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Gunshot Wounds to the Brain—A Civilian Experience

WILLIAM D. SHERMAN, MD; MICHAEL L. J. APUZZO, MD, JAMES S. HEIDEN, MD; VIESTURS T. PETERSONS, MD, *and* MARTIN H. WEISS, MD, *Los Angeles*

A study involving 79 patients who were considered for surgical treatment for craniocerebral gunshot injuries between 1972 and 1978 was carried out to develop criteria for radiographic assessment and surgical operation, as well as to improve operative techniques and preoperative planning. The study focused on differences between military and civilian injuries, as well as criteria for gross prediction of outcome.

Of note in the overall perspective of the series were (1) the predominance of low-velocity missiles, (2) the high rate of self-inflicted injuries (34 percent), (3) the overall mortality of 23 percent with the rate for persons older than 60 being approximately 70 percent, (4) the correlation between preoperative patient assessment and mortality, (5) complications predominated by cerebrospinal fluid fistulas (10 percent), (6) the value of computerized axial tomographic (CAT) scanning in patient assessment and operative strategy and (7) the ultimate employability rate in survivors (78 percent).

An historical review of the development of management principles based on operative experience in the military sector as well as other recent civilian literature also deserves consideration.

CHANGES IN SOCIAL BEHAVIOR and attitudes are reflected in the diseases and injuries that medical practitioners confront in their patients. In the United States, assaults and deaths by firearms have increased substantially.[1,2] In one representative metropolitan county in the Midwest, the death rate attributed to such assaults increased 135 percent from 1960 to 1970.[2] This paper presents the experience of the Los Angeles County-University of Southern California (LAC-USC) Medical Center in treating gunshot wounds to the brain.

Management of this injury has been well documented in military experience.[3-27] The surgical principles of removal of foreign bodies and devitalized tissue, reduction of mass affect and the concepts of wound closure have not changed, but differences between military and civilian cases make analysis of gunshot wounds to the brain of timely interest.

Patients

The LAC-USC Medical Center is the primary trauma center for the southeastern region of the Los Angeles County which has a population of

From the Department of Surgery, Division of Neurosurgery, University of Southern California School of Medicine, Los Angeles.

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Reprint requests to: Michael L. J. Apuzzo, MD, LAC/USC Medical Center, Box 27, Dept. of Neurosurgery, 1200 N. State St., Los Angeles, CA 90033.

TABLE 1.—*Age Distribution of Patients*

Age (Years)	Number of Cases (Percent)
1-10	2 (2.5)
11-20	14 (17.7)
21-40	47 (59.5)
41-60	10 (12.7)
>60	6 (7.6)
TOTALS	79 (100.0)

TABLE 2.—*Mortality Versus Clinical Stage*

Clinical Stage*	Number of Patients (Percent)	Deaths (Percent)
1	21 (27)	0 (0)
2	15 (19)	0 (0)
3	16 (20)	3 (19)
4	12 (15)	5 (42)
5	15 (19)	10 (67)
TOTALS	79 (100)	18 (23)

*Distribution of patients in each stage according to the seriousness of their condition before operation.

2.7 million and is the secondary referral center for the entire county, serving a population in excess of 8 million. The periods reviewed were from January 1972 to December 1976 and from January through December 1978. In the first period only patients undergoing surgical operations (N=65) were studied. During the second period, the review included all patients (N=34) with computerized axial tomographic (CAT) scanning data to rule out intracranial penetration from missile or bone fragmentation, or both. All charts were evaluated in a retrospective manner.

Of the patients in both periods who were treated surgically there were 64 males and 15 females. Ages ranged from 15 months to 81 years with a median of 21 years (Table 1). Most injuries resulted from low-muzzle energy weapons of .22 or .38 calibre. A single case was from a metal fragment of an exploding rifle.

Of the injuries, 34 percent were stated to be self-inflicted; 51 percent were entrance wounds between the nose and the right ear and 68 percent were entrance wounds on the right. These data are relevant when considering the final outcome and possible complications of this type of injury. The time from injury to admission to hospital ranged from ten minutes to three days, with a median of two hours. The time from injury to surgical operation ranged from two hours to 11 days with a median of ten hours.

The clinical rating system of Raimondi and Samuelson[25] was used. This system consists of five clinical grades:

- Stage 1—Alert, no loss of consciousness, no neurologic deficit;
- Stage 2—Alert, no loss of consciousness, localizing neurologic deficit;
- Stage 3—Awake, agitated, confused and lethargic;
- Stage 4—Comatose, responding only to pain;
- Stage 5—Comatose and posturing.

The distribution of patients in each stage was as follows: 21, stage 1; 15, stage 2; 16, stage 3; 12, stage 4, and 15, stage 5 (Table 2).

Management of Patients

All patients in coma were intubated to maintain adequate ventilation and to prevent aspiration. Arterial blood gases were monitored to insure adequate oxygenation and hyperventilation maintaining the carbon dioxide pressure (P_{CO_2}) in the range of 25 to 30 mm of mercury. Intracranial monitors were used infrequently in the second review period. Antibiotics were given to 95 percent of the patients. Seventy-five percent received ampicillin alone in a dosage of 160 mg per kg of body weight per 24 hours in divided doses, initially administered intravenously and subsequently orally. Twenty percent received a second antibiotic (erythromycin, streptomycin, cephalothin sodium, kanamycin, methicillin or gentamicin), in conjunction with or after ampicillin for bacteriologically resistant infections. Diphenylhydantoin was used as the only anticonvulsant in 60 percent of the patients, 30 percent received both diphenylhydantoin and phenobarbital and 10 percent received no anticonvulsants.

Radiographic Assessment

Plain film findings were significant in that in 49 percent of the patients metal and bone fragments were noted only adjacent to the entrance site. Another 40 percent of the patients had metal or bone fragments, or both, at least 4 cm from the entrance site. In three patients, pneumocephalus was noted.

Cerebral angiography was done in 52 percent of the patients in the first review period. The decision for angiography was made on clinical and radiographic grounds. Clinical indications for angiography included a comatose status with preservation of brain stem reflexes and spontaneous respirations. The radiographic criterion for angiography was a 4-cm or greater separation between the entrance and exit wound or between the main missile mass and the entrance wound. Abnormal angiographic findings were identified in 31 of the 34 angiograms as follows: venous sinus occlusion, 5; traumatic aneurysm, 4; subdural hematoma, 11; epidural hematoma, 3; mass affect alone, 10, and mass affect and other lesions, 21.

In the second review period (1978) CAT scans were carried out on 34 patients who received gunshot wounds to the face or head. Studies were obtained in any neurologically viable person in whom intracranial penetration or injury was suspected. Ten showed no intracranial penetration. Of the remaining 24 patients, ten had no operation, seven because they were moribund at admission and three because there was felt to be no dural penetration. Of the 14 patients operated on, CAT scans showed the location of metal and bone fragments as well as the presence of intracerebral hematomas, contusions, depressed skull fractures or a combination of these complications.

Surgical Management and Findings

Patients selected for surgical treatment included all who could speak or follow simple commands and comatose patients who maintained respirations and brain stem reflexes. Apneic patients with no brain reflexes were not considered for operations. Procedures were designed to remove foreign material (such as metal and bone fragments, dirt, hair, powder granules), to evacuate extraaxial and intraaxial hematomas, to debride necrotic brain and soft tissue, and to achieve an adequate closure of the dura and soft tissue layers. The goals were to mitigate intracranial pressure excursions, to prevent infection and to establish a climate for maximum neurologic recovery.

Surgical findings (Table 3) established the presence of intracranial hematomas greater than 20 ml in volume in 52 percent of the patients. Essentially all cases had areas of nonviable contused cerebral tissue and 75 percent of the patients required a significant lobe resection. The entire missile tract was not routinely debrided. Bone fragments were removed only if they were within the field of resection or palpable immediately beneath this area. Deeper fragments were not pursued. Cultures of the wound and bone fragments were done. Dural closure was obtained in 80 percent of the cases. Irrigation with bacitracin was used throughout the surgical procedures. Skin closure consisted of a single layer of wire.

TABLE 3.—*Incidence of Intracranial Hematomas*

Type of Intracranial Hematoma	*Number of Cases* (Percent)*	*Percentage of Cases From Literature†*
Subdural hematoma	7 (9)	21
Intracerebral hematoma	21 (27)	23
Epidural hematoma	1 (1)	3
Subdural hematoma and/or epidural hematoma and/or intracerebral hematomas	12 (15)	..
TOTALS	41 (52)	47

*Total number of cases in study was 79.
†Byrnes, et al.[4]

TABLE 4.—*Mortality Versus Age*

Age of Patient (Years)	*Number of Patients*	*Deaths (Percent)*
1-10	2	0 (0)
11-20	14	5 (36)
21-40	47	7 (15)
41-60	10	2 (20)
> 60	6	4 (67)
TOTALS	79	18 (23)

Results

The overall mortality was 23 percent (Table 4). There were no deaths in stages 1 or 2 (Table 2). Mortality in stages 3, 4 and 5 were 19 percent, 42 percent and 67 percent, respectively (Table 2). There were five survivors in stage 5; two of these were able to care for themselves but unemployable, and three were dependent on others because of residual intellectual or physical deficits, or both. Mortality in patients older than 60 was 70 percent while for those in the 21 to 40 age group, mortality was 15 percent (Table 4).

Complications (Table 5) were dominated by cerebrospinal fluid (CSF) fistulas and seizures. There were eight patients with cerebrospinal fluid fistulas (seven rhinorrhea and one otorrhea). Meningitis developed in two of these patients despite administration of antibiotics. In five of the eight patients, fistulas resolved with nonsurgical management, in two surgical closure was required and one died with a persistent fistula. The high incidence of rhinorrhea reflects the frequency of close-range, basifrontal injuries.

Seizures were seen within the first week of injury in seven patients; in the four who survived, convulsive symptoms continued to occur. Late

TABLE 5.—*Complications Resulting From Gunshot Injuries*

	Patients
Disseminated intravascular coagulopathy	3
Obstructive hydrocephalus	1
Retained bone fragments	1
Postoperative cerebrospinal fluid fistulas	8*
Rhinorrhea	7
Otorrhea	7
Wound infections	5
Meningitis	4
Cerebritis	1
Seizures	21
Early	7
Late	14

*In five of the patients fistulas resolved without surgical treatment and in two surgical closure was needed. One patient died with a persistent fistula.

seizures—those observed a week or more after injury—were seen in 14 patients. The rate of incidence of seizures in cases followed for more than two years was 36 percent (18 of 50 survivors). Twenty of the 21 patients with early or late seizures began receiving anticonvulsants shortly after admission.

A second operative procedure was carried out in eight patients. The causes were persistent CSF fistulas in two patients, retained bone and metal fragments in two, subdural hygroma in one, wound infection in two and increased intracranial pressure in one. All three patients with diffuse intravascular coagulopathy died.

The follow-up of survivors is presented for the 1972 to 1976 series only, and ranged in length from six months to four years with a median of 27 months. Of the survivors, 78 percent were neurologically capable of employment; 8 percent were unemployable but self-sufficient and 14 percent remained dependent.

Discussion

Literature on missile wounds to the brain reflects primarily wartime experience.[3-21,23-27] Although there have been several civilian reports[1,4,9-11,25,28] published recently, the principles developed by military surgeons continue to provide basic guidelines.

The modern era of military neurosurgery began during World War I. Jefferson's review[17] stressed the importance of early operation to prevent sepsis and fungus cerebri. He felt fungus represented an increase in intracranial pressure secondary to sepsis and stressed the removal of the bone fragments driven into the brain. Cushing[12] introduced techniques of debridement and closure of open wounds.

In World War II the basic techniques of Cushing were used, although incisions had evolved from a tripod to a linear or curved configuration.[27] Local anesthesia was still preferred.[16] Although some[16,27] recommended a 48- to 72-hour delay in surgical procedures to allow stabilization, most surgeons advocated early operation.[20,21] Debridement of "macerated, devitalized cerebral tissue"[27] as well as foreign materials, bone fragments and clotted blood was stressed. The dura was opened under depressed skull fractures or open wounds if the dura appeared abnormal, whereas this was not done in World War I. Tight closure of the dura and skin were again recommended. Antibiotics were administered—penicillin (20,000 units given intramuscularly every three hours) and sulfadiazine being the only agents available.[27,29]

By the Korean war, the basic principles of early operation, debridement of bone and metal fragments, resection of devitalized tissue, closure of dura and skin, and prophylactic antibiotics were well established.[2,18,21,26] The importance of maintaining an adequate airway was recognized, and patients were nursed in the "coma" position or had tracheostomies.[21] A high incidence of intracranial hematomas was observed.[3,21] The necessity of a second surgical operation for removal of retained bone fragments was emphasized, although it was recognized that not all fragments could be removed because of their locations.[20]

In a Korean series,[3] 39 percent of missile wounds to the head were examined within three hours, 78 percent within six hours, and 88 percent within 8 hours. In Vietnam, patients were triaged by paramedical personnel while being transported by air to neurosurgical units.[19] One report stated that the average time from injury to admission and from admission to surgery was 45 minutes and 16 minutes, respectively.[19] Other series reported intervals of half an hour to five hours, and one to seven hours from injury to admission and from admission to surgery, respectively.[23] The choice of antibiotics available had changed. Chloramphenicol, penicillin, streptomycin and ampicillin were the drugs most frequently used.[19,23] Specialized power equipment, such as air-driven perforators, craniotomes and modern electrocautery units were available.[19,24] General anesthetics were used.[19,24] There was no hesitation in opening the dura under depressed fractures if there were clinical signs of cortical damage or dural discoloration.[24]

A notable difference between gunshot wounds to the brain seen in warfare and those seen in civilian practice is due to the wounding agent. In Vietnam, only 20 percent to 38 percent of brain wounds were due to bullets.[19,24] Most missile wounds resulted from exploding metal fragments from high-velocity weapons, such as the American M-16 and the Russian AK-47 rifles, with muzzle velocities of 3,350 and 2,508 feet per second, respectively. The muzzle velocity of a hand gun is within 600 to 800 feet per second.[12] The energy imparted by a bullet is proportional to the mass times the square of the velocity, that is, $KE = 1/2\ mv^2$. The injuries in our series were remarkable in that 34 percent were self-inflicted, close-range and right-frontal. A total of 51 percent of the wounds were in the right frontal region. In the military, there was also a preponderance of frontal wounds,[24] but these were not reported as being basifrontal as was frequently seen in our injuries. This fact may be the reason why cerebral spinal fluid fistulas were much more frequent in our series (12 percent) than in the military (0.79 percent).[24] Our experience did not reflect any tangential wounds to the head with the massive brain guttering and soft tissue loss as described in the military literature.

This clinical series does not describe the management of patients dying without surgical operations. Of the patients with gunshot wounds of the brain admitted to our center, 30 percent died with no operation. In a Vietnam series of 2,187 cases of missile wounds to the head, 20 percent died without surgical operation.[14] These figures are not comparable because of differences and reasons already stated between military and civilian wounds, but they make the point that a significant number of patients do not survive long enough for surgical treatment. The criterion for selection of patients for surgical procedures is a predominant variable influencing overall outcome. In one Vietnam series,[19] the authors stated that "those with bilateral nonreactive pupils, general extremis, rigidity and Cheyne-Stokes respiration" were accorded the lowest surgical priority. Authors of a second study[23] stated inoperability of injuries of the head was indicated by a progressive clinical deterioration in association with at least three of the four following observations: (1) coma, (2) serious central respiratory dysfunction, (3) absence of pupillary responses and (4) decorticate posturing.

TABLE 6.—*Mortality Associated With Surgical Treatment in Wartime Conflicts*

Author	*Percentage of Mortality*	*Conflict*
Jefferson[17]	19.3	World War I
Cushing[12]	28.3	World War I
Haynes[16]	13.0	World War II
Weaver[27]	12.3	World War II
Meirowsky[21]	7.8	Korea
Plaut[23]	11.9	Vietnam
Hammond[14]	9.7	Vietnam
Adeloye[31]	14.0	Nigeria
Byrnes[4]	56.0	Ireland

Operative mortality has shown a steady decline from World War I to the Vietnam conflict (Table 6).[30-32] Findings reported in a recent study from Belfast[5] are substantially out of line with those of other studies and deserve mention. The operative mortality was 56 percent. This figure is attributable to unique circumstances. The Royal Victorian Hospital is closely situated to the area of conflict. A medical officer was sent with each ambulance to retrieve the victims, who were brought directly to the hospital, usually within half an hour of wounding. If a patient was comatose or coughing and retching, he was intubated and placed under general anesthesia with controlled hyperventilation. Surgical procedures were carried out as soon as blood was available. It was considered that patients would have succumbed if not operated on with immediacy. The initiation of general anesthesia made evaluation and recognition of neurologic deterioration impossible. Therefore, surgeons were operating on patients who would not have been considered surgical candidates in other circumstances.

In the 1978 series, 10 of the 14 patients who were treated surgically were transferred to LAC-USC Medical Center from outside hospitals. Of the ten transferred patients, three either had neurologic deterioration documented from the time of their admission to the outside hospital to the time of their transfer to LAC-USC Medical Center or had neurologic deterioration documented shortly after their arrival at our medical center.

The differences in operative mortality in our series (23 percent) and in the Vietnam conflict (9 percent to 12 percent)[14,15,23,24] also reflect the ages of injured patients. In the age group of 21 to 40 years, mortality was 15 percent in our study.

The relationship of wound infection and retained bone fragments has been controversial. The overall infection rate in World War I was so high, it is not comparable. In World War II, one series[29,33] reported an overall incidence rate of "deep infection" (such as cerebritis or abscess) of 16 percent. When this figure was divided between deep infections with bone fragments and deep infections without bone fragments, the infection rates were 40 percent and 4 percent, respectively. Another study of cases from World War II[34] reported an incidence rate of deep infections associated with retained bone fragments of 25 percent. Even in World War II some authors[34] felt that reexploration should be reserved for those with clusters of bone fragments, not those with single isolated bone fragments distant to the site of operation. In Vietnam, it was the Army command policy[5,19] that all retained bone fragments be removed in a subsequent surgical operation. The overall infection rate in Vietnam was variously reported as 12 percent, 14 percent and 15 percent, which was similar to that during World War II. However, the deaths directly attributed to infection represent only 2 percent of surgical cases.[5] The incidence of infection with retained fragments is difficult to evaluate because it was routine to reexplore postsurgical patients if fragments were found. One study from Vietnam[6,7] attempted to assess the infective potential of bone fragments—45 consecutive cases had cultures taken of the external wound, brain tissue and bone fragments. (The bone fragments, usually numbering seven to nine, were cultured together so that the infected potential of a single fragment could not be stated.) In the series of cultures obtained, 44 of 45 external wound cultures, 5 of 45 brain tissue cultures and 21 of 45 bone fragment cultures showed contamination. In that study bone fragments removed during a second operation in ten patients were cultured; of these, four yielded positive cultures. The authors reported that of 16 patients operated on a second time to remove retained fragments, four had serious complications (increased dysphasia, coma and epidural abcess) or died. The authors concluded that bone fragments should be removed only if they are readily accessible within the operative field. This is the approach used at the LAC-USC Medical Center. Repetition of surgical procedures for removal of retained bone fragments is rare.

Findings in our study were similar to those recorded in wartime experience regarding frequency and location of intracranial hematomas (Table 5).[3,33] The significance of these hematomas is that their localization determines appropriate surgical procedures. Matson[33] stated that if he saw a foreign body on the contralateral side from the entrance wound, he explored that side looking for hematomas. Another author[14] felt that after initial debridement at the entrance site, if the "walls of the debridement tract" did not collapse, oftentimes he carried out trephination of the contralateral hemisphere.

Another difference between civilian practice and military practice is the diagnostic modalities available. From Cushing's time to the Vietnam conflict, neurosurgeons were forced to rely on their clinical examinations and the plain radiographs. In our study, angiography was used exclusively during the 1972 to 1976 period and computerized axial tomographic scanning was used in 1978. CAT scanning has now replaced angiography except in unusual cases where a sinus or vascular injury is considered likely. Computerized tomographic scans have proved to be extremely useful in excluding intracranial penetration. CAT scanning accurately discloses the location of metal and bone fragments as well as hematomas, depressed fractures, and areas of contused and edematous brain tissue. Often it is possible to see the course of the bullet tract through the brain and to see points of ricochet within the cranium. Artifacts produced by the metal fragments have not decreased the usefulness of CAT scanning.

Conclusion

Our study reemphasizes the basic tenets of surgical care developed by wartime surgeons, and also suggests modifications in current civilian practice that can improve the care of gunshot victims. Evacuation systems should be organized as they were in Vietnam to bring patients from the scene of the injury to definitive care hospitals. CAT scanning provides a valuable radiographic adjunct, which facilitates and increases the accuracy and sophistication of operative planning. The question of repeated surgical procedures for retained bone fragments is still an unanswered one, although there is a rationale for not removing all retained bone fragments. The use of intracranial pressure monitoring may prove to be another area of improvement in treating victims of gunshot wounds to the brain.

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Magnesium Deficiency: An Unrecognized Cause of Convulsions, Arrhythmias, and Neuromuscular Impairment

TREATMENT OF HYPOCALCEMIA due to magnesium deficiency involves simply replacing the magnesium. It does little good to try to give large doses of vitamin D or calcium . . . . Although the serum magnesium level can go back up fairly promptly, it takes a number of days for a full effect of the magnesium to be manifested. So . . . we usually persist for at least five days.

—FREDERICK R. SINGER, MD, *Los Angeles*

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