Surgical Management of Penetrating Brain Injury

I. RECOMMENDATIONS

A. Standards
The available data are not sufficient to support a treatment Standard for surgical management of penetrating brain injury (PBI).

B. Guidelines
The available data are not sufficient to support a treatment Guideline for this topic.

C. Options
Treatment of small entrance bullet wounds to the head with local wound care and closure in patients whose scalp is not devitalized and have no “significant” intracranial pathologic findings is recommended. (Note: The term “significant” has yet to be clearly defined. However, the volume and location of the brain injury, evidence of mass effect, e.g., displacement of the midline > 5 mm or compression of basilar cisterns from edema or hematoma, and the patient’s clinical condition all pertain to significance.)

Treatment of more extensive wounds with nonviable scalp, bone, or dura with more extensive debridement before primary closure or grafting to secure a watertight wound is recommended. In patients with significant fragmentation of the skull, debridement of the cranial wound with either cranectomy or craniotomy is recommended.

In the presence of significant mass effect, debridement of necrotic brain tissue and safely accessible bone fragments is recommended. Evacuation of intracranial hematomas with significant mass effect is recommended.

In the absence of significant mass effect, surgical debridement of the missile track in the brain is not recommended, on the basis of Class III evidence that outcomes are not measurably worse in patients who do not have aggressive debridement. Routine surgical removal of fragments lodged distant from the entry site and reoperation solely to remove retained bone or missile fragments are not recommended.

Repair of an open-air sinus injury with watertight closure of the dura is recommended. Clinical circumstances dictate the timing of the repair. Any repairs requiring duraplasty can be at the discretion of the surgeon as to material used for closure.

II. OVERVIEW
The foundations of our present knowledge about surgical management of penetrating brain injury (PBI) lie in the battlefield. Much of this information is attributed to Cushing’s World War I description of the technique of en bloc craniectomy under aseptic conditions; thorough debridement of scalp, bone, brain, metal, and bone fragments; and watertight closure of the scalp. By the end of the war, Cushing’s own record of postoperative mortality from PBI dropped from 55% to 28%, even in this preantibiotic period.1 Mortality decreased even further in World War II, primarily because neurosurgical personnel were present in forward military hospitals and antibiotics were introduced. The operative approach, however, was largely the same, that of radical debridement. Treatment consisted of four tiers: immediate saving of life through control of persistent bleeding and cerebral decompression; prevention of infection through extensive debridement of all contaminated, macerated, or ischemic tissues; preservation of nervous tissue through prevention of meningoencephalotomies; and restoration of anatomic structures through accurate closure of the dura and scalp. Although untested against other management approaches, this approach became the de facto standard of treatment for PBI. Indeed, in the United States military, thorough debridement of intracranial bone and metal fragments was official military policy through the Vietnam War. Such protocol-driven treatment provided a valuable, large database that allowed reevaluation of this treatment practice. In later foreign military conflicts and in the civilian sector, various debridement techniques have also improved our understanding of the appropriate application of the technique. Certain considerations are called for when evaluating military and civilian literature:

1. Most PBIs incurred on the battlefield are from shrapnel, not bullets, like most civilian PBIs.
2. Most individuals wounded on the battlefield by a high-velocity bullet to the head presumably never make it to medical care because of the extremely damaging cerebral injuries that these bullets inflict (field triage under battle conditions requires the corpsman to identify the injured who have a low probability of surviving and to not prioritize them for rapid transport; this practice skews the remaining military PBI population toward lower velocity shrapnel wounds).
3. The determinants of the methods and applications of field resuscitation and triage are difficult to control and compare with the civilian situation.
4. Wounds are much more likely to be contaminated on the battlefield.
5. The conditions of early surgical treatment in the military setting are generally unique and limited compared with civilian treatment facilities (e.g., only inferior and limited radiographic imaging technology are usually available during early treatment), which impairs early
diagnosis. Also, as described in the literature, although computed tomographic (CT) scanning was generally available in civilian emergency centers in the 1970s, the first reports describing routine use of CT scanning on the battlefield date from conflicts in the early 1980s.²,³

For these reasons, it is difficult to extrapolate from the protocol-driven, shrapnel-predominating, battlefield conditions of the military setting, where gunshot wounds to the head are characteristically high-velocity insults, to the civilian situation where generally low-velocity gunshot wounds constitute the vast majority of PBIs. The exigencies of early resuscitation and triage are also completely different between the civilian situation and the battlefield. Modes of injury, such as a high prevalence of suicide in the civilian setting, are also different. Comparative analysis of data from such vastly differing situations is made more difficult by a paucity of multivariate control of confounding variables in both bodies of literature.⁴ For these reasons, the military literature is analyzed separately here from the civilian literature.

III. PROCESS

A MEDLINE search from January 1966 to January 2000 used the search terms wounds, gunshot, and brain injuries or head injuries. When limited to human subjects, 382 articles were identified. An additional 33 articles were then selected from the bibliographies of reviewed articles. Eighty-eight articles were rejected on the basis of clearly irrelevant titles. The primary selection process, therefore, identified 327 articles for further review. Two independent reviewers read the 327 abstracts and rejected those meeting the following criteria: non-English language, case reports, irrelevance to the project, atypical mechanisms of injury, and series of less than 10 subjects with no other unique reasons for inclusion. The remaining 65 articles were then read in detail. During this process, more articles were considered from the bibliographies of the 65 articles and rejected or added to the active list using the above inclusion and exclusion criteria. Of the 65 articles, 52 were directly relevant to the topics of surgical management, monitoring of intracranial pressure, and treatment of cerebrospinal fluid (CSF) leaks. Twenty-four articles were appropriate for this section of the Guidelines and were analyzed in detail for this topic.

IV. SCIENTIFIC FOUNDATION

The Military Literature

Aggressive Debridement

Although the literature reports a mortality rate from PBIs under wartime conditions ranging from 8% to 43%, it is generally reported to be in the 20% range.²,³,⁵,⁻¹¹ The mortality rate from military gunshot wounds has been reported to be 2.5 to 4 times more than from shrapnel.²,³,⁵,¹⁰ Unfortunately, using mortality as the dependent variable when comparing different treatment methods is even less reliable in the military setting than in the civilian setting. It has been suggested that a lower mortality rate reflects early triage and survivability decisions as much as treatment effectiveness.⁸,¹² In general, mortality rates from wartime PBIs in the U.S. military from World War II through the Vietnam War did not change significantly.¹² Notably correlated with these figures is the relatively unchanged military policy during that period regarding the management of PBI. The most cogent aspect is the mandate to completely remove intracranial bone or metal fragments, using repeated surgeries as necessary.¹⁵ The rationale for such aggressive debridement was the perceived value in preventing complications, such as infection, epilepsy, and cerebral edema, that result from retained fragments.

Wartime studies reveal that repeated craniotomy to remove retained fragments results in significant morbidity and mortality.¹⁰,¹⁴,¹⁵ Carey et al., describing the Vietnam experience, reported four complications resulting from 23 operations in 16 patients. Three of the four were major, with one resulting in death.⁸ In addition, follow-up studies of patients wounded in Vietnam (where more sophisticated plain radiographic equipment and CT scanning were available) suggest that a significant number of patients retained fragments of bone despite repeated attempts at complete removal.¹⁶ Therefore, the risk/benefit ratio of attempting to remove all intracranial fragments, either through vigorous explorations during the initial surgery or repeated craniotomies, has been questioned in terms of its effectiveness in preventing infection or seizures and improving outcome.

Furthermore, as documented in the section of these Guidelines on antibiotic prophylaxis, the literature from recent military conflicts when broad-spectrum antibiotics were widely used suggests that retained bone fragments no longer appear to be independently associated with increased risk of infection. Therefore, the argument for aggressive debridement no longer appears to be supported.⁴

Less Aggressive Debridement in the Military Circumstance

As noted previously, until the end of the Vietnam War, the U.S. military’s command policy mandated vigorous debridement and reoperation for retained bone. No useful data from U.S. war efforts are available to allow analysis of less aggressive approaches. However, six studies from non-U.S. conflicts do describe less aggressive management policies.²,⁷,⁹,¹⁴,¹⁷,¹⁸ Four of these studies include data on a full spectrum of severity of injuries from the immediate postinjury course and focus on outcome.²,⁷,⁹,¹² Notably, CT scanning was available to all these investigators except Vrankovic et al.,¹⁸ in contrast to the U.S. military reports.

Gonul et al. describe a retrospective review of 148 patients whose PBIs were locally debrided and the dura tightly closed without attempts to remove deeper fragments of bone or metal.⁹ They report a discharge mortality rate of 8% and an infection rate of 6% (slightly greater among patients without retained bone).
Brandvold et al.\(^7\) and Levi et al. studied the same cohort of patients and reported on the first routine use of CT scanning to evaluate combat casualties. They prospectively studied 116 patients treated with local debridement, removal of hematomas, and watertight dural closure without removal of distant or nonencountered fragments of bone or metal.\(^2,3\) Ten percent of patients did not undergo craniotomy but had local wound closure only. Their mortality rate at discharge was 26%, including 7% who were judged not salvageable and did not undergo surgery. The authors stressed the utility of CT scanning in preoperative planning.

Taha et al. reported on 32 patients whose wounds were treated with simple wound closure.\(^17\) The selection criteria for these patients included the following: initial Glasgow Coma Scale (GCS) score > 10; presented for treatment within 6 hours of injury; entry wound < 2 cm (with or without visible cerebral tissue through wound or in-driven bone); no exit wound; trajectory not through the proximal Sylvian fissure; and no significant intracranial hematomas.\(^17\) Wounds were closed in a single layer in the emergency room and the patients were treated with intravenous methicillin for 3 days. This approach resulted in no deaths and one brain abscess as the only infection (3%). The authors stressed that their selection criteria attempted to eliminate patients with significant amounts of devitalized tissue (e.g., eliminating patients with exit wounds in an attempt to select against high-velocity gunshot injuries).

### Post-PBI Epilepsy in Military Victims

One of the supporting arguments for vigorous debridement has been the prevention of seizures. The incidence of epilepsy after military PBI has been reported to range from 22% to 53%.\(^7,19,20\) Salazar et al., studying a nonbiased sample of 421 of the 1,131 Vietnam veterans in the Vietnam Head Injury Study (VHIS), reported an incidence of epilepsy of 53% at 15-year follow-up.\(^20\) They demonstrated that lesion location and size, as well as the presence of metal fragments, correlated with the development of epilepsy; however, they found no relationship between retained bone fragments and seizure disorder. Studying a cohort of patients treated without vigorous debridement or reoperation for retained fragments, Brandvold et al. reported a similarly positive correlation for metal fragments and a negative correlation for bone fragments. This study involved a much smaller (n = 49) group of prospectively studied patients with a 6-year follow-up, and the authors did not use a multivariate control for confounding variables.\(^7\) Gonul et al. reported no seizures through 1 year of follow-up in 148 prospectively studied patients treated in a similarly conservative fashion (although these patients took phenytoin during this period).\(^9\) Although none of these studies used multivariate analysis to control for all confounding variables, they do suggest that an analysis of the available evidence does not support the need to remove all bone fragments in order to decrease subsequent seizure disorder. However, whether or not removal of metal fragments reduces the risk of subsequent seizure disorder is less clear.

This data analysis suggests that the military literature does not support the need for vigorous removal of all bone and metal fragments, including repeated craniotomy. The lack of internally controlled studies and the use of multivariate statistics to control for other confounding variables in the analysis of this question renders the level of confidence in this Guideline’s evidence-based process entirely at the Class III level. If the issue is to be settled more scientifically, controlled trials are needed. Currently, however, it appears that vigorous debridement is not necessary to prevent infection, has no obvious efficacy in preventing epilepsy, and is associated with morbidity and mortality without resulting in any clear advantage in mortality.

### CSF Leaks in Military Injuries

The presence of an acute or delayed CSF leak is the variable most highly correlated with intracranial infection after PBI in studies of infectious complications of military injuries or outcome from CSF fistulae.\(^6,7,10,16,21–23\) In studies that include data on incidence of CSF leaks in unselected populations, 49.5% to 63% of such patients became infected.\(^10,22\) The one published study that focused directly on CSF fistulae studied the 101 patients with leaks of the 1,133 patients in the VHIS.\(^22\) In that study, only 50% of leaks were at the wound site; the others were presumably caused by the fractures and dural rents resulting from the concussive effect of the projectile. Forty-four percent of the leaks closed spontaneously. Seventy-two percent of the leaks appeared within 2 weeks of injury. Mortality for patients with CSF leaks was 22.8% versus 5.1% for patients without leaks, although no control for confounding variables was used. The incidence of infection in this study was 49.5% versus 4.6% in the 1,032 casualties without CSF leaks. The authors suggested treating CSF leaks vigorously when they are detected. They stressed watertight closure of wounds (with a graft if necessary) and closure of the scalp in layers. They concluded that wounds associated with transventricular trajectories are most at risk of leaking and suggested a course of CSF drainage in such cases. They also emphasized vigilance for rhinorrhea or otorrhea, particularly in cases where the fistula is not continuous with the entry or exit wounds, and stressed the need to close the fistula.

The only article that directly addresses closure methods for CSF leaks through entry wounds concluded that autolo-
gous material is preferable, particularly fascia lata, but it included no statistics or controls for confounding variables. The choice of closure technique and material for closure, therefore, remains entirely at the discretion of the surgeon.

**Craniotomy versus Craniectomy in Military Injuries**

Rish et al. was the only group to study craniectomy versus craniotomy to manage PBI. The standard protocol included exposure of the surgical field by craniectomy from the skull defect outward in order to remove devitalized tissue. This was a case-control study, retrospectively matching the 63 cases who underwent craniotomy with the remaining 774 cases in the VHIS database who did not have wounds involving sinuses or facio-orbital penetration. The authors attempted to match the patients on five variables. They found no difference between these two groups in terms of morbidity (including postoperative infection) and mortality. They were unable to control for the factors that initially led to the decision to perform craniotomy rather than craniectomy.

**Timing of Cranioplasty in Military Injuries**

Hammon and Kempe, reporting on 417 cranioplasties performed at one center over 13 years, describe a morbidity rate of less than 2% after using a strict surgical protocol that called for delaying cranioplasty for a minimum of 1 year after injury. Rish et al. also looked at complications associated with cranioplasty for cosmetic or protective purposes after military PBI. In that study, numerous surgeons performed cranioplasties at a variety of centers. The authors found that the incidence of postcranioplasty complication was greatly increased (56%) among patients who had a complication (e.g., infection or CSF leak) during initial care. They also found that complications increased among patients whose cranioplasty was performed less than 1 year after injury (20%) versus more than 1 year after injury (4%). In cases without initial complications, there did not appear to be any difference in infection rate as a function of timing of cranioplasty.

**Civilian Literature**

As noted previously, military PBI and civilian PBI differ markedly. In contrast to the battlefield situation, civilian PBIs most often result from low-velocity gunshot wounds, frequently the result of suicide attempt. The injured are transported over relatively short distances under comparatively well-controlled conditions, and are usually treated at hospitals with modern diagnostic, monitoring, and treatment capability. In many cases, this means that a wide variety of modern resources can be used for patients with wounds, resulting in a case-fatality ratio estimated by the U.S. Centers for Disease Control and Prevention at approximately 94%.

The combination of efficient and effective prehospital triage and very high mortality focuses on the limits of salvageability. In the absence of consensus on prognostic variables, this means that studies are confounded by the presence of significant numbers of patients who are deemed unsalvageable and who therefore receive limited or no treatment on the basis of nonstandardized and generally vaguely specified decision criteria. This represents the most powerful confounding variable in the field setting because it impairs the interpretation of variables as diverse as surgical mortality and the incidence of PBI-related epilepsy. As such, in combination with the absence of multivariate analysis, the entire literature base on civilian PBI can be rated no higher than Class III.

**Surgical Aggressiveness in Civilian PBI**

Surgical aggressiveness includes both the decision to operate and the extent of the surgical procedure. The former is a question of prognosis and is discussed in the section of these Guidelines on prognosis of PBI. The issue of extent of surgery is well represented in the civilian literature. Studies describing limited debridement were published in the civilian literature in the late 1970s, over a decade before the military literature.

Lillard’s operative approach in the years before routine CT scanning included neither the pursuit of inaccessible bone or metal fragments nor the exploration of the bullet track. Surgery was performed on all patients who had accessible entrance wounds and who were judged viable. Lillard reported no increase in incidence of infection (4%), posttraumatic epilepsy (13%), or mortality among patients who underwent operation, despite the retained foreign bodies (33%). Potapov et al. reported a series of civilian PBIs in Russia with initial debridement in regional hospitals who subsequently had CT scanning and reoperation for removal of hematomas and accessible foreign bodies. The incidence of infection in this group was 18%, and the identified risk factors for infectious complications of the PBI were tranventricular injury, CSF leakage, and reoperation. They operated to remove intracerebral foreign bodies only when they believed the operative intervention would not aggravate the severity of the cerebral injury.

Hubschmann et al., also in the absence of routine CT scanning, limited their debridement and did not aggressively pursue intracranial bullets if they were not readily accessible. They thought that surgery should be performed only on patients who had “the potential for functional neurological recovery.” This produced a potentially self-determined mortality rate of 92% among patients who did not undergo surgery and a mortality rate of 22% among those who did. These authors reported infectious complications (meningitis) in 4% of patients. Although it is difficult to rigorously compare these studies with others using more aggressive surgical approaches, the lack of obvious increases in mortality or the frequency of complications is consistent with the recent military literature in suggesting that vigorous pursuit of intracranial fragments is not necessary. Unfortunately, since all available studies are Class III, any comparison must be interpreted with caution.
In 1987, Suddaby et al. presented the results of minimal surgery on relatively neurologically intact patients injured by .22 caliber weapons in which debridement was reserved for patients whose condition had deteriorated or who had hematomas.23 In their study, most patients received local wound care in the emergency room. The overall mortality and incidence of complications, particularly infection, were not notably different from studies involving more aggressive surgical approaches. Sarnaik et al. extended the concept of targeted surgery to injuries from all calibers of bullets among a small group of children who were comatose after PBI. They performed intracranial pressure monitoring and aggressive prophylaxis against intracranial hypertension in all cases and limited debridement and hematoma removal to the treatment of intracatable ICP elevation (although all such patients eventually underwent surgery). In another study, Shoung et al. concluded that the only indication for aggressive surgery was the presence of an expansive intracranial lesion (e.g., contusion, hematoma) seen on CT scan in a patient who was not decerebrate or flaccid.30 Otherwise, local wound care, debridement, and dural closure were performed. Their mortality rate among patients judged candidates for treatment was 35%. Although these studies are limited in subject, numbers, and scope, they do raise the question regarding the need for debridement in addition to careful wound care and watertight closure.

Hematomas in Civilian Injuries

The importance of identifying and removing hematomas to improve outcome from PBI was stressed even before CT scanning was commonly used.31–37 The association between hematomas with mass effect and intracranial hypertension when intracranial pressure (ICP) is monitored has led to the general approach of removing hematomas in all patients judged viable candidates for resuscitation. As noted above, several publications posit that the only indication for surgery beyond wound care is mass effect such as that associated with hematomas.23,30,38 The approach of Sarnaik et al. is derived from the importance of the mass effect of hematomas (and thus the necessity for surgery) in comatose children directly on the presence of associated intracranial hypertension. However, all patients treated in this manner in their study eventually underwent surgery.38 Several authors opined that surgical removal of hematomas is indicated in some patients whose neurologic examinations placed them in the "nonsalvageable" category and that would have precluded surgical treatment had there been no clot.27,34 There are no controlled trials of hematoma removal in PBI patients and no studies large enough to allow the use of multivariate statistics to evaluate the independent contribution to outcome of hematoma removal. Thus, no strong conclusions can be drawn regarding the removal of hematomas. However, it would be consistent with common practice, as reflected in the literature, to remove hematomas from all patients judged capable of functional survival unless the hematoma is thought to be of no consequence in terms of mass effect. ICP monitoring should be considered as an adjunct for supporting such a decision and for following the course of the hematoma in cases where the hematoma is not removed.

Timing of Surgery in Civilian Injuries

It is difficult to differentiate the effects on outcome of the timing of surgery from those resulting from rapid field triage and resuscitation. Although authors often state that early surgery is desirable, no solid evidence supports this practice.22,27,33,37 Hubschmann et al. stated that early surgery is indicated because the highest incidence of hematomas is between 3 and 8 hours after injury. However, they presented no clinical evidence supporting the effectiveness of early operative intervention.27 One study focused directly on the timing of surgery, but was unable to control for the various prognostic variables (i.e., GCS score, CT scan diagnosis) that led to the decision for no, early, or late surgery.15 The study patients undergoing late surgery were so different from the other two groups that no solid conclusions could be made about the actual timing of surgery. Arendall and Meirowsky studied PBI associated with air sinus injuries in 163 patients from the Korean War.39 Although their inability to control for the cause of the delay to surgery confounded their findings, they reported an infection rate of 5% for patients who underwent surgery within 12 hours as compared with 38% for those whose surgery was delayed longer than 12 hours. Timing of surgery will also be influenced by the results of ICP monitoring, whereby patients initially judged not in need of intracranial surgery might undergo surgery later on the basis of the development of intracranial hypertension. Sarnaik et al. delayed surgery on the basis of the ICP course and did not believe it altered outcome, although this was a subjective impression.38

On the basis of the present body of literature, the question of timing of surgery has not been adequately studied to make evidence-based recommendations. Clearly, the general practice is to operate as soon as the indications for surgery are recognized. If simple wound care is elected, this should be performed expeditiously to prevent the complications associated with CSF contamination. If intracranial surgery is indicated, this should also be performed promptly. If the intracranial findings are equivocal, follow-up CT scanning and intracranial pressure monitoring should be strongly considered as adjuncts to determining the need for and timing of surgical intervention.

V. SUMMARY

Currently, surgical management of PBI clearly tends toward minimizing the degree of debridement. There are no controlled studies that have examined the relative effi-
cacy of various degrees of debridement to prevent infection and minimize the development of seizure disorders. The evidence supporting the current trend toward less debridement is Class III. Furthermore, the majority of data come from the civilian sector, and thus are weak with respect to the military setting, where shrapnel wounds are predominant and bullet wounds are generally the result of much higher velocity weapons. If a lexicon of injury classification variables is developed that allows patient stratification, it should be possible in a multicenter, prospective, randomized study to answer the question of how aggressive debridement needs to be.

VI. KEY ISSUES FOR FUTURE INVESTIGATIONS

Comparative studies of limited versus radical debridement of missile head wounds should be conducted taking into consideration variables such as type of injury, admission GCS score, and timing of surgery, and examining outcome related to mortality, morbidity, and disability. The diagnostic, prognostic, and therapeutic role of neurophysiologic monitoring in the management of PBI should be determined.

It would be worth investigating which hematomas or areas of contused (and, presumably, nonviable) brain should be removed and when. Although never formally studied, it appears that the removal of obvious mass lesions among patients judged capable of functional survival is associated with improved survival. The unclear issues include what constitutes a surgical mass lesion and how this should relate to the timing of surgery. A prospective investigation should document the interaction between ICP and cerebral perfusion pressure monitoring (and perhaps cerebral oxygen delivery).

VII. Evidentiary Table: Surgical Management of Penetrating Brain Injury

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<tr>
<th>Authors, Year</th>
<th>Description of Study</th>
<th>Data Class</th>
<th>Conclusions</th>
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<tr>
<td>Aarabi et al., 1998</td>
<td>Surgical experience with casualties from the Iran-Iraq War. Retrospective study of infectious complications among 105 patients with univariate and multivariate analysis of predictors of intracranial infection in the entire group, including projectile type, injury mode, air sinus involvement, number of involved lobes, transventricular injuries, location of exploration, CSF leak, GCS score, retained bone, and retained metal.</td>
<td>III</td>
<td>Clinical infection in 105 patients, 82 meningitis, 20 abscess. Causative organisms, 45% gram-negative and 15% gram-positive. Features related to infection were mainly CSF leaks, transventricular injury, and paranasal sinus injury.</td>
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<td>Aarabi, 1987</td>
<td>Surgical experience with casualties from the Iran-Iraq War at primary and tertiary hospitals. Comparative study of bacterial contamination of scalp wound, in-driven bone fragments, and brain track in two groups of patients with missile head wounds from the Iran-Iraq War. Group A (n = 62) had primary and group B (n = 53) had secondary exploration at the study center. Postsurgical infection rate and the potential for retained bone fragments to cause delayed infection were evaluated.</td>
<td>III</td>
<td>Positive cultures in approximately 20% of samples of bone removed at surgery. Infection associated with retained bone is highly confounded by other risk factors for infection, such as CSF leaks, type of injury, or wound dehiscence. The variable most highly correlated with intracranial infection was the presence of an acute or delayed CSF leak. With adherence to principles of debridement, tiny bone chips if impossible to remove, pose a negligible threat of deep infections.</td>
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<td>Arendall and Meirowsky, 1983</td>
<td>Evaluation of casualties from the Korean War with air sinus injuries. CSF fistula was noted in 28% of the patients associated with high incidence of infection. The authors recommend exenteration of the sinuses and watertight repair of basal dura with graft.</td>
<td>III</td>
<td>High mortality associated with penetrating wound of air sinuses can be reduced by prompt and radical debridement and by exenteration of the injured air sinus. Prevention of CSF fistula by meticulous dural repair reduces infection. The variable most highly correlated with intracranial infection is the presence of an acute or delayed CSF leak. Infection rate of 5% for surgery within 12 h as compared with 38% for surgery at a greater delay.</td>
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<td>Benzel et al., 1991</td>
<td>Victims of civilian gunshot wounds to the head were evaluated 3–4 mo after surgical and nonsurgical management for their outcome on the basis of the state of consciousness.</td>
<td>III</td>
<td>Surgical removal of hematomas is indicated in some patients with neurologic examinations that would place them into the &quot;nonsalvageable&quot; category in the absence of a hematoma. Identifying and removing hematomas is important in improving outcome.</td>
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<td>Brandvold et al., 1990</td>
<td>III</td>
<td>Military (n = 113). Casualties from Lebanese-Israeli conflict were debrided less vigorously to save additional cerebral tissue. Bone fragments were not chased and superficial irrigation was applied to remove necrotic material.</td>
<td>Limiting surgical goals to removal of gross contamination and any hematomas with minimal manipulation of cerebral tissue, with no attempt to remove fragments that are not readily accessible produced a discharge mortality rate of 13%, an infection rate of 8%, and no correlation between retained bone and epilepsy (22%). The variable most highly correlated with intracranial infection is the presence of an acute or delayed CSF leak.</td>
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<td>Carey et al., 1971</td>
<td>III</td>
<td>Military (n = 45). Bacteriologic studies were performed on skin wound, brain, and in-driven fragments retrieved within 2–4 h of injury in Vietnam.</td>
<td>45% of fragments obtained were positive on culture (suggested that about 25% of all intracranial fragments would be bacteriologically positive if all fragments were obtained).</td>
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<td>Carey et al., 1972</td>
<td>III</td>
<td>Military (n = 89). The surgical management of U.S. servicemen in Vietnam is discussed correlating increased mortality with decreased consciousness. Surgical procedure and early complications are described.</td>
<td>Reported 4 complications (3 were major, 1 resulted in mortality) resulting from 23 reoperations for retained bone in 16 patients.</td>
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<td>Gonul et al., 1997</td>
<td>III</td>
<td>Military (n = 148). Evaluation of immediate and long-term surgical complications (infections, CSF leaks, retained bone fragments) and mortality in casualties with penetrating craniocerebral wounds</td>
<td>The variable most highly correlated with intracranial infection is the presence of an acute or delayed CSF leak, which had a 63% infection rate. Retained bone fragments did not increase infection rate. Performed limited debridement with a discharge mortality of 8%, an infection rate of 9%, and no seizures through 1-y follow-up.</td>
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<td>Hammon, 1971</td>
<td>III</td>
<td>Military (n = 417). Reported on 417 cranioplasties performed over 13 years using a strictly followed surgical protocol delayed for a minimum of 1 y after injury and all performed at one center.</td>
<td>Reported zero mortality and a morbidity rate of &lt;2% using their approach. Mortality from military gunshot wounds 2.5 times that from shrapnel.</td>
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<td>Helling et al., 1992</td>
<td>III</td>
<td>Civilian (n = 89). Early surgical management (within 24 h) results are compared with late surgery (&gt;24 h) and no surgical intervention patients with gunshot wounds to the head taking into consideration GCS score and CT scan findings.</td>
<td>Early surgical intervention seemed to result in better survival but was unable to statistically control for the various prognostic variables (i.e. GCS score, CT scan diagnosis) that led to the actual decision to proceed with no, early, or late surgery. Identifying and removing hematomas is important in improving outcome. Some patients with severe neurologic deficit or bihemispheric injuries might benefit from aggressive management.</td>
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<td>Hubschmann et al., 1979</td>
<td>III</td>
<td>Civilian (n = 82). Correlating a simplified neurologic examination as a strong prognosticating tool among patients with civilian gunshot wound to the head in a 2-y study.</td>
<td>Limited debridement with no exceptional operative mortality (22%). Surgical removal of hematomas is indicated for some patients whose neurologic examinations place them in the “nonsalvageable” category in the absence of a hematoma. Thought that early surgery was beneficial, but presented no data.</td>
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<td>Levi et al., 1990</td>
<td>III</td>
<td>Military (n = 116). Cohort study of casualties from Israeli-Lebanese conflict with emphasis on CT imaging, the extent of surgery, and factors determining mortality and outcome over a 6-y follow-up.</td>
<td>Mortality from military gunshot wounds was 80% vs. 19% from shrapnel injuries. Limited debridement in a military situation resulting in an acceptable discharge mortality of 26% and no relative increase in infection or epilepsy. Stressed the utility of CT scanning in preoperative planning.</td>
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<td>Lillard, 1978</td>
<td>III</td>
<td>Civilian (n = 83). The report reviews the clinical course and treatment of victims with civilian penetrating GSW seen over a 5-y period. Mortality, morbidity, and conservative surgical approach in less devastated patients are emphasized.</td>
<td>Limited debridement approach produced no increase in incidence of infection (4%), posttraumatic epilepsy (13%), or mortality among patients taken for surgery despite retained foreign bodies in 33%.</td>
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Surgical Management of Penetrating Brain Injury

VII. Continued

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<tr>
<td>Meirowsky et al., 1981</td>
<td>Military (n = 101). Review of patients in the Caveness-Rish database from Vietnam with missile head wounds complicated by CSF fistulas. The morbidity and mortality related to vertex and basilar fistulas and their relation with dural closure and discontinuous fractures are discussed.</td>
<td>III</td>
<td>Only 50% of CSF leaks at wound site; the remainder being rhinorrhea or otorrhea from remote basal skull fractures; 44% of leaks closed spontaneously; 72% of leaks appeared ≤2 wk after injury. Mortality with CSF leaks was 22.8% vs. 5.1% without leaks. Infection incidence was 49.5% vs. 4.6% in the 1,032 casualties without CSF leaks. Stressed vigilance for leaks and definitive treatment when found. The variable most highly correlated with intracranial infection was the presence of an acute or delayed CSF leak, which had a 49.5% infection rate.</td>
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<td>Potapov et al., 1999</td>
<td>Civilian (n = 159). 72 patients admitted in acute period, 87 after acute period. 51 of 72 patients had initial debridement in regional hospitals. CT scanning performed at neurosurgical center followed by removal of hematomas, mass lesions, and accessible foreign bodies in 17 patients, craniobasal fragments in 2, and closure of basal CSF fistula in 1.</td>
<td>III</td>
<td>Intracranial infection in 13 patients (18%). Risk factors of intracranial infection were transventricular injury, CSF leakage, and reoperation (p &lt; 0.05). Outcome: good to moderate recovery, 54%; severely disabled, 29%; dead, 17%.</td>
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<td>Rish et al., 1979</td>
<td>Military (n = 491). Study of cranioplasty in the Caveness-Rish database from Vietnam, performed at a variety of centers by numerous surgeons with various synthetic materials.</td>
<td>III</td>
<td>Incidence of cranioplasty complications greatly increased if there had been any complication accompanying the initial care (i.e., infection or CSF leak) if the cranioplasty was performed within 1 y of injury (20%; 56% if the initial complication was infection) vs. subsequently (4%). In cases completely devoid of initial complications, there did not appear to be any difference in infection rate as a function of time to cranioplasty.</td>
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<td>Rish et al., 1980</td>
<td>Military (n = 63). Cohort-control study, retrospectively matching the 63 cases performed via craniotomy from the remaining 774 remaining cases in the Caveness-Rish database that did not have wounds involving sinuses or facio-orbital penetration.</td>
<td>III</td>
<td>Found no difference between craniotomy or craniectomy groups in terms of morbidity (including postoperative infection) or mortality. They were unable to control for the factors that initially led to the selection of the 63 patients for craniotomy rather than craniectomy. Craniotomy gives better exposure for debridement and no need for future cranioplasty.</td>
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<td>Rish et al., 1981</td>
<td>Military (n = 37). Factors contributing to the formation of brain abscess after missile head wounds were evaluated in casualties in the Caveness-Rish database from Vietnam in this follow-up study of patients from Vietnam using more sophisticated plain radiographic equipment and CT scanning.</td>
<td>III</td>
<td>3% incidence of abscess in 1,221 patients. High frequency of retained bone among patients with infections but were unable to control for incidence of bone fragments in noninfected patients. Almost all instances of infections associated with bone fragments were associated with one or more (generally several) other powerful risk factors, such as CSF leak. Retained fragments of bone common despite repeated attempts at complete removal.</td>
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<td>Salazar et al., 1995</td>
<td>Military (n = 342). Long-term follow-up study of Vietnam veterans in the Caveness-Rish database from Vietnam, looking into the question of posttraumatic epilepsy and consciousness, and psychological outcome of patients with craniocerebral missile wounds.</td>
<td>III</td>
<td>53% incidence of epilepsy after military PBI at 15-y follow-up. Posttraumatic epilepsy was related to extent of brain damage, retained metal fragments, intracerebral hematomas, residual motor and speech deficits, and visual field deficits. No relationship between retained bone fragments and posttraumatic epilepsy.</td>
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<td>Sarnaik et al., 1989</td>
<td>Civilian (n = 14). Pediatric study. Better functioning children underwent simple wound care and observation. Performed ICP monitoring and aggressive prophylaxis against intracranial hypertension in all severe cases. Limited debridement and hematoma removal to the treatment of intractable ICP elevation.</td>
<td>III</td>
<td>Determined the importance of mass effect of hematomas (and thus the necessity for surgery) in comatose children directly on the basis of the presence of associated intracranial hypertension. Reported outcomes well within those reported for more aggressive surgical protocols (33% mortality in comatose children).</td>
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compliance, etc.), and anatomic studies. Such a study would involve the controversial issue of the limits of salvageability and who should be treated aggressively.

REFERENCES


Surgical Management of Penetrating Brain Injury


