Traumatic Brain Injury Due To Gunshot Wounds: A Single Institution's Experience With 442 Consecutive Patients

Silah Yaralanmalarına Bağlı Travmatik Beyin Hasarı: Tek Bir Kurumun 442 Hastaya İlişkin Tecrübesi

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ABSTRACT

AIM: Traumatic brain injury (TBI) caused by a gunshot wound is a complex injury with a broad spectrum of symptoms and high rates of mortality and morbidity. This study presents an evaluation of TBI caused by gunshot wounds presenting at a single institution and discusses possible predictive factors for the outcome of surgical intervention.

MATERIAL and METHODS: The study sample consisted of 442 patients who underwent surgery for TBI over a 16-year period. All injuries were caused by gunshot wounds, such as bullets and shrapnel. All patients underwent surgical intervention.

RESULTS: Almost all patients (99.3%) were male, and the mean patient age was 22.3 years. Wounds were caused by shrapnel in 68 percent of patients. The Glasgow Coma Scale (GCS) score at admission was below 8 in 116 patients (26.2%) and above 8 in 326 patients (73.8%). In total, 47 patients (10.6%) died despite surgical management, with diffuse brain injury the most common cause of death.

CONCLUSION: Low GCS scores, ventricular injuries and bihemispheric injuries are correlated with poor prognosis. Early and less invasive surgery in conjunction with short transportation time to the hospital could decrease mortality rates.

KEY WORDS: Traumatik brain injury, Gunshot wounds, Surgery, Prognosis, Brain injury

ÖZ

AMAÇ: Silah yaralanmalarına bağlı travmatik beyin hasarı (TBH) oldukça geniş bir semptom profiline sahip ve yüksek oranda mortalite ve morbiditeye neden olan kompleks bir yaralanmadır. Bu çalışmada, tek bir kuruma gelen silah yaralanmasına bağlı TBH'larının değerlendirilmesi sunuldu ve cerrahi girişimin sonuçlarına etki eden muhtemel faktörler tartışıldı.

YÖNTEM ve GEREÇ: Bu çalışma 16 yıl boyunca TBH nedeniyle cerrahi uygulanan 442 hastayı kapsamaktadır. Tüm TBH'larının nedeni kurşun ve şarapnel gibi silahlara bağlı yaralanmalardır. Tüm hastalara cerrahi girişim uygulandı.

BULGULAR: Neredeyse tüm hastalar (%99,3) erkek idi ve ortalama yaş 22,3'dür. Hastaların %68'inde yaralanma nedeni şarapneldir. Geliş Glasgow Koma skoru (GKS) 116 hastada (%26,2) 8'in altında, 326 hastada ise (%73,8) 8'in üzerinde idi. Diffüz beyin hasarı, en sık ölüm sebebi, olan toplam 47 hasta (%10,6) cerrahi müdahaleye rağmen kaybedildi.

SONUÇ: Düşük GKS, ventriküler hasar ve bihemisferik yaralanmalar kötü prognoza sahiptir. Hastaneye hızlı transportasyon zamanı ile birlikte erken ve az invazif cerrahi mortalite oranını düşürebilir.

ANAHTAR SOZCÜKLER: Travmatik beyin hasarı, Silah yaralanmaları, Cerrahi, Prognoz, Beyin yaralanmaları

INTRODUCTION

Traumatic brain injury (TBI) occurs when the brain is damaged as a result of physical trauma. TBI may be caused by a penetrating (open) head injury, in which an object pierces the skull and enters the brain tissue, or a closed head injury, in which the skull is not breached (19), and frequently results in the major long-term disability of individuals surviving head injuries sustained in war zones. Cranial gunshot wounds often result in severe injury to the brain and related central nervous system (CNS) structures (7,11,23,32). Such wounds can be classified as tangential, perforating, or penetrating (11). The latter are the most devastating type of missile injury to the head. Penetrating gunshot wounds, especially those that cross the coronal or midline sagittal planes, are usually fatal (11,22).

TBI is classified according to the extent of brain damage as mild, moderate or severe. A low Glasgow Coma Scale (GCS) score at admission and a lateral penetrating injury is usually correlated with severe TBI (22), the outcome of which can be anything from complete recovery to permanent disability or death. Mild and moderate TBI may also cause a host of temporary or permanent physical, cognitive, emotional and social problems (17).

Severe TBI resulting from a gunshot wound is usually treated surgically. Data on morbidity and mortality may be helpful in determining which patients are likely to benefit from surgical intervention. Patients presenting in poor neurological condition may not be operated on because of the surgeon’s perception that they will not have a good outcome.

This paper presents clinical, radiological and surgical assessments of 442 patients with TBI caused by gunshot wounds incurred in a military setting, and it evaluates the possible predictive factors for the outcome of surgical intervention.

PATIENTS and METHODS

The Gulhane Military Medical Academy Department of Neurosurgery treated 442 patients (439 male, 3 female; mean age: 23.2 years; age range: 4-54 years) with TBI caused by gunshot wounds between 1992 and 2008. Individuals who had gunshot wounds that did not penetrate the cranium were excluded from the study.

Following initial evaluation and immediate life-saving procedures performed by paramedics in the field, patients were transferred by helicopter ambulance to the center for neurosurgical management. The mean time-lapse between injury and arrival was 2 hours. Pre-operative skull x-rays were taken in all patients, and those in stable condition (n=349) underwent computed tomography (CT). X-rays and CT scans both revealed intracranial bone fragments; foreign bodies, including metal, stone and mud (Figures. 1A,B,C, 2A and 2B); and blood-filled bullet trajectories (Figure 3). All patients were treated surgically.

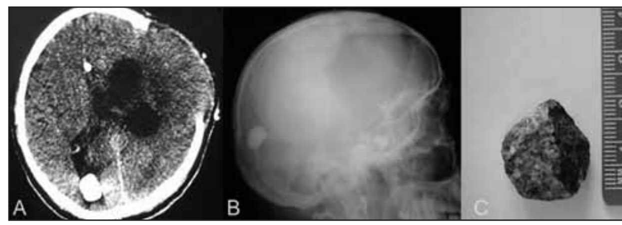

Figure 1: *(**A**) CT scan and (**B**) x-rays of a patient with a right occipital stone caused by landmine explosion. The diameter of the stone was approximately 2 cm (**C**).*

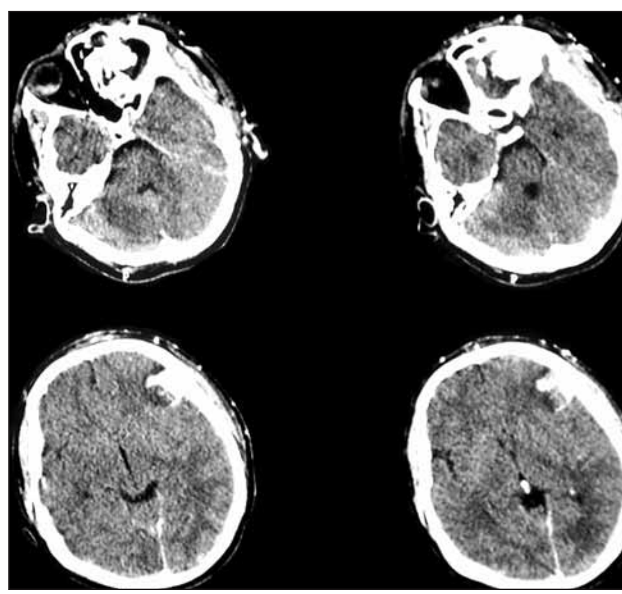

Figure 2A: *Four slices CT scan of a patient with left orbitocranial injury caused by landmine explosion. A foreign body in the left orbit and hemorrhage in the left frontal lobe are obvious.*

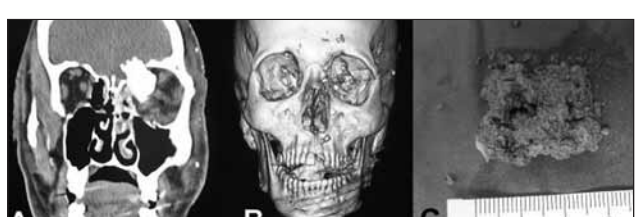

Figure 2B: *The coronal (**A**) and 3-dimensional (**B**) CT scans of the same patient revealed a big foreign body on the anteromedial edge of the orbit. The fragment was composed of mud (**C**).*

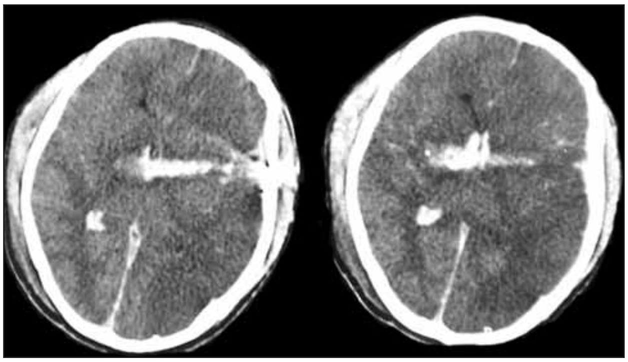

Figure 3: *Two slices CT scan of a patient with craniocerebral penetrating injury by bullet. The trajectory filled with blood crossed the midline and lateral ventricles.*

During the primary surgery, intracranial bone and metal fragments that were visible and palpable pre-operatively were removed, necrotic cerebral tissue was debrided and active hemorrhages were stopped. Bone and metal fragments of deep or eloquent locations were left in place. In most cases, the dura was closed with primary suturing; however, in cases with large gaps between the dural edges, duraplasty was performed using pericranium, temporalis muscle fascia or tensor fascia lata tissue, or, in some cases, with cadaveric dura.

All patients received a standard medication protocol that included third-generation cephalosporins for 14 days post-operatively together with antiedema, anticonvulsant and analgesic agents. All patients were followed by CT scans, postoperatively with 3-month intervals. Patients with CT scans showing extensive brain edema (5.2%; n=23) were intubated and attached to a mechanical ventilator, and their intracranial pressure (ICP) was monitored, with antiedema therapy administered according to their ICP levels. For patients with deep bone and metal fragments, treatment was conservative, with no further surgery performed until neurological findings appeared normal.

Secondary surgery was performed on patients with large cranial defects, intracranial infections such as intracerebral abscess or empyema, cerebrospinal fluid (CSF) fistulae and wound-healing problems following primary surgery. In most cases, porous polyethylene was used to repair orbitocranial injuries, whereas large cranial defects were corrected using methylmetacrylate. Burned skin after the gunshot injury does not heal very well; therefore, it is necessary to debride the edges of the skin for primary healing of the scalp. Otherwise secondary scalp repair is required.

Digital subtraction angiography (DSA) was used to detect traumatic aneurysms in patients experiencing severe headaches and neck stiffness after treatment. CT scans with contrast enhancement were periodically performed on patients with deep located fragments.

The number and causes of death were recorded. Patients suffering neurological impairment following surgery underwent rehabilitation. Follow-up for all patients consisted of neurological examination including CT scans at 3-month intervals after discharge.

RESULTS

The injuries were caused by shrapnel in the majority (68%) of patients in this study, and the remaining injuries by bullets (32%). Physical and radiological examination showed the most common site of injury (n=146) to be the frontal lobe, followed by the temporal and parietal lobes, whereas fronto-parietal, fronto-occipital and other multiple injury sites were seen in 43 patients. The relationship between injury site and mortality is shown in Table I. Mortality rates were highest for posterior fossa and brain stem injuries and lowest for frontal injuries. The relationship between the GCS score and the mortality is shown in Table II. GCS scores at admission ranged from 3 to 8 in 126 patients and 8 and 15 in 326 patients.

Following initial neurological and radiological evaluation, all patients underwent primary surgery

Table I: The relationship between the site of injury and mortality.

Site of injury	Number of patient	Number of death (%)
Frontal lobe	146	4 (2.7%)
Temporal lobe	76	7 (9.2%)
Parietal lobe	74	4 (5.4%)
Occipital lobe	46	2 (4.3%)
Posterior fossa and brain stem	15	14 (93.3%)
Orbitocranial region	42	4 (9.5%)
Multiple sites	43	12 (27.9%)
Total	442	47 (10.6%)

Table II: The relationship between GCS score at admission and mortality.

GCS score	Number of patient	Number of death (%)
15-8	326	20 (6.1%)
8-3	116	27 (23.2%)
Total	442	47 (10.6%)

that included necrotic tissue debridement, hemorrhage control, removal of superficial foreign bodies and dural repair. The dura was closed primarily in 67 cases (15.1%), with pericranium or temporal muscle fascia in 252 cases (57%), with tensor fascia lata graft in 19 cases (4.2%) and cadaver dura graft in 9 cases (2%). Retained bone and/or metal fragments were detected in 143 (32.4%) patients after the primary surgery. Fragments lodged in deep locations and eloquent brain areas were left in place. Ventricular injuries were detected in 75 (16.9%) patients.

The most common complication of primary surgery was infection, which was observed in 27 (6.1%) patients. The infection was either systemic or local, but required long-term and broad-spectrum antibiotic regimen. Other surgical complications included intracranial hematomas, hydrocephalus, wound-healing problems and CSF fistulae (Table III). DSA was performed in 46 (10.4%) patients with severe headache and neck stiffness after surgery, but no traumatic aneurysms were detected.

The mortality rate among the patients in this study was 10.6% (n=47), and the most common cause of death was diffuse brain injury (57.4%; n=27), followed by infection (21.3%; n=10), brain stem injury (17.1%; n=8) and pulmonary embolism (4.2%; n=2) (Table IV).

Table III: The types and the number of postoperative complications after gunshot wounds.

Complication	Number of patients
Infection (Local or systemic)	27 (6.1%)
CSF fistula	20 (4.5%)
Hydrocephalus	9 (2%)
Intracranial hematoma	16 (3.6%)
Wound healing problems	8 (1.8%)
Drug reactions	52 (11.7%)
Total	132 (29.8%)

Table IV: The causes and the number of deaths in this series.

Causes of death	Number (%)
Diffuse brain damage	27 (57.4%)
Infection	10 (21.3%)
Brain stem injury	8 (17.1%)
Pulmonary embolism	2 (4.2%)
Total	47 (100%)

The mean follow-up period for all patients was 2 years (range: 3 months-3 years). All patients required extended hospital stays, mainly due to the length of post-operative rehabilitation. Of the 442 patients in this study, 313 (70.8 %) gained the ability for self-care and were discharged, whereas 82 (18.6%) who failed to recover were transferred to another medical facility, where they began rehabilitation as soon as they were clinically stable.

DISCUSSION

Although there have been many studies the craniocerebral injuries, there has been little analysis specifically of the prognostic factors in TBI caused by gunshot wounds. In this study, we have tried to present our large series of TBI caused by gunshot wounds, to share our surgical experience, and demonstrate the possible prognostic factors for such injuries.

TBI caused by gunshot wounds is one of the most common causes of death and disability in warfare. This is becoming an issue of growing concern in modern warfare, in which rapid surgical interventions are effective in saving the lives of soldiers with severe head injuries (19). Although much of the literature on craniocerebral gunshot injuries is derived from military experience (11,16,21), civilian gunshot wounds are extremely common in certain populations (26,35). In the United States, for example, TBI due to firearm injury is an epidemic health problem. This is a vast public health problem that may be escalating further, particularly in children and adolescent age groups. The mean patient age is reported to be 35 years, but this may decline as larger numbers of children and adolescents are involved. Most patients do not survive to receive treatment (11,16,23,25,35).

Men and women in military service run a higher risk of incurring TBI than the civilian population.

Not only are individuals involved in armed conflict exposed to the risk of a penetrating brain injury caused by bullet or shrapnel, they are at an even greater risk of TBI caused by a concussive blast wave from an explosive device. The number, type, and severity of injuries sustained by military personnel have changed as a result of developments in weapon and armor technology and the nature of warfare (41). The frequent use of improvised explosive devices in combat theaters such as Iraq and Afghanistan has meant that American troops in these wars are at a much higher risk of incurring TBI in comparison to earlier wars (20,41), to the extent that TBI has been labeled the "signature injury" of the wars in Iraq and Afghanistan (17,30). According to the Defense and Veterans Brain Injury Center, a research and treatment agency run by the Pentagon and Veterans Affairs Department, 64% of injured troops have suffered brain injuries (18).

In the case of penetrating head wounds – usually the result of a high-velocity missile or handgun fired at close range, as, for example, in a suicide attempt – the entry wound is smaller than the exit wound, and there is variation in the degree of cavitation along the bullet's path through the brain, whose diameter is usually several times larger than that of the bullet itself. The bullet's transit is accompanied by a percussion wave that is transmitted through the brain, causing explosive skull fractures and widespread destruction of neuronal cell membranes. The shock wave may propagate as far down as the medulla oblongata, causing transient cardiorespiratory impairment, which may manifest clinically as acute respiratory arrest. The transmission of kinetic energy to the brain results in a sharp rise in ICP upon injury, followed by a slow, slight decline and subsequent second increase in ICP due to intracranial bleeding from torn blood vessels and progressive edema. In cases where the bullet's trajectory crosses the coronal or midline sagittal planes, the results are usually fatal (11).

In contrast to most forms of traumatic death, in which death occurs immediately after the traumatic event, a large percentage of brain trauma fatalities occur days or weeks after the primary trauma (33). Approximately 40% of TBI patients deteriorate, rather than showing improvement, following hospitalization (29). This high rate of deterioration cannot be adequately explained by the primary damage to tissues and blood vessels; rather, the deterioration is a result of secondary injury, which includes a complex set of biochemical events that occur in the minutes to days following the trauma (40) and which contribute greatly to the high morbidity and mortality rates of TBI (37). Simply put, cerebral contusions are parenchymal bruises, all of which demonstrate some perivascular extravasation and edema on a microscopic level. In the case of craniocerebral gunshot injuries, contusions are commonly located beneath the site of the missile impact and are caused by inward movement of the skull, with or without fracture, based on the frequent finding of cerebral contusions in superficial and tangential injuries. Violent shock waves or cavitary tissue displacement in which the skull impacts on the brain parenchyma may also cause contusions to form at sites remote from the missile tract (27,36). The same forces may also result in diffuse parenchymal injury, or "diffuse axonal shear injury" (36,42). In our study, radiological examination showed that diffuse parenchymal damage was present in 57 (12.9%) cases and that this was associated with poor prognosis in the series.

Radiographic assessment of TBI caused by gunshot wounds usually differs from that of closed head injuries, mainly because of the nearly universal involvement of multiple anatomic levels, including the scalp, skull, orbit and cranial vault. It is obvious that specific pathophysiologic lesions such as scalp lacerations, skull fractures, hemorrhages, and contusions are not unique to gunshot wounds and carry the same clinical and radiographic implications individually as they do in closed head injuries. Regardless of whether or not clinical evidence of penetration exists, all patients with TBI should undergo CT, except in extreme cases that require immediate surgical intervention, or when the patient is clinically and neurologically moribund and there is no hope for survival (10).

Different types of imaging studies are used for TBI. Ideally, CT imaging should produce 5 mm-thick contiguous slices from the vertex to the foramen magnum. The most recent CT scanners can image the entire head in less than 5 minutes. In fact, most of the time involved in CT is related to patient transport. Magnetic resonance imaging (MRI), although superior to CT in imaging extracerebral fluid collection (with the exception of subarachnoid hemorrhage [SAH]), edema, nonhemorrhagic contusions and shear injuries, early and small cerebral infarctions and most lesions in the posterior fossa or brainstem (11,24), has little use in the evaluation of head injury in the acute setting. Moreover, the presence of a metallic foreign body must be considered a relative contraindication to MRI (11,14,15), although it may be appropriate in certain cases, depending on the location and type of bullet. DSA for craniocerebral gunshot wound injuries remains an option in the acute setting only if CT is not available. Its most important role, however, is in the definitive diagnosis of vascular injury, including traumatic aneurysms, arteriovenous fistulas, arterial dissections, occlusions, and dural venous sinus injuries. In our study, CT scans were performed in most patients preoperatively and in all patients postoperatively.

Some authors have stated intracranial bone fragments that are not removed can cause infection (7,8). Pitlyk et al. (31) revealed that the bone fragments did not increase the infection rate itself, but that the infection rate became 10 times higher if the fragment combined with scalp or hairs. Carey et al. (8) reported two minor complications, one major complication and one death after secondary debridement in 103 patients. Meirowsky (28) noticed increasing neurological deficit in 4 of 116 (3.4%) patients who underwent reoperation. However, it has also been reported that attempts to remove intracranial fragments may increase the risk of neurological defects. In his study of 379 patients wounded during the Iran-Iraq War, Aarabi (1) noted that retained bone fragments increased the risk of CNS infection, but the increase was not statistically significant. Aarabi reported (1) that the longer time to intervention did not increase the infection rate and emphasized that adequate debridement of infected and contaminated necrotic tissues, dural repair, and antibiotic therapy all serve to decrease the infection rate even when intervention time is so long. Brandvold et al. (7) supported less aggressive methods and reported an infection rate of 11%. In comparison to the previous study, our study found a higher infection rate of 6.1%, but the TBI caused by landmines has increased the rate of infection in recent years because these injuries cause more dirty wounds (34). The dirty wounds which were caused by landmines injuries increased our infection rate although we used less aggressive techniques during surgery and did not try to remove the deep located fragments.

A report by the British Society for Antimicrobial Chemotherapy recommended an antimicrobial prophylaxis of 1.2 g intravenous co-amoxiclav every 8 hours or 1.5 g followed by 750 g intravenous cefuroxime every 8 hours, together with 500 mg intravenous metronidazole every 8 hours (or 1 g every 12 hours by rectum or 400 mg every 8 hours by mouth) in the treatment of military craniocerebral injuries, civilian intracranial gunshot wounds and civilian penetrating intracranial injuries from other causes (6).

Administration of antimicrobial prophylaxis should begin as soon as possible after injury and continue for 5 days after surgery (11). In the case of military craniocerebral injuries, we recommend continuing prophylaxis for 14 days. Human anti-tetanus immunoglobulin administered intramuscularly should also be given to all patients. In the event of meningitis, wound infection, osteomyelitis, or brain abscess, standard therapy for these conditions is instituted without delay along with appropriate surgical exploration or excision. It should be kept in mind that the range of possible causative organisms is wide and may include coagulase-negative staphylococci, Staphylococcus aureus, gram-negative bacilli, or anaerobes. The possibility of fungal infection, although remote, should not be discounted.

Another complication associated with craniocerebral gunshot wounds is posttraumatic epilepsy, which reflects the extent of brain damage and is positively correlated with coma (9). While some reports have linked seizures to increased mortality and morbidity (11,39), Rish et al. (32) stated that posttraumatic epilepsy is not related to mortality, but is another parameter of the extent of brain damage. This condition appears early after a penetrating head injury during the same period when most deaths occur. In our series, we observed postoperative seizures in 11 patients (2.5%), but there were no associated deaths. All individuals who suffered brain damage received anticonvulsants as part of routine medical treatment in our study. Anticonvulsants were discontinued if no seizures were reported after 2 years.

Craniocerebral gunshot wounds are associated with high mortality rates (2,5,11,21,22,23,28), with post-surgical mortality of approximately 20% (11). Mortality and morbidity in craniocerebral missile wounds are affected by many factors, including patient transport, antibiotic therapy, surgical techniques and follow-up procedures (3,5,11,15,21). During the Vietnam War, the neurosurgical postoperative mortality rate was 8% to 10% (8,16). For combat casualties of the Vietnam War, resuscitation in the field by paramedical personnel, rapid transportation by helicopter to specially equipped medical facilities, bountiful supply of whole blood, and sophistication of care rendered by these facilities contributed to an improved survival rate (8,11). The neurosurgical postoperative mortality rate was 10.6% in our study.

Ventricular injury is a predictor of poor outcome (11,12,21,22). In the case of a penetrating craniocerebral gunshot wound, injury by a foreign body (bullets, shrapnel) can result in a significant accumulation of intraventricular blood. This type of damage is associated with particularly poor prognosis. It is seen on CT as high-attenuation material usually layered dependently within the occipital horns of the lateral ventricles, although a large amount of clot may form a virtual cast of ventricles. Intraventricular hemorrhage results from direct penetration by the missile or transmitted shear, and tensile stresses on the ventricular walls result in vessel injury (38). Contrast enhancement of intraventricular ependymal tissue or the accumulation of intraventricular contrast material indicates serious ventricular injury (4). Penetrating brain injuries involving the ventricular system are more susceptible to intracranial sepsis because the disturbance of CSF flow dynamics makes them prone to CSF leakage, and then infection (13). In our study, ventricular injury was observed in 75 patients (17%), 24 of whom (32%) died despite surgical treatment.

CONCLUSION

Although our surgical care of patients with TBI caused by gunshot wounds is not optimal, rapid transportation to the hospital and urgent surgical intervention could have reduced mortality rates. The surgeon should not be discouraged by a low GCS score at admission or by posterior fossa injuries and ventricular involvement. Moreover, recent advances particularly in neuroimaging and surgical techniques could save more lives than medical advances.

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