Risk of Infection Following Penetrating Abdominal Trauma: A Selective Review

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Received October 21, 1985

Post-operative infectious complications following penetrating abdominal trauma are a major cause of morbidity and contribute significantly to increased length of hospitalization and costs of patient care. Our recent study suggests the individual patient's probability of major infection following traumatic intestinal perforation is high and can be predicted from risk factors identified at the time of surgery. The determinant of primary importance for development of infection confirmed by this study is peritoneal contamination by intestinal contents. Other significant risk factors \((p < 0.05)\) were number of organs injured, number of units of blood administered, ostomy formation for left colon injury, and the patient's age. Risk of infection can be calculated from these data and could potentially be used to guide post-operative decisions. Areas of trauma care in which alteration of therapy might result in significant savings include choice of antibiotics, duration of antibiotic administration, and wound management. This study supports the use of standardized operative procedures and parenteral antibiotics effective against endogenous aerobic and anaerobic organisms. If such observations continue to be supported by further randomized prospective studies, there is tremendous potential to further tailor surgical management for the individual patient in a more cost-effective manner.

Recent efforts at reducing mortality from penetrating abdominal trauma have been largely successful, but morbidity associated with post-traumatic infectious complications remains a major problem. Economic considerations over the past few years have greatly stimulated interest in risk factors' predicting and, thus, potentially preventing these septic events. It is generally accepted that post-operative infection following elective surgical procedures increases significantly utilization of resources, length of hospital stay, and, therefore, overall costs [1]. Although little published data are available regarding the economic impact of sepsis following penetrating abdominal trauma, it may be assumed that such costs to individuals and society are considerable, due to the high incidence of infection in these patients [2]. Specific risk factors for development of infection in this setting are poorly understood, but have important implications for cost containment in all aspects of trauma care, including patient resuscitation, surgical treatment of specific injuries, wound management, and appropriate use of antibiotics. Earlier recognition of the individual patient's potential for post-traumatic sepsis could better direct therapeutic options, thereby reducing infection rates, shortening hospital stay, and lowering costs accordingly. The authors will examine, in this selective review of the recent surgical literature, risk factors and clinical and experimental work relevant to the prediction of infection following penetrating abdominal trauma, and propose methods of tailoring therapeutic modalities to the individual patient based upon these observations.

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Frequently encountered major septic complications directly related to trauma include: bacteremia, peritonitis, intra-abdominal abscess, and wound infection. Secondary nosocomial infections such as pneumonitis or urinary tract infection also frequently occur in these critically ill patients due to prolonged hospitalization and invasive support measures. Published reports [3,4,5] on management of abdominal trauma demonstrate the efficacy of various antimicrobial regimens in reducing these infectious complications, but further cost-efficient advances are needed in areas such as wound management, choice of antimicrobial agents, and duration of post-operative antibiotic administration. Unfortunately, clinical studies often fail to identify clearly risk factors predictive of post-traumatic sepsis that could positively influence therapeutic decision making in regard to these questions. Defective study design, poor patient selection, lack of standardized operative technique, and non-uniform reporting format are other general problems greatly reducing the value of some studies toward development of rational strategies for lowering infection in these patients.

RISK FOR INFECTION

Not all patients with penetrating abdominal trauma necessarily share the same risk for subsequent development of sepsis. Earlier investigators proposed that trauma increased risk of infection by introduction of exogenous aerobic bacteria, such as staphylococci, from skin and foreign material into the peritoneal cavity or other tissues [6]. Clinical and microbiological studies [2,4,7] demonstrate intestinal perforation and peritoneal contamination by endogenous aerobic and anaerobic microorganisms are the primary determinants for development of post-operative infection following abdominal trauma. In general, studies of abdominal trauma patients without evidence of intestinal spillage have shown substantially lower rates of infection regardless of the surgical techniques or antibiotic protocols used [2,8]. Prompt intervention, sound surgical judgment, and skillful operative technique are critical in reducing infection following trauma [9,10]. In addition, factors such as severity and number of organs injured, degree of bacterial contamination, blood loss, therapeutic delay, and choice of antibiotics may significantly effect the outcome of treatment [5]. Individual risk factors, like age and diabetes mellitus, are possibly important but not as well defined.

A recent joint clinical study from our institution, the Charity Hospital of Louisiana at New Orleans, and San Francisco General Hospital investigated potential risk factors in patients at high risk for infection from penetrating abdominal trauma [2]. All 145 patients included in this study had documented intestinal perforation and underwent standardized surgical management of specific intra-abdominal injuries. Patients received either cefoxitin and placebo or a combination of clindamycin and gentamicin, utilizing a randomized, prospective, double-blind investigational protocol following appropriate informed consent. When this study was initiated, clindamycin and gentamicin were considered the antibiotic regimen of choice for penetrating abdominal trauma because of broad-spectrum efficacy against endogenous aerobic and anaerobic bacteria [7]. At that time, cefoxitin was the only available cephalosporin with a comparable anti-microbial spectrum, particularly against *Bacteroides fragilis* [11]. Since a single agent (cefoxitin) was being compared to a combination of agents (clindamycin and gentamicin), it was necessary to use a placebo infusion (normal saline) along with the single agent to protect the double-blindedness of the protocol. All patients in the study received medication doses, whether antibiotic or placebo, on a schedule as if two drugs were being administered; therefore, the agent or
agents in use could not be deduced by physicians involved in the cases and potentially interfere with the interpretation of results.

Infections occurred in 20 percent (cefotixin) and 23 percent (clindamycin and gentamicin), respectively; 9 percent of which in each group were major infections, including septicemia, intra-abdominal abscess, and peritonitis. Minor infections occurred in 13 percent and 15 percent and were almost entirely related to the abdominal incision, which was closed primarily in all cases after irrigation with saline. A parallel group of 144 abdominal trauma patients was excluded from the formal study after receiving one dose of pre-operative antibiotics to inhibit contamination from intestinal spillage. Follow-up observation of these patients demonstrated major trauma-related infections in 2.8 percent and minor infections in 4.8 percent, a significantly lower infection rate than was observed in the study patients.

These findings compare favorably with infection rates reported in other recent studies using similar protocols and confirm previous observations that documented perforation of the bowel is the primary risk factor in predicting post-traumatic infection [3,4]. Individual risk factors ($p < 0.05$) for development of infection noted in our study were age, ostomy formation (performed for all left colon injuries), shock, number of organs injured, and amount of blood or blood products administered at surgery. Other authors have made similar observations for risk of infection using the standard injury severity score (ISS) [12]. Unlike some published reports, factors such as mechanism of injury (gunshot vs. stab wounds), small vs. large intestinal injury, and volume of blood in the peritoneal cavity at time of exploration were not predictive of infection [3,4,5,12]. It was determined that risk of infection following penetrating abdominal trauma could be described mathematically using a multiple logistic-regression analysis derived from the individual risk factors, according to the following formula:

$$\text{Probability of infection} = \frac{1}{1 + (2.892 - 1.05 \times A - 0.049 \times B + 2.516 \times C - 0.076 \times D)}$$

where 2.892 is a constant

- $A$ = number of organs injured
- $B$ = units of blood transfused during surgery
- $C$ = ostomy score (1 if ostomy required, 2 if not required)
- $D$ = age in years

This equation can easily be entered into a programmed pocket calculator for access at the time of surgery to calculate the risk of infection predicted by these variables. We are presently investigating use of this mathematical model as a guide for therapeutic decisions regarding wound closure and duration of antibiotic therapy. The study protocol currently in progress at our institution uses this formula in the following manner for trauma patients with gastrointestinal perforation:

1. if risk of infection (ROI) is $<0.40$, then the wound is closed and antibiotics are administered for two days following operation;
2. if ROI is $>0.40$ and $<0.70$, then the wound is closed and antibiotics are administered for five days; or
3. if ROI is $>0.70$, then the wound is packed open and antibiotics are administered for five days. It remains to be demonstrated whether this strategy of wound and antibiotic management, based on the individual patient’s risk of infection, will be
successful in reducing the high incidence of post-traumatic infections and, thus, length of hospital stay and overall costs.

GASTROINTESTINAL MICROFLORA

Every traumatic wound is by definition contaminated by some exogenous bacteria, but this fact alone does not necessarily result in infection. Infection occurs when the bacterial inoculum is sufficient to overwhelm local and host defense mechanisms. Degree of bacterial contamination within the peritoneal cavity becomes crucial in predicting the risk of infection following penetrating abdominal trauma. The importance of intestinal perforation in determining this risk becomes apparent when one compares the variation and density of microflora present in each portion of the gastrointestinal tract with other potential sources of contamination [10]. Introduction of relatively smaller numbers of skin bacteria, such as Staphylococcus aureus, by surgery or foreign material have recently been shown in microbiological studies to play only a minor role in infection following penetrating abdominal trauma [2,3,4,7]. Site of intestinal perforation and extent of spillage are much more predictive of the quantity and character of contaminating organisms found in post-traumatic infections (Table 1) [10,13,14,15].

Normally the concentration of microorganisms within the stomach is low, less than $10^4$ colonies/ml, due to the inhibitory effects of gastric acidity and motility [10,13]. The small intestine usually contains $10^6$-8 colonies/ml with highest concentrations of organisms found in the ileum. There is a transition in the small bowel from aerobic bacteria, like streptococcus and enterococcus, proximally to gram-negative coliforms and anaerobes in the distal ileum [10,14]. The microflora change dramatically beyond the ileocecal valve; bacteria form 20 percent of fecal mass with a ratio of coliforms or facultative organisms to obligate anaerobes, including Bacteroides fragilis, of 1:1,000. Colon contents may harbor greater than $10^{10}$-11 colonies/ml due to concentration and solidification of feces [10,15]. Thus, soilage by fecal material from anywhere in the colon, especially the left colon, results in substantial peritoneal inoculation by both aerobic and anaerobic organisms. In addition, these obligate anaerobes are often resistant to many of the antibiotics frequently used in treatment of trauma patients, a factor which may also influence risk of infection [7].

All patients entered into our study had documented intestinal perforation distal to the duodenum. This report did not find a statistical difference in the risk of infection between small and large bowel injuries, which is surprising in view of the quantitative differences in bacterial contamination. It should be noted, however, that all left colon injuries in this study were treated uniformly by colostomy, which was a significant risk factor for infection, although the mechanism of this finding may not be clear [2].

EXPERIMENTAL STUDIES

Experimental studies have added much information to our understanding of the bacteriology of penetrating abdominal trauma. The prominent role of anaerobic microorganisms was long underestimated due to inadequate methods of identifying their presence by routine laboratory procedures [7]. Fecal peritoneal contamination using a rat model demonstrated the importance of aerobic bacteria, such as Escherichia coli, in producing early mortality from peritonitis and bacteremia, and of anaerobic bacteria, like Bacteroides fragilis, in the development of later intra-abdominal abscesses in those animals that survived [16].
RISK OF INFECTION FOLLOWING ABDOMINAL TRAUMA

TABLE 1
Bacteria Causing Post-Operative Infection Following Penetrating Abdominal Trauma

| Organ | Aerobes             | Anaerobes       |
|-------|---------------------|-----------------|
| Stomach | Streptococci       | Bacteroides species |
|       | E. coli             | Peptostreptococci |
|       | Klebsiella          | Fusobacteria    |
|       | Enterobacter        |                 |
| Ileum | E. coli             | Bacteroides fragilis |
|       | Group D Strep.      | Bacteroides species |
|       | Klebsiella          | Clostridia species |
|       | Enterobacter        | Peptostreptococci |
| Colon | E. coli             | Bacteroides fragilis |
|       | Klebsiella          | Bacteroides species |
|       | Enterobacter        | Clostridia species |

From [10, 13, 14, 15]

In studies by Weinstein et al. [17], a standard inoculum of pooled rat feces was placed into the peritoneal cavity of rats, resulting in a 37 percent mortality. In one group of rats that received gentamicin alone (aerobic coverage) mortality was reduced to 4 percent, but 98 percent of those rats surviving developed intra-abdominal abscesses. Another group received clindamycin alone (anaerobic coverage), 35 percent died of peritonitis, but only 5 percent of survivors developed abscesses. A third group received a combination of gentamicin and clindamycin, with an acute mortality of 7 percent and late abscess formation of only 6 percent. Extension of these experimental studies using a human stool inoculum demonstrated even greater synergism between aerobes and anaerobes in both the early and late stages of intra-abdominal sepsis [18]. These studies demonstrate experimentally the polymicrobial nature of abdominal sepsis and effectiveness of antibiotic therapy against aerobic and anaerobic organisms following fecal contamination.

ANTIMICROBIAL THERAPY

Rational antibiotic therapy for patients with penetrating abdominal trauma should include parenteral antibiotics effective against both aerobic and anaerobic bacteria (Table 2) [2,7,10,19]. Parenteral antibiotics should be administered prior to surgical intervention in doses sufficient to achieve adequate tissue concentrations. Antimicrobial agents in this setting are not prophylactic in the sense applied to elective surgical procedures, since endogenous contamination, if present, has already occurred in most cases. Duration of antibiotic therapy is an important cost-containing issue for which there are little objective data. Antibiotics appear to be efficacious when limited to one pre-operative dose if no gastrointestinal injury is found [2]; otherwise therapy should be continued for two to five days, depending upon degree of contamination and risk of infection.

OPERATIVE MANAGEMENT

Attention to operative technique may also prevent errors in patient management resulting in infectious complications. General principles include rapid resuscitation, restoration of blood volume, and prompt surgical intervention. Control of hemorrhage
and fecal spillage are primary steps during the initial survey of abdominal injuries. Injuries to solid organs, including splenic trauma, should be treated conservatively. Open Penrose drainage is often accompanied by an increased incidence of infection, and a closed suction system is currently recommended if drainage is required [20]. Severe duodenal injuries frequently require diversion and drainage. Debridement and closure or resection and reanastomosis are most often performed for stomach and small bowel injuries. This approach can also be used for uncomplicated right and transverse colon injuries. It is currently preferred that any major colon injuries with gross fecal spillage and all left colon injuries be treated by diverting colostomy. Copious irrigation of the peritoneal cavity with warm saline will reduce residual soilage. In cases of gross contamination or high risk for infection, the abdominal wound should be irrigated with saline, packed open, and closed secondarily.

CONCLUSION

In this review we have discussed many of the important issues currently under investigation regarding risk of infection following penetrating abdominal trauma. Intestinal perforation and spillage, especially from the left colon, have been shown to be of primary importance due to the high concentrations of offending organisms. Although appropriate use of antibiotics effective against both aerobic and anaerobic bacteria has made a major impact on trauma care, timely surgical intervention and sound judgment are of most importance. Identification of risk factors predictive of post-operative infection can influence both surgical and medical decisions, resulting in lower infection rates and reduction of costs. Examples of important areas in which cost-effective alterations in therapy are possible include: choice of appropriate antibiotics, duration of antibiotic administration, treatment of specific abdominal injuries, and wound management. Further clinical investigations into these more cost-conscious and cost-effective aspects of trauma care are currently under way, employing objective assessment of the individual patient’s risk of infection based on the predictive nature of risk factors at the time of surgery for penetrating abdominal trauma.
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