The treatment of penetrating wounds of the brain sustained in warfare

A historical review

E. STEPHEN GURDJIAN, M.D.
Department of Neurosurgery, Wayne State University, Detroit, Michigan

The author reviews the history of the management of head injuries with particular emphasis on penetrating wounds from antiquity to modern times. He traces the influence of gunpowder weaponry and early instrumentation on the development of treatments.

Key Words: • history of neurosurgery • head injury • penetrating wounds • gunpowder

EGYPTIAN physicians of antiquity studied the anatomy of the skull in the living patient, since autopsy and dissection of the human body after death were not permitted. Although the treatment of cases with head and spinal injuries is described in the Edwin Smith papyrus, the connection between brain and spinal cord was not appreciated until it was pointed out by Herophilus in the 3rd century B.C. For 5000 years surgical treatment of head injuries concerned itself primarily with lacerations of the scalp and fractures of the skull. An open dura or a perforation through this membrane was considered an incurable lesion. The surgeon viewed the dural lining as an uncrossable barrier and its contents as “off limits.” Only toward the end of that period did some surgeons incise an inflamed or discolored dura for the purpose of draining a blood clot or pus, and not until the 1870’s and the advent of antiseptic and aseptic surgery was the interior of the head explored surgically.

Early Experiences with Penetrating Wounds of the Skull and Brain

Warriors of the pre-gunpowder era used both short-range weapons such as the sword, knife, hatchet, club, and mace, and long-range weapons such as the lance, spear, javelin, arrow, sling, and rock (thrown or catapulted) (Figs. 1 and 2). The great pre-gunpowder wars included the battles of Marathon, Thermopylae, and Platea between the Greeks and Persians, in which about 70,000 soldiers perished. There is little doubt that head injury and multiple injuries of the body were important causes of death. The same may be said of the wars of Alexander the Great, the Saracen wars, and the Crusades.

In Homer’s Iliad there is a description of a warrior’s helmet and head that burst in two when hit by a rock thrown during the siege of Troy. Froehlich estimated a mortality rate of 77.6% in 140 cases of penetrating wounds of the body described in...
the *Iliad* and *Odyssey*. Sword and spear wounds caused a higher mortality than arrow wounds, possibly because in an arrow wound with no injury to vital structures, there may be healing without infection after the weapon is removed. Apparently tissue elasticity produced a "pucker" around an arrow wound that discouraged external infection.

**Fracture of the Skull**

Ancient Egyptian physicians were familiar with open, gaping wounds of the head sustained from short-range weapons. In such cases they palpated the interior of the wound; if the bone was perforated and the dura found torn, the case was considered incurable and was not treated. However, supportive management was given to this class of seriously injured patients in the Greco-Roman period, and also during the Crusades.

In cases of depressed or comminuted fracture in ancient Egypt, the initial laceration was extended, or in the absence of laceration, surgical exposure was accomplished with a cross incision (Fig. 3). Free fragments of bone were removed, and the wound was dressed with lint soaked with warm wine and oil of rose placed against the dura. Linen balls soaked in vinegar and oil of rose were then applied externally, the wound was drained with strips of silk and hemp, and the head was bandaged over a dressing. The dressing was taken off in 3 to 4 days, and thereafter it was dressed every 2 days until the wound healed. Hippocrates
did not believe in elevating depressed fractures of the skull.\textsuperscript{1,8,10}

Celsus\textsuperscript{8} reported that a patient with head injury who remained unconscious was thought to have a fracture of the skull, and Hippocrates\textsuperscript{1} advocated a surgical opening into the skull in the vicinity of the fracture site. If the patient was paralysed or had unilateral convulsions, the fracture was assumed to be located in the contralateral side. Unconsciousness, paralysis, and convulsions were looked upon as indications of a torn dura.

Hippocrates\textsuperscript{1} and Galen\textsuperscript{16} both warned against mistaking a suture for a fracture. To establish the depth of a linear fracture, the surgeon applied ink to it, and if scraping with a bone scraper caused the ink mark to disappear, the surgeon knew he was dealing with an incomplete fissure, the break only involving the external portion of the skull. Linear fractures were treated by making openings in the skull with a perforator or terebra and a circular saw; even then, care was taken not to injure the dura. Much later, in European surgery, the dura was protected with a dural separator or a meningophylax.

In the early management of depressed and expressed fractures necessitating craniectomy and removal of free fragments, it was apparently agreed that not all fracture lines should be followed to their termination but rather that the operation be limited to the general vicinity of the open wound. Some depressed fragments were excised by making openings in the skull in the attached portion of the depression and unifying the

\textbf{FIG. 3.} Operative incisions used from antiquity to the time of antiseptic surgery. At times an incision was made across a laceration for better exposure. A cross-incision (in the form of an X) was used in the Greco-Roman period. Early Greek, Roman, and Islamic and early European surgical knives and razors are illustrated below.
holes with bone cutters until the entire depressed fragment could be removed or elevated. An expressed fracture was excised by scraping the bone and eventually removing the fragments with bone forceps (Fig. 4). The wound edges in an open fracture were then freshened; this was the first mention of debridement and was reported by Avicenna and Theodoric, in early European and late Mohammedan writings.

**Epidural Surgery**

Beginning with the time of Hippocrates and Galen, if a patient remained unconscious or semiconscious with hemiparesis, hemiplegia, or seizures, contralateral exploration of the epidural space was performed, usually by means of a cross-incision of the skin and perforation of the bone. Dressings were applied to control bleeding, and later the wound was reopened and the edges of the skin held apart. In the Christian era it was appreciated that a skull bone that looked paler than the surrounding cranium might be concealing a collection of blood or purulent matter, and this area was explored.

![Fig. 4. Upper Left: Open depressed fracture presumably associated with coma treated by trepanning the skull. Later, in the middle ages, this method was used to excise or elevate a depressed fragment. Upper Right: Elevation of a depression with an elevator. Center Left: Use of the lenticular and circular saw. Center Right: Multiple exploratory trephine openings looking for the “mischief” causing the patient’s clinical condition. Lower: Use of straight and hollow chisel and bone clippers (rongeurs) to remove bone between trepan holes.](image-url)
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In the early 1700's, the head was trephined in various places on both sides to locate and remove a clot or purulent collection; this was the beginning of so-called "woodpecker surgery."

From early times surgeons removed abnormal epidural fluids from between the skull and dura. The same was true of infection under the scalp, osteomyelitis of the skull, and epidural abscess. In

FIG. 5. Examples of instruments for cranial surgery. These include the terebra, augur, lenticular, chisel and mallot of antiquity, a dural separator or meningophylax of the 13th century A.D., ancient saws and circular saws, a brush to remove bone dust, a combination of augur, perforator and elevator from the 1st century A.D. and a 13th century bone cutter. The triploid of the 1st century is shown in the lower left corner.
FIG. 6. Upper: Approximation of a laceration of the scalp in old Egypt. Adhesive linen strips or bandage to hold the edges of the wound together. Center: A gaping wound of the head is packed with linen-soaked wine and/or oil of rose and a ball of scraped linen (wool), then the wound is approximated with a bandage. Scalp laceration repair with continuous stitch is shown (right). Lower: A head bandaged by Scultetus (left), and bandaged in the style of Heister, Pott and Cooper (right). The use of pledgets during operation is also shown.
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the precontemporary period (1700-1870), Heister and Pott operated on patients with subdural lesions. In the American Revolutionary War, Jones drained a subdural hematoma in a patient who later recovered.

Instrumentation, Anesthesia, and Dressings

Anesthesia was not practiced until the 19th century. Before this, medication in the form of coca (used by the Incas), opium, atropine and scopalamine were used to control the patient during the incision of the scalp. As early as 100 A.D., Heliodorus appreciated that the dura was sensitive; however, to make patients drunk before operative procedure was a common practice.

From early Egyptian times knives, chisels, mallots, saws, and bone forceps were available, and in the Greco-Roman period a trephra and circular saw were added for trephination (Fig. 5). Over the years some ingenious techniques of questionable value were developed for the management of depression. The “triploid” involved a perforator which could be screwed into a depressed fragment and the fragment could then be elevated by an unscrewing device. Bone forceps were improved over the years until de Mondeville, de Chauliac, Heister, Pott, and others developed rongeurs of various shapes and sizes, including some early precursors of DeVilbiss and Kerrison.

From antiquity on, bandages, swabs, pieces of lint, pledgets of silk, hemp and lint were used in closing and dressing wounds. A simple laceration of the scalp could be approximated with adhesive lint or bandaging and later with stitches to hold the skin edges together (Fig. 6). The various materials used in dressings included warm wine, vinegar, and oil of roses, the latter productive of “laudable pus.”

Conservative management of head injury and the treatment of the patient after surgery included venesection, purgatives, a light diet, some medication for pain, and drugs to make the patient more quiet. A contusion of the scalp was often treated with the application of the skin of a rat or a rabbit or poultice of raw meat, a practice still perpetuated in the present day popular use of raw meat applied to a “black eye.”

Experiences After the Introduction of Gunpowder

In antiquity the Chinese were familiar with gunpowder and Roger Bacon discovered it anew in the early part of the 12th century. In 1313, following the discovery of its propulsive qualities by Mark B. Schwartz, a monk, gunpowder was rapidly adapted to warfare. By 1325 cannons and explosive bombs had been constructed; small firearms were not developed until the last quarter of the 14th century. Cannons in the early 14th century hurled 160-lb rocks, while field artillery fired iron balls. During the next six centuries, the hand cannon, matchlock, wheellock, snaphaunce, flintlock, and revolver were developed in succession. In 1846 the cartridge and the breech loader were invented; rimfire, pinfire, and finally central fire were developed in sequence. Shells containing explosive material were the most recent development.

With the advent of smokeless powder and alterations of bullet shape, high muzzle velocities have been achieved without dangerous muzzle pressure. The muzzle velocities and energies of different bullets are given in Table 1 (see also Fig. 7). Patients with head wounds from low velocity guns often survived, but high velocity guns usually killed at once unless the missile was almost spent. Present-day ammunition used in war include the M-16, 223 Remington with a bullet weight of 56 grains, muzzle velocity of 3300 ft/sec and muzzle energy of 1300 ft/lb, and the Russian AK-47, 7.62 mm with a bullet weight of 122 grains, muzzle velocity of 2400 ft/sec and muzzle energy of 1560 ft/lb (Fig. 8).

Gunpowder is composed of saltpeter, carbon, and sulfur; an effective combination is sodium nitrate or saltpeter 74.6 parts, carbon 13.5 parts, and sulfur 11.8 parts. Black gunpowder contains potassium nitrate and may be used for hunting guns. Smokeless powder is used for rifle cartridges; it consists of nitrocellulose and nitroglycerin in powder form. Powder for use in large guns and cannons is manufactured in cylindrical pellets containing perforations parallel to the length. The perforations accelerate the burning with lower breech pressure and better propellant quali-
Fig. 7. Cartridges and bullets of present day. The Italian Carcano (16) killed President Kennedy. Number 17 was used in World War I.

TABLE 1

Ballistic statistics on various bullets in current use

<table>
<thead>
<tr>
<th>No.*</th>
<th>Bullet</th>
<th>Bullet Weight (grains)</th>
<th>Muzzle Velocity (ft/sec)</th>
<th>Muzzle Energy (ft lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.22 short</td>
<td>29</td>
<td>1155</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>.22 long rifle</td>
<td>40</td>
<td>1335</td>
<td>158</td>
</tr>
<tr>
<td>3</td>
<td>.22 magnum</td>
<td>40</td>
<td>2000</td>
<td>355</td>
</tr>
<tr>
<td>4</td>
<td>.25 automatic or 6.35 mm</td>
<td>50</td>
<td>810</td>
<td>73</td>
</tr>
<tr>
<td>5</td>
<td>.32 S &amp; W positive</td>
<td>85</td>
<td>680</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>.32 S &amp; W long</td>
<td>98</td>
<td>705</td>
<td>115</td>
</tr>
<tr>
<td>7</td>
<td>.32 automatic or 7.65 mm</td>
<td>71</td>
<td>960</td>
<td>145</td>
</tr>
<tr>
<td>8</td>
<td>.380 automatic</td>
<td>95</td>
<td>955</td>
<td>190</td>
</tr>
<tr>
<td>9</td>
<td>.38 S &amp; W positive</td>
<td>145</td>
<td>685</td>
<td>150</td>
</tr>
<tr>
<td>10</td>
<td>.38 S &amp; W special</td>
<td>lead &amp; copper coated metal jacket</td>
<td>158</td>
<td>855</td>
</tr>
<tr>
<td></td>
<td></td>
<td>metal jacket</td>
<td>110</td>
<td>1370</td>
</tr>
<tr>
<td>11</td>
<td>.357 magnum (metal jacket)</td>
<td>110</td>
<td>1690</td>
<td>697</td>
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<td>12</td>
<td>.9 mm Luger</td>
<td>115</td>
<td>1140</td>
<td>330</td>
</tr>
<tr>
<td>13</td>
<td>.32-20 Winchester</td>
<td>100</td>
<td>1030</td>
<td>235</td>
</tr>
<tr>
<td>14</td>
<td>.45 automatic (metal jacket)</td>
<td>230</td>
<td>850</td>
<td>370</td>
</tr>
<tr>
<td>15</td>
<td>.30 cal. carbine</td>
<td>110</td>
<td>1980</td>
<td>955</td>
</tr>
<tr>
<td>16</td>
<td>6.5 mm (Italian Carcano)</td>
<td>156</td>
<td>2340</td>
<td>1898</td>
</tr>
<tr>
<td>17</td>
<td>.30-06 Cal.</td>
<td>180</td>
<td>2700</td>
<td>2910</td>
</tr>
</tbody>
</table>

* See Fig. 7.

ties. Dynamite contains 75% nitroglycerin and 25% Kinsulgher earth. Gelatin dynamite consists of 75% nitroglycerin, 16% potassium nitrate, and 6% nitrocellulose, with the addition of some wood and chalk. Trinitrotoluene (TNT) is used in the manufacture of bombs, mines, shells, and torpedoes, as well as grenades.

Grenades have been used since the early part of the 16th century. These small missiles containing a high explosive may be percussion- or time-detonated. Present-day grenades are made of TNT and Anatol, containing ammonium nitrate. The use of grenades was renewed in the beginning of the 20th century in the Russo-Japanese war (1904-1905). They were extensively used in trench warfare in World War I and World War II and accounted for most of the fragment injuries in the Korean and Vietnam wars.

The introduction of gunpowder necessi-
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Fig. 8. The AK 47 and the military M-16 bullets, present-day high velocity missiles.

tated new methods of treating wounds. Toward the end of the 15th and beginning of the 16th centuries, Brunschwig and DeVigo considered wounds by cannon and gun to be poisonous. Boiling elder oil was applied to prevent putrefaction of the wound. This technique was meticulously used for over 50 years, until Par6 noted that wounds looked and healed better in the absence of the boiling oil treatment.

Statistical information is not available on the Thirty Year's War, the wars of Louis XIV, or the Napoleonic wars. McLeod found a mortality rate of 73.9% in 898 cases of head wounds in the Crimean War. In the American Civil War, 71.7% in one series of 704 cases of penetrating head wounds were fatal. It is interesting to note that these mortality rates are comparable to the 76% deduced from the literary compilation by Froehlich for penetrating wounds during Homeric times, circa 900 B.C.

After development of antiseptic and aseptic surgery, more vigorous measures were taken to treat the surviving patients with a torn dura. Cushing introduced the technique of debridement and closure of open wounds in World War I; this reduced the mortality rate to about 35%. In World War II, with the additional help of chemotherapy and antibiotics, the rate dropped to 14%, and in the Korean and Vietnam wars to under 10%. There was a 5% mortality rate with scalp lacerations in World War I, and none in World War II. In cases of fracture of the skull without dural penetration, the mortality rate was 10% in World War I, 1.6% in World War II, and 0.88% in the Korean War. Fracture of the skull with dural penetration caused a mortality rate of 35% in World War I, 14% in World War II, and 9.6% and 9.74% in the Korean and Vietnam wars respectively.

With the greater capability of transporting the wounded in Vietnam, many terminal casualties were brought in who died soon after reaching the medical facility. Hammond pointed out that 455 of 2187 casualties were treated by médecine expectante, and died within a few hours.

Discussion

The surgical treatment of head injuries changed little from the days of the Edwin Smith papyrus to the Greco-Roman period. Later improvements included better techniques for elevation of depressed fractures and an increasing appreciation of diagnostic neurology as exemplified by operating on the side opposite a hemiparesis. The “laudable pus” theory was fought successfully by Theodoric, de Mondeville, de Chauliac, Paracelsus, and others. Paré disproved the theory that gunshot wounds were poisonous. Exploratory trephination was effective with some cases of recovery after removal of a hematoma or pus.

Although dural tears and perforations were considered an incurable form of penetrating wound, occasional patients survived this complication. Review of related reports over the past 1000 years makes it clear that some cases with dural penetration and perforation recovered with médecine expectante; as the only therapy. Thus, de Mondeville, Paré, Scultetus, Larrey, and others described patients with macerated brain on the head, face, and clothing, who recovered with simple closure of the wound. In some cases of perforation of the skull by arrow, healing took place in spite of the fact that during removal of the arrow macerated brain tissue exuded from the wound. Probably the reason for survival was that such wounds were treated by médecine expectante, whereas
exploratory surgery would have led to infection and possibly death from brain abscess and cerebral fungus. High mortality rates from penetrating wounds of the head were recorded up to the end of the 19th century. Since that time treatment of such wounds by thorough debridement, removal of entrapped blood clots, and the use of antibacterial and antibiotic agents has produced better results. In wars penetrating wounds of the body and head have been important causes of death second only to communicable diseases. Before the advent of aseptic surgery, if a penetrating wound of the brain did not result in immediate death, most of the survivors died of infection. Cerebral fungus was recognized in the first century A.D. and has been discussed by Celsus. Because of their higher velocities, bullet wounds have always been more deadly than those caused by shell fragments. The higher the velocity, the greater the energy per unit of time and the larger the temporary cavitation, with damage not only along the path of the missile, but in areas relatively remote from this path as the missile traverses a closed system such as the head and skull. With present-day high-velocity missile injury, death is almost a certainty on the battlefield. Among those who survive the wounding, morbidity and mortality are high. In Hammon's series, gunshot wounds caused a 22.73% mortality, and fragment wounds 7.64%.

References
11. de Chauliac G: La Pratique en Chirurgie du Maistre de Chauliace. Lyon, Bathelemy Buyer, 1478
19. Heliodorus: Quoted by Paulus of Aegina, ref 28
22. Larrey DJ: Surgical Memoirs of the Campaigns of Russia, Germany and France. (Translated by J C Mercier.) Philadelphia, Carey and Lea, 1832
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Address reprint requests to: E. Stephen Gurdjian, M.D., Department of Neurosurgery, Wayne State University, 540 East Canfield Avenue, Detroit, Michigan 48201.