preoperative dose of prophylactic antibiotics with broad-spectrum aerobic and anaerobic coverage should be administered to all patients sustaining penetrating abdominal wounds.
2. Prophylactic antibiotics should be continued for not more than 24 hours in the presence of a hollow viscus injury in the acutely injured patient.
3. Absence of a hollow viscus injury requires no further administration of antibiotics.

Level 2

1. There are no Level 2 recommendations.

Level 3

1. In patients admitted with hemorrhagic shock, the administered dose of antibiotics may be increased twofold or threefold and repeated after transfusion of every 10 units of blood until there is no further blood loss.

2. Aminoglycosides should be avoided because of suboptimal activity in patients with significant injuries if possible.

SCIENTIFIC FOUNDATION

Historical Background

Penetrating abdominal trauma results in a spectrum of injuries associated with various degrees of microbial contamination of the peritoneal cavity and tissues. The basic tenets of operative management are prompt control of hemorrhage and contamination coupled with early debridement of devitalized tissue and restoration of tissue perfusion and are central to minimizing both SSI and intra-abdominal infection. To help clarify the role of prophylactic antibiotics in penetrating abdominal trauma, the EAST PMG Committee developed a guideline on this topic that was published in 1998.³ The guideline was based on the review of 39 articles in the literature from 1976 through 1997. The only Level I recommendation was that a single preoperative dose of antibiotics with broad-spectrum aerobic and anaerobic coverage was the standard of care for trauma patients sustaining penetrating abdominal wounds. No additional doses of antimicrobials were necessary if there was no bowel injury. A Level II recommendation supported the continuation of antibiotics for only 24 hours when there was a hollow viscus injury. In addition, Level 3 recommendations were made regarding alteration of antibiotic dosing for patients presenting with hemorrhagic shock.

A prospective randomized study comparing kanamycin and cephalothin with kanamycin and clindamycin in 1973 established the importance of broad-spectrum anaerobic and aerobic antimicrobial coverage for penetrating abdominal trauma.⁶ This study was influential in the formulation of the 1998 guideline. The group receiving clindamycin, which provides anaerobic coverage, had a significantly lower infection rate (10%) compared with that of the cephalothin group (27%). The demonstrated difference was caused by a greater number of anaerobic infections in the cephalothin group (21%) compared with those in the clindamycin group (2%). This landmark article established the basis for the addition of antimicrobial agents that provided coverage of anaerobic organisms, in addition to aerobic organisms, for penetrating wounds of the intestinal tract.

Several studies have evaluated various antimicrobial agents regarding the specific pathogens that should be covered. Many of the antibiotics used in the earlier studies are no longer used in clinical practice. However, these prospective studies did demonstrate the need for broad anaerobic and aerobic coverage and are summarized in the previous guideline.³

Duration of Antibiotic Therapy

Despite the wide acceptance of the need for broad-spectrum antibiotics in penetrating wounds of the abdomen, the duration of antimicrobial therapy necessary to prevent SSIs remains controversial. The 1998 EAST guideline found evidence to support only a 24-hour course of antibiotics when there was a bowel injury.³ Kirton et al.⁷ confirmed this recommendation in a prospective, randomized, double-blind,

placebo-controlled study, which compared the use of ampicillin/sulbactam for 24 hours versus 5 days. There was no difference in infection rates between the groups, supporting the recommendation made by the EAST PMG in 1998 that antimicrobial coverage for 24 hours is adequate. Independent risk factors for the development of postoperative surgical and nonsurgical site infections were noted to be both the total number of units of blood transfused and a Penetrating Abdominal Trauma Index (PATI) score greater than or equal to 25 ($p = 0.001$ and $p = 0.003$, respectively). However, an associated colonic injury was not found to be an independent risk factor for SSI. This Class I study provided additional evidence to support a Level I recommendation that antibiotics should not be continued for more than 24 hours in the presence of any hollow viscus injury. Another prospective randomized trial in 1999 compared cefoxitin for 24 hours versus 5 days in penetrating abdominal wounds and found no difference in overall infection rates; however, the infection rates were higher in patients with a blood pressure less than 90 mm Hg (shock) at admission or when there was an injury to the colon or central nervous system or two or more organ injuries.⁸ A subsequent study also concluded that colonic injuries were associated with a higher rate of SSI regardless of the duration of antimicrobial treatment.⁹

Delgado et al.¹⁰ compared the duration of antibiotics after penetrating abdominal wounds associated with a bowel injury and rates of infections. Although retrospective, the authors concluded that there was no reduction in infection rates when antibiotics were administered longer than 24 hours (18 of 76 vs. 3 of 21; $p = 0.273$). Risk factors for postoperative complications were defined as those who were transfused two or more units of blood, PATI score greater than or equal to 12, and operative time exceeding 2 hours. Furthermore, patients were stratified according to high and low risk for infection. In the 78 low-risk patients, there was no difference in infection rates when the antimicrobials were stopped after 24 hours (1 [6%] of 18 vs. 10 [17%] of 60, $p = 0.219$). In the high-risk patients, there was no significant difference observed in infection rates regardless of adherence to the EAST guidelines (2 [67%] of 3 vs. 8 [50%] of 16, $p = 0.542$).

Timing of Administration

Studies have suggested that infection can be best prevented if therapeutic doses of antimicrobials are present in tissues before or at the time of bacterial contamination, which is not feasible with traumatic injuries.^{11–13} Therefore, prompt antimicrobial administration before laparotomy for trauma or as soon as feasible following gross contamination should be the goal.

Two studies in the early 1970s highlighted the benefit of early preoperative antibiotic administration and reduced SSI after penetrating trauma with intestinal injury. Fullen et al.¹⁴ retrospectively reviewed 295 patients and correlated skin and intra-abdominal abscesses with timing of administration of antimicrobials (either preoperatively, intraoperatively, or postoperatively). There was a significant decrease in infection rates in the group receiving a preoperative dose (7%) compared with the intraoperative (33%) and postoperative groups (30%). A criticism of this study was the small number of patients

in the preoperative group compared with the other two groups. The presence of a concomitant colon injury was associated with infection rates of 11%, 57%, and 70%, respectively, implicating colonic injury as an independent risk factor for SSI. This finding has since been questioned. These findings do corroborate those of Thadepalli et al.⁶ who compared antibiotic administration at admission to the emergency department versus in the operating room. They concluded that a single preoperative broad-spectrum antibiotic dose with aerobic and anaerobic coverage resulted in the lowest rate of infection.

Administration of Additional Antibiotics During Prolonged Operations

To date, there are no studies that have evaluated the timing of additional doses of antibiotics intraoperatively because of duration of operation in patients with penetrating abdominal trauma.

DCL: Role of Prophylactic Antibiotics in the Open Abdomen

At the same time the original PMG was being developed in 1997, the concept of DCL was gaining popularity and being increasingly used in the management of severely injured patients.¹⁵ Initially, there was concern that delayed closure of the abdomen would be an independent risk factor for subsequent infection. This argument was only strengthened by the high association of the “lethal triad” with patients undergoing DCL and the relationship between disseminated intravascular coagulopathy as a risk factor for infection. Despite the lack of scientific evidence, many trauma surgeons at that time continued antibiotics until the abdomen incision was closed, which frequently did not occur for several days. Our current review of the literature failed to identify any articles specifically addressing the role of prophylactic antibiotics when the laparotomy incision is left open, demonstrating a need for further research in this patient population.

Impact of Specific Mechanism of Penetrating Injury on Antibiotic Administration

Penetrating wounds are produced by high and low energy forces. They are typically classified as medium to high energy (gunshot wounds) and low energy (stab wounds). The degree of tissue damage varies by the specific mechanism, with the high-energy wounds creating the greatest degree of soft tissue damage that typically results in ischemic/necrotic tissue that is an ideal environment for bacteria to establish an infection. Few studies have controlled for the type of penetrating wound; however, all studies suggested that prophylactic antibiotics should not be continued for more than 24 hours when there is an intestinal injury.³

Dosing of Antibiotics in Hemorrhagic Shock

The original PMG made a Level III recommendation that repeated administration of antibiotics in patients with hemorrhagic shock should be considered because of the vasoconstriction and decreased tissue delivery of antibiotics. These recommendations were based on studies by Ericsson et al.¹⁶ who found subtherapeutic antibiotic levels in trauma patients and an inverse correlation between increasing the

dose of amikacin and infection rates. There remain insufficient clinical data to provide meaningful guidelines for reducing infectious complications in trauma patients with hemorrhagic shock. Thus, the 2012 guidelines have also maintained this Level III recommendation that antibiotic dosage may need to be increased twofold or threefold and repeated after every transfusion of 10 units of blood until there is no further blood loss.

Use of Aminoglycosides in Trauma Patients

Furthermore, the 1998 guideline recommended that aminoglycosides be avoided because of presumed altered pharmacokinetics of drug distribution in injured patients. This recommendation was supported by a study that demonstrated subtherapeutic aminoglycoside levels in trauma patients because of a greater volume of distribution from aggressive resuscitation.¹⁷ Reed and colleagues¹⁸ further studied the relationship between aggressive volume expansion, drug elimination, and antibiotic dosing in the postinjury period and demonstrated that antibiotic dosing should be high, rather than low, and should be dosed frequently during fluid resuscitation. A Level III recommendation is maintained in this article, but this may need to be readdressed in the future as resuscitation strategies evolve.

EVIDENTIARY TABLE

The table included in this update consists of outcome studies arranged according to chronological class. Studies consist of those included in the previous 1998 outcomes table as well as more recent relevant studies (Table, Supplemental Digital Content 1, at <http://links.lww.com/TA/A191>).^{19–54}

SUMMARY

Prophylactic antimicrobials have an important role in decreasing infection in patients with penetrating wounds of the abdomen when associated with an injury to a hollow viscus. Numerous studies demonstrate the importance of broad-spectrum aerobic and anaerobic coverage. Studies, to date, do not support more than 24 hours of antimicrobial coverage for prevention of infection associated with a hollow viscus injury.

FUTURE STUDIES

Future studies are necessary to better understand risk factors associated with trauma-related infections and to determine the need for and duration of antimicrobial usage in the setting of DCL.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

- Fraser J, Drummond H. A clinical and experimental study of three hundred perforating wounds of the abdomen. *Br Med J*. 1917;5:321–330.
- Wallace C. A study of 1200 cases of gunshot wounds of the abdomen. *Br Med J*. 1916;4:679–743.
- 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;48:508–518.
- Oxman AD, Sackett DL, Guyatt GH. User's guide to the medical literature. *JAMA*. 1993;270:2093–2095.
- Hawn MT, Itani KM, Gray SH, et al. Association of timely administration of prophylactic antibiotics for major surgical procedures and surgical site infection. *J Am Coll Surg*. 2008;206:814–819.
- Thadepalli H, Gorbach SL, Broido PW, Norsen J, Nyhus L. Abdominal trauma, anaerobes, and antibiotics. *Surg Gynecol Obstet*. 1973;137:270–276.
- Kirton OC, O'Neill PA, Kestner M. 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.
- Bozorgzadeh A, Pizzi WF, Barie PS, et al. The duration of antibiotic administration in penetrating abdominal trauma. *Am J Surg*. 1999;177:125–131.
- Cornwell EE 3rd, 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.
- Delgado G Jr, 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.
- Burke JF. The effective period of preventive antibiotic action in experimental incisions and dermal lesions. *Surgery*. 1961;50:161–168.
- Alexander JW, Altemeier WA. Penicillin prophylaxis of experimental staphylococcal wound infections. *Surg Gynecol Obstet*. 1965;120:243–254.
- Griffiths DA, Shorey BA, Simpson RA, et al. Single-dose preoperative antibiotic prophylaxis in gastrointestinal surgery. *Lancet*. 1976;2:325–328.
- Fullen WD, Hunt J, Altemeier WA. Prophylactic antibiotics in penetrating wounds of the abdomen. *J Trauma*. 1972;12:282–289.
- Rotondo MF, Schwab CW, McGonigal MD, et al. Damage control: an approach for improved survival in exsanguinating penetrating abdominal injury. *J Trauma*. 1993;35:375–382.
- Ericsson CD, Fischer RP, Rowlands BJ, et al. Prophylactic antibiotics in trauma: the hazards of underdosing. *J Trauma*. 1989;29:1356–1361.
- Townsend PL, Fink MP, Stein KL, Murphy SG. Aminoglycoside pharmacokinetics: dosage requirements and nephrotoxicity in trauma patients. *Crit Care Med*. 1989;17:154–157.
- Reed RL 2d, Ericsson CD, Wu A, Miller-Crotchet P, Fischer RP. The pharmacokinetics of prophylactic antibiotics in trauma. *J Trauma*. 1992;32:21–27.
- Fabian TC, Croce MA, Payne LW, Minard G, Pritchard FE, Kudsk KA. Duration of antibiotic therapy for penetrating abdominal trauma: a prospective trial. *Surgery*. 1992;112:788–795.
- Fabian TC, Hess MM, Croce MA, Wilson RS, Wilson SE, Charland SL, Rodman JH, Boucher BA. Superiority of aztreonam/clindamycin compared with gentamicin/clindamycin in patients with penetrating abdominal trauma. *Am J Surg*. 1994;167:291–296.
- Fabian TC, Hoefling SJ, Strom PR, Stone HH. Use of antibiotic prophylaxis in penetrating abdominal trauma. *Clin Ther*. 1982;5:38–47.
- Griswold JA, Muakkassa FF, Betcher E, Poole GV. Injury severity dictates individualized antibiotic therapy in penetrating abdominal trauma. *Am Surg*. 1993;59:34–39.
- Heseltine PN, Berne TV, Yellin AE, Gill MA, Appleman MD. The efficacy of cefoxitin vs. clindamycin/gentamicin in surgically treated stab wounds of the bowel. *J Trauma*. 1986;26:241–245.
- Jones RC, Thal ER, Johnson NA, Gollihar LN. Evaluation of antibiotic therapy following penetrating abdominal trauma. *Ann Surg*. 1985;201:576–585.
- Nelson RM, Benitez PR, Newell MA, Wilson RF. Single-antibiotic use for penetrating abdominal trauma. *Arch Surg*. 1986;121:153–156.
- Nichols RL, Smith JW, Klein DB, Trunkey DD, Cooper RH, Adinolfi MF, Mills J. Risk of infection after penetrating abdominal trauma. *N Engl J Med*. 1984;311:1065–1070.
- Schmidt-Matthiesen A, Röding H, Windolf J, Sommerfeldt D, Gutt C, Pannike A, Encke A. A prospective, randomised comparison of single- vs.

- multiple-dose antibiotic prophylaxis in penetrating trauma. *Chemotherapy*. 1999;45:380–391.
28. Sims EH, Thadepalli H, Ganesan K, Mandal AK. How many antibiotics are necessary to treat abdominal trauma victims? *Am Surg*. 1997;63:525–535.
29. Tyburski JG, Wilson RF, Warsow KM, McCreddie S. A trial of ciprofloxacin and metronidazole vs. gentamicin and metronidazole for penetrating abdominal trauma. *Arch Surg*. 1998;133:1289–1296.
30. Crenshaw C, Glanges E, Webber C, McReynolds DB. A prospective random study of a single agent versus combination antibiotics as therapy in penetrating injuries of the abdomen. *Surg Gynecol Obstet*. 1983;156:289–294.
31. Demetriades D, Lakhoo M, Pezikis A, Charalambides D, Pantanowitz D, Sofianos C. Short-course antibiotic prophylaxis in penetrating abdominal injuries: ceftriaxone versus cefoxitin. *Injury*. 1991;22:20–24.
32. Fabian TC, Boldreghini SJ. Antibiotics in penetrating abdominal trauma. Comparison of ticarcillin plus clavulanic acid with gentamicin plus clindamycin. *Am J Med*. 1985;79:157–160.
33. Feliciano DV, Gentry LO, Bitondo CG, Burch JM, Mattox KL, Cruse PA, Jordan GL Jr. Single-agent cephalosporin prophylaxis for penetrating abdominal trauma: results and comment on the emergence of the *Enterococcus*. *Am J Surg*. 1986;152:674–681.
34. Gentry LO, Feliciano DV, Lea AS, Short HD, Mattox KL, Jordan GL Jr. Perioperative antibiotic therapy for penetrating injuries of the abdomen. *Ann Surg*. 1984;200:561–566.
35. Hofstetter SR, Pachter HL, Bailey AA, Coppa GF. A prospective comparison of two regimens of prophylactic antibiotics in abdominal trauma: cefoxitin versus triple drug. *J Trauma*. 1984;24:307–310.
36. Kreis DJ Jr, Augenstein D, Martinez O, Echenique M, Plasencia G, Vopal JJ, Byers P, Gomez GA. A prospective randomized study of moxalactam versus gentamicin and clindamycin in penetrating abdominal trauma. *Surg Gynecol Obstet*. 1986;163:1–4.
37. Lou MA, Thadepalli H, Sims EH, Mandal AK. Comparison of cefamandole and carbenicillin in preventing sepsis following penetrating abdominal trauma. *Am Surg*. 1985;51:580–586.
38. 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.
39. Moore FA, Moore EE, Mill MR. Preoperative antibiotics for abdominal gunshot wounds: a prospective, randomized study. *Am J Surg*. 1983;146:762–765.
40. O'Donnell V, Mandal AK, Lou SM, Thadepalli H. Evaluation of carbenicillin and a comparison of clindamycin and gentamicin combined therapy in penetrating abdominal trauma. *Surg Gynecol Obstet*. 1978;147:525–528.
41. Oreskovich MR, Dellinger EP, Lennard ES, Wertz M, Carrico CJ, Minshew BH. Duration of preventive antibiotic administration for penetrating abdominal trauma. *Arch Surg*. 1982;117:200–205.
42. Posner MC, Moore EE, Harris LA, Allo MD. Presumptive antibiotics for penetrating abdominal wounds. *Surg Gynecol Obstet*. 1987;165:29–32.
43. Rosemurgy AS 2d, Dillon KR, Kurto HA, Albrink MH. Ceftizoxime use in trauma celiotomy: pharmacokinetics and patient outcomes. *J Clin Pharmacol*. 1995;35:1046–1051.
44. Rowlands BJ, Ericsson CD. Comparative studies of antibiotic therapy after penetrating abdominal trauma. *Am J Surg*. 1984;148:791–795.
45. Rowlands BJ, Ericsson CD, Fischer RP. Penetrating abdominal trauma: the use of operative findings to determine length of antibiotic therapy. *J Trauma*. 1987;27:250–255.
46. Salim A, Teixeira PG, Inaba K, Brown C, Browder T, Demetriades D. Analysis of 178 penetrating stomach and small bowel injuries. *World J Surg*. 2008;32:471–475.
47. Sims EH, Lou MA, Williams SW, Ganesan N, Thadepalli H. Piperacillin monotherapy compared with metronidazole and gentamicin combination in penetrating abdominal trauma. *J Trauma*. 1993;34:205–210.
48. Van Rensburg LC, Warren B, Warren V, Muller R. Ceftriaxone (Rocephin) in abdominal trauma. *J Trauma*. 1991;31:1490–1494.
49. Weigelt JA, Easley SM, Thal ER, et al. Abdominal surgical wound infection with improved perioperative *Enterococcus* and *Bacteroides* therapy. *J Trauma*. 1993;34:579–584.
50. Croce MA, Fabian TC, Patton JH Jr, Lyden SP, Melton SM, Minard G, Kudsk KA, Pritchard FE. Impact of stomach and colon injuries on intra-abdominal abscess and the synergistic effect of hemorrhage and associated injury. *J Trauma*. 1998;45:649–655.
51. Dellinger EP, Oreskovich MR, Wertz MJ, Hamasaki V, Lennard ES. Risk of infection following laparotomy for penetrating abdominal injury. *Arch Surg*. 1984;119:20–27.
52. Dente CJ, Tyburski J, Wilson RF, Collinge J, Steffes C, Carlin A. Ostomy as a risk factor for posttraumatic infection in penetrating colonic injuries: univariate and multivariate analyses. *J Trauma*. 2000;49:628–634.
53. Hooker KD, DiPiro JT, Wynn JJ. Aminoglycoside combinations versus beta-lactams alone for penetrating abdominal trauma: a meta-analysis. *J Trauma*. 1991;31:1155–1160.
54. O'Donnell VA, Lou S, Alexander JL, Mandal AK. Role of antibiotics in penetrating abdominal trauma. *Am Surg*. 1978;44:574–577.