The influence of war on the development of neurosurgery

Historical vignette

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The treatment of craniospinal war wounds proved to be a significant driving force in the early growth of neurosurgery as a specialty. This publication explores the historical relationship between the evolution of combat methodology from antiquity through modern conflicts as it dovetails with and drives corresponding advancements in the field of neurosurgery.

Whether it’s the basic management principles for intracranial projectile wounds derived from World War I experiences, the drastic improvement in the outcomes and management of spinal cord injuries observed in World War II, or the fact that both of these wars played a crucial role in the development of a training system that is the origin of modern residency programs, the influence of wartime experiences is pervasive.

I would remind you again how large and various was the experience of the battlefield, and how fertile the blood of warriors in rearing good surgeons.

Hieronymous Brunswig, 16th century

Since the dawn of humankind, a symbiotic relationship has existed between casualties of human conflicts and those tasked with the treatment of these casualties. As humankind has developed more effective combat weaponry and methodology, so has humanity evolved in its ability to treat the resultant wounds of war. This relationship has been a critical factor behind the development of medicine and surgery and, in the nascent field of neurosurgery, an important driving force in the early growth of the specialty.

Prehistoric Times Until the 19th Century: From Ancient Trephinations to the Beginning of the Modern Age

The discovery of a trephined Peruvian skull by Squier in the 1860s and the excavation of Neolithic skulls in Central France by Prunières in the 1870s showcased the art of trephination to an increasingly modern and scientific world. Anthropologists subsequently sought to determine the circumstances under which prehistoric peoples would venture into the intracranial spaces as early as 10,000 years ago. Several theories were proposed. Paul Broca postulated in 1874 that these ancient trephinations were performed mostly in children for relief of evil spirits. Sir Victor Horsley disagreed, advancing his theory in 1887 that these ancient forays into the skull were for the relief of epilepsy due to depressed skull fractures overlying the motor cortex. After investigation of a large number of trephined Peruvian skulls excavated near an ancient fort, paleopathologist Roy Moodie concluded that the practice was most commonly used for the treatment of battle injuries. Although it is not completely certain why ancient trephiners on different continents chose to delve into the cranial contents millennia before aseptic principles and a modern understanding of cerebral function existed, the relief of war wounds was one of the primary indications.

The art of cranial surgery was thought to have remained primarily in the purview of primitive, prescientific surgeons until discovery of the Edwin Smith Surgical Papyrus in 1862 and its subsequent translation in 1930 (Fig. 1). This historic document provided the first evidence of a decidedly scientific approach to the cranial contents that dated back to approximately several thousand years BC. In fact, this Egyptian treatise on battle surgery provides many of the first descriptions of neuroanatomical structures as well as being the first known document to chronicle the

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Abbreviations used in this paper: MNSU = mobile neurosurgery unit; SCI = spinal cord injury; WWI, WWII = World War I, World War II.
Fig. 1. Timeline highlighting formative events in the understanding and treatment of war wounds with neurosurgery. Photo credit: Stocktrekimages/iStock/Photos.com/Thinkstock.
Influence of war on the development of neurosurgery

link between cranial damage and deficits in other parts of the body.\textsuperscript{3,42} The ancient Egyptian anatomical foundations were further advanced by Hippocrates, Galen, and others several hundred years before and after the time of Christ. Building on the Grecian developments, Persian physicians Avicenna, Rhazes, and Spanish-born Albucasis made significant contributions during the intellectual Dark Ages of Western Europe.\textsuperscript{43,49,52} Although Renaissance-era surgeons and scientists advanced the neuroanatomical fund of knowledge, especially with the work of Vesalius,\textsuperscript{31,69} it wasn’t until the contributions of 19th-century neurologists that the mysteries of the central nervous system could begin to be more extensively unraveled.

19th-Century Wars and Scientific Breakthroughs: Planting the Seeds of a Specialty

A series of discoveries by Broca, Brown-Sequard, Charcot, and John H. Jackson, among others, led to the emergence of neurology as a specialty toward the end of the 19th century.\textsuperscript{10,39} This steady stream of breakthroughs in cerebral localization combined with the seminal work of Joseph Lister would provide ripe conditions for the evolution of neurosurgery from the mystical shaman practitioners of the ancient world into the realm of surgeon-scientists. Other, perhaps less heralded advancements in wartime data collection during this period also laid the groundwork for an increasingly data-centric approach to the evaluation and treatment of craniospinal war wounds. The British surgeon G. H. B. MacLeod was the first to systematically compile large-scale data on war wounds from his experiences in the Crimean War in the 1850s. He reported that approximately 10% of all combat gunshot wounds involved the head and noted that 24 of the 28 cases in which the trephine was applied resulted in death.\textsuperscript{35,42}

The American Civil War represented an even larger-scale effort at wartime record keeping. Moreover, it marked a turning point in human combat because this was the first sizeable conflict in which gunshot wounds outnumbered puncture wounds and crude injuries wrought by more primitive weapons of war.\textsuperscript{23} The multivolume “Medical and Surgical History of the War of the Rebellion” published following the Civil War contained detailed descriptions of 983 brain injuries, the largest case series of any kind to date.\textsuperscript{24} This monumental work also detailed 911 operations for nonsuperficial cranial injuries, resulting in an overall mortality rate of 45%, along with a 57% mortality rate with trephinations.\textsuperscript{37,38,50} The Civil War also provided the backdrop for the largest experience of traumatic spinal cord injuries (SCIs) to date. In fact, Hanigan and Sloffer\textsuperscript{7} perhaps best summed up the advances in treatment of SCIs from the Civil War in writing that “operative intervention was no longer a rarity” with 63 cases by Union surgeons alone and, most importantly, “it was obvious that for national armies in very large conflicts, casualties with SCIs could no longer be ignored, left in bed, and allowed to die.”

While the Civil War raged on in North America, arguably the greatest advancement allowing for the growth of neurosurgery, and all of surgery in general, was germinating across the Atlantic with the work of Joseph Lister. Upon publication of his paper titled “On the Antiseptic Principle in the Practice of Surgery” in \textit{Lancet} in 1867,\textsuperscript{41} Lister triggered a sea change that would eventually surge to reach every surgeon’s armamentarium and every operating theater in the world. It was this advancement in surgery, along with World War I (WWI), that set the stage for the final maturation of neurosurgery into a distinct specialty in the early 20th century.

World War I: A Specialty Defined

Building on the pioneering work of Lister and early neurologists, in the years leading up to the Great War, Cushing, Von Bergmann, Keen, and Horsley transformed the prospects of safe and successful intracranial surgery from the realm of the possible to the probable.\textsuperscript{27,35,61} The progression of battlefield weaponry during this time also played a significant role in establishing a dire need for competent wartime intracranial surgeons. Prior to the outbreak of WWI, the changes in the shape and weight of projectiles as well as the increasing reliance on heavy artillery and automatic rifles spawned the conditions from which a massive amount of penetrating cranial traumas would emerge.\textsuperscript{2,25} Although Harvey Cushing’s 1905 lecture “The Special Field of Neurological Surgery” served as a declaration of sorts regarding the development of neurosurgery,\textsuperscript{25} the field had yet to be fully accepted as a distinct subspecialty among members of the existing medical establishment as WWI commenced. Nonetheless, the sheer volume of patients with craniospinal trauma and the exposure of innumerable physicians and personnel to these patients during the war would serve to solidify neurosurgery’s position alongside the recognized subspecialties as the war continued to progress. Although Harvey Cushing ventured to France as a volunteer in 1915, several years before America’s entrance into the war,\textsuperscript{36} it was the US that provided the first official military recognition of this fledgling specialty.\textsuperscript{24} Building on the substantial work of Sargent, Barany, and other surgeons,\textsuperscript{16,31,56,57} Cushing crystallized standards for the description and treatment of traumatic war wounds of the head.\textsuperscript{22,23,28} One of the more prescient recommendations by Colonel Cushing regarded the early operation of head-injured patients in forward areas when he observed that “the farther back a man with a cranial wound goes, the more gloomy becomes the prognosis.”\textsuperscript{22,38} He further explained: “the accepted high mortality of the craniocebral cases could be reduced fully 50% if these cases were operated upon in forward areas. A series of about 200 patients operated upon in the fall of 1917 at a casualty clearing station of the British Expeditionary Force, which was given over entirely to wounds of the head, gave 28.5% mortality; a similar series operated upon at a later period by members of the same team in an American base hospital attached to the British Expeditionary Force gave a mortality of about 45%.”\textsuperscript{24}

Significant progress was also made in regard to the diagnosis and treatment of peripheral nerve injuries during WWI. Although the outcomes of surgical treatment of these injuries in WWI demonstrated that technical methods for nerve grafting and primary repair were still
in their embryonic stages, essential lessons were nonetheless realized, especially with respect to surgical exposure of peripheral nerves and basic transplantation and nerve suturing techniques.34

Another often overlooked yet indispensable influence that WWI ultimately had on the development of the field concerned providing a basis for a more systematic method of neurosurgical training. As a result of the great demand for surgeons versed in the competent treatment of intracranial injuries brought about by the war, a short, 6-week course was initially established, which soon progressed to a 70-day experience in several cities around the country. Although 230 surgeons eventually graduated from this rudimentary curriculum, only 3 continued to practice neurosurgery full time after the war.36 Nevertheless, this served as the first time an attempt was made at standardizing neurosurgical training. This demand for skilled wartime neurosurgeons also served to heighten the profile of the emerging specialty and led William Mayo, the then-president of the American College of Surgeons, to proclaim the founding of a new surgical specialty at the annual meeting soon after the Treaty of Versailles.36 Consequently, WWI, which occurred at a time when the evolution of war weaponry dovetailed with an increasingly safe and systematic approach to the intracranial contents, played an especially crucial role in the recognition of neurosurgery as a distinct specialty.

World War II: Progress in SCIs and Formal Neurosurgical Training

Whereas WWI provided the backdrop for the formal acknowledgment of neurological surgery as a specialty, and significant progress was made regarding management of intracranial wounds from projectiles, WWII marked a turning point in the treatment of SCIs. Reflecting on the treatment of SCIs in WWI, Cushing wrote in 1927: “These did very badly throughout, as was anticipated. Most of them were immediately evacuated to base hospitals and fully 80 percent died in the first few weeks in consequence of infection from bed sores and catheterization. The conditions were such, owing to the pressure of work, as to make it almost impossible to give these unfortunate men the care their condition required. No water beds were available, and each case demands the almost undivided attention of a nurse trained in the care of paralytics. Only those cases survived in which the spinal lesion was a partial one.”24 The timing was ripe for progress to be made. Due to improvements in bladder management, nutrition, and prevention of bedsores, along with the growing recognition of the importance of physical rehabilitation at facilities dedicated to patients with SCI, dramatic improvements were achieved.8,32,39,40,54,59 One such improvement, the litter-turning method, became instrumental in the prevention of decubitus ulcers. Howard Rusk, a pioneer in rehabilitative medicine, wrote “It is worth noting that of the four hundred men who became paraplegics in World War I, a third died in France, another third died within six weeks thereafter, and of the remaining third, 90 percent were dead within a year. In World War II there were 2,500 American service-connected combat paraplegics, and three-fourths of them were alive twenty years later. I might add parenthetically that, of these survivors, 1,400 were holding down jobs.”30,54 R. Glen Spurling and Barnes Woodhall later noted “there is no brighter chapter in the history of neurosurgery in WWII than the competent and compassionate long-term management of injuries of the spinal cord”21 and that “more was achieved for the paraplegic in WWII, in comparison with his status in previous wars, than for any other type of casualty.”36

In addition to improving SCI treatment, WWII provided another opportunity for building on the rudimentary foundation of neurosurgical training established in WWI. Logistically, Woodhall described the need for neurosurgeons as follows: “The situation was extremely serious. The need for neurosurgical personnel was promptly evident, partly in the light of the WWI experience and partly in the light of the high proportion of neurosurgical casualties among the wounded returned from N. Africa in the early months of fighting there. To meet the requirements of tables of organization of general and other hospitals would have stripped every civilian hospital and clinic in the country and still left the Army short of needed neurosurgical personnel.”21 The training program progressed from the 70-day curriculum of WWI to at least a 4-month program consisting of an initial month of instruction, including cadaveric dissections and lectures, followed by a 3-month clinical and surgical preceptorship that could be extended by up to 6 more months if necessary. Woodhall later recounted that “In the opinion of many observers, the neurosurgical training program was one of the major medical accomplishments of the war.”21 Another advancement evident during WWII concerns antibiotic therapy. With the advent and widespread use of penicillin and sulfa antibiotics during WWII, a greater emphasis was placed on the bacteriology of war wounds. In 1944, Hugh Cairns on the British side and Arthur Ecker from Australia recognized early on the danger of gram-negative bacilli in wound infections.14,28 In addition, Cairns sought to transform Cushing’s ideas regarding early operative intervention to a new standard with the development of forward mobile neurosurgery units (MNSUs) capable of operative treatment of traumatic head injuries within 48 hours of wounding. “Each unit had its own electricity generator, tentage and water supply, as well as other necessary items such as two operating tables, suction apparatus, diathermy and illumination. In fact, there was all the equipment needed to carry out at least 200 operations without replacements.”58 However, the story of the first MNSU, commanded by Major Henderson, was somewhat abbreviated; the unit was sent to France in 1940, eventually captured with the patients and personnel taken prisoner, and was unable to participate further in the war.15,58 Despite this initial setback 8 more MNSUs took part in WWII, with impressive results. The incidence of infection, including brain fungus, was reduced from 25% to 5%, and more than 90% of wounds healed by primary intention.58 All in all more than 20,000 neurosurgical casualties were treated in the MNSUs, and a full 80% of head-injured patients in the theaters of war served by the MNSUs were treated in these units.15
The continual reduction in mortality rates associated with penetrating cranial wounds lent itself to a relatively new problem: an increasing number of surviving veterans in need of cosmetic repair of large skull defects. Even though cranioplasty with precious metals has been around since 2000 BC, the search for stronger, lighter, and more malleable materials was ongoing in the years before and during WWII, with civilian surgeons working with the newly manufactured composites vitallium, ticonium, and tantalum, along with natural metals such as lead, platinum, and aluminum. Spurling described tantalum’s preeminence after the war: “In WWII, the experience with Vitallium, Ticonium, and tantalum for cranioplasty left little justification for the employment of other metallic materials, and, at the end of the war, most of those familiar with the subject considered tantalum the metal of choice for the repair of the larger defects.” New developments unique to WWII such as antibiotic agents, hemostatic gel foam, and MNSUs as well as an overall improvement in surgical technique brought about by implementation of many of Cushing’s WWI recommendations allowed for a reduction in the mortality rate of penetrating craniocerebral trauma from 28% in WWI to 14% in WWII.

**Korea and Vietnam: Increasingly Sophisticated Triage and the Helicopter**

Hugh Cairn’s organization of forward MNSUs in WWII underscored the benefits of early operative treatment of head injuries and reinforced the truth of Cushing’s recommendations dating back to WWI. Building on the successes of Cairn’s approach and disappointed with delays in early definitive neurosurgical treatment leading to significant complications and infection at the outset of the Korean War, a new 2-tiered triage and evacuation system was fully implemented shortly after the outbreak of the war. This new triage system incorporated the newest development in aviation technology: the helicopter. This 2-tiered system and the increasingly expeditious battlefield evacuation afforded by the helicopter allowed for rapid transfer of patients with head injuries to MNSUs for primary definitive treatment before final evacuation to a tertiary center thereafter. Guidelines regarding operative techniques were evolving as well. Meirowsky and Harsh published a series in 1952 that not only credited early operative interventions at forward MNSUs with a drastic reduction in meningeal infection rates from more than 40% to less than 1%, but also advocated an open surgical treatment for fungating cerebritis. Although the importance of removal of bone fragments, secondarily if necessary, had been acknowledged by some WWII-era surgeons, it became a well-recognized staple by the end of the Vietnam War. This fairly strict recommendation requiring secondary removal of all retained bone fragments would be further questioned and scrutinized in subsequent conflicts. All told, the principal neurosurgical legacy from the Korean and Vietnam Wars is mostly a logistical one regarding the cultivation and relative perfection of a swift and agile triage and battlefield evacuation system.

**The 1980s—Lebanese-Israeli Conflict and the Iran-Iraq War: Indriven Fragments Revisited and Recognition of Traumatic Cerebrovascular Injuries**

The Lebanese-Israeli conflict in the early 1980s saw the introduction of routine CT use in combat. As a result not only of this new imaging capability that allowed Israeli surgeons to locate indriven bone fragments preoperatively but also a reassessment of the evidence regarding the relationship between retained fragments and late complications, surgeons at Rambam Maimonides Medical Center in Haifa, Israel, adopted a new, less aggressive policy: “No efforts were made to locate or remove indriven bone or metal fragments visualized on CT unless they readily presented themselves on gentle irrigation. In fact, it was elected to treat a number of patients without intracranial hematomas nonoperatively. The acute outcome was quite similar to that reported in Vietnam series in respect to both complications and mortality.” This less aggressive approach was further advocated by Iranian neurosurgeons who investigated 1150 patients with penetrating craniocerebral wounds from the Iran-Iraq War. Both of these studies readily admitted the role of CT imaging in allowing the surgeon a degree of comfort in choosing the more conservative route. In addition to re-evaluating the treatment of penetrating wounds, the Iran-Iraq War provided the backdrop for pioneering work in the early recognition and treatment of traumatic cerebrovascular injuries. Amirjamshidi et al. noted that 5.7% of casualties evaluated with angiography exhibited posttraumatic aneurysm formation and were treated with either open clipping or observation.

Although the pace of advancement in the treatment of wartime craniospinal trauma slowed somewhat with the Vietnam War and subsequent conflicts, technological advances toward the end of the 21st century would serve to usher in a new area of accelerated progress coinciding with the forthcoming US campaigns in Iraq and Afghanistan.

**Conflicts in the Modern Middle East: Guerrilla Warfare, Early Decompressive Hemicraniectomies, and Endovascular Innovation**

The US conflicts in Iraq and Afghanistan mark a significant departure from traditional state-based warfare tactics to engagement with less-well-defined enemies easily capable of camouflaging themselves within native populations. Although neither guerrilla warfare nor the increasing reliance on improvised explosive devices by those forces opposing the US are truly novel concepts, they have become the defining aspects of modern US warfare and thus have heavily influenced the type of craniospinal casualties emerging from these conflicts. The increased number of traumatic blast injuries caused by improvised explosive devices has contributed to a paradigm shift, with an emerging assertiveness and willingness of wartime surgeons to perform early decompressive...
cranectomies in severely injured patients.\textsuperscript{40,51} This trend of early decompression leading to increased survival has, in turn, unmasked growing numbers of traumatic cerebrovascular injuries.\textsuperscript{6,9} Whereas Aarabi previously described clip ligation for posttraumatic aneurysms, Bell et al.\textsuperscript{2} have demonstrated the safety and efficacy of newly adopted endovascular techniques. Furthermore, the increased survival afforded by early decompression is providing the backdrop for intensive study of traumatic cerebral vasospasm, which may prove to have significant emerging developments are just beginning to find their way to publication, the full story regarding the evolution of wartime neurosurgical techniques shaped by these ongoing conflicts has yet to be fully written.

Conclusions

Beginning with the trepanations performed by primitive, prescientific surgeons, and progressing through the modern conflicts of the 21st century, the reciprocal relationship between the evolution of war-making methodology and its effect on the development of neurosurgery has been profound. As Brunswig noted more than 500 years ago, the blood of ancient and modern warriors spilled onto the battlefields of history has proven to be fertile ground indeed not only for the development of neurosurgery but for all of medicine.

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