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Nelson’s wound: treatment of spinal cord injury in 19th and early 20th century military conflicts

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During the first half of the 19th century, warfare did not provide a background for a systematic analysis of spinal cord injury (SCI). Medical officers participating in the Peninsular and Crimean Wars emphasized the dismal prognosis of this injury, although authors of sketchy civil reports persuaded a few surgeons to operate on closed fractures. The American Medical and Surgical History of the War of the Rebellion was the first text to provide summary of results in 642 cases of gunshot wounds of the spine. The low incidence of this injury (0.26%) and the high mortality rate (55%) discouraged the use of surgery in these cases. Improvements in diagnoses and the introduction of x-ray studies in the latter half of the century enabled Sir G. H. Makins, during the Boer War, to recommend delayed intervention to remove bone or bullet fragments in incomplete injuries. The civil experiences of Elsberg and Frazier in the early 20th century promoted a meticulous approach to treatments, whereas efficient transport of injured soldiers during World War I increased the numbers of survivors. Open large wounds or cerebrospinal fluid leakage, signs of cord compression in recovering patients, delayed clinical deterioration, or intractable pain required surgical exploration. Wartime recommendations for urological and skin care prevented sepsis, and burgeoning pension systems provided specialized long-term rehabilitation. By the Armistice, the effective surgical treatment and postoperative care that had developed through decades of interaction between civil and military medicine helped reduce incidences of morbidity and dispel the hopelessness surrounding the combatant with an SCI.

KEY WORDS • military • neurosurgery • spinal cord injury

Abbreviation used in this paper: SCI = spinal cord injury.
eral mobility of the bone on the back or neck. The prognosis in forward dislocations was hopeless. Posterior displacements could be treated with extension and pressure. Principles of closed reduction that were followed for centuries (Fig. 1). Hippocrates’ method left nothing to the imagination:

But the physicians, or some person who is strong, and not uninstructed, should apply the palm of one hand to the hump, and then, having laid the other hand upon the former, he should make pressure, attending whether this force should be applied directly downward, or toward the head, or toward the hips. This method of applying force is particularly safe; and it is also safe for a person to sit upon the hump while extension is made, and raising himself up, to let himself fall again upon the patient. And there is nothing to prevent a person from placing a foot on the hump, and supporting his weight on it, and making gentle pressure. . . .

Fracture management was similar for civil or battle casualties. Albucasis, Oribasius, Celsus, Scultetus, and others devised their own platforms or traction devices. Benjamin Bell stretched his patients over a wine cask. Fabricius Hildanus used pillows, or if that failed, an awl passed through the spinous processes and connected using a curved forceps. A rope tied to the forceps was used to distract the “luxation” and the hapless patient. The most extreme measure was one of the most ancient. “Succession” required strapping the patient to a ladder upside down and letting gravity do the rest. Even Hippocrates struggled with this technical feat:

Wherefore succession on a ladder has never straightened anybody, as far as I know, but it is principally practiced by

![Image](78x129 to 251x369)

those physicians who seek to astonish the mob—nor to such persons these things appear wonderful, for example, if they see a man suspended or thrown down, or the like: and they always extol such practices, and never give themselves any concern whatever may result from the experiment, whether bad or good. But the physicians who follow such practices, as far as I have known them, are all stupid . . . indeed, for my own part, I have been ashamed to treat all cases in this way, because such modes of procedure are generally practiced by charlatans.41

Given the extreme measures of closed reduction, physicians turned to surgical intervention. The indications varied from cosmetic repair of the gibbus to removal of bone fragments to relieve cord compression. Perhaps the first proponent was Paulus Aegineta who, after warning the patient of the danger, incised bone fragments in patients with vertebral fractures. The French military surgeon, Ambrose Paré, recommended removal of free bone fragments; bone chips attached to the periosteum were left in place. Other physicians inserted various concoctions into open wounds, leaving “the rest to God and the goodness of nature.” Treatment continued “until the wound has healed or the patient dead.” Surgeries quickly appreciated two clinical facts: forced reduction in patients without SCIs was dangerous and therapy was futile for patients with complete paralysis.60

The introduction of large armies, rudimentary medical services, and gunpowder separated the experiences of civil and military surgeons. Although combatants occasionally fractured their vertebrae, particularly those in the cavalry, the majority of battle casualties with SCIs sustained penetrating injuries. The distinction, however, was an artificial one, as reports of injured soldiers or sailors mingled with cases of fractures in civilians. In 1753, the surgeon Géraud performed an operation in an Irish soldier from a Dilon regiment, who had been wounded by a musket ball at the Battle of Fontenoi. Géraud tried five times to remove the ball and bone fragments at the level of the third lumbar vertebra. The wound became infected, but the soldier may have regained function in his legs.60 Louis, the permanent secretary of the French Royal Academy of Surgery described 14 cases of vertebral fractures and luxations during a lecture in April 1774, which was eventually published in 1836.55 The seventh case was that of Captain Villedon from the regiment of Vaubecourt, who was shot while at the Bridge of Aménebourg sur l’Horn in November 1762. Duplessis, the Surgeon-Major of the army, treated the thoracic wound at a hospital near Marbourg. Captain Villedon remained paralyzed, but the ball was removed. The soldier was then transported to Rosdorff, where Duplessis conferred with Louis. Exploring the wound with his fingers, Louis managed to remove several large bone fragments. On the following day, the surgeons explored the wound again and removed more fragments, justifying their intervention with a direct comparison with exploration of a cranial fracture. The wound developed “suppuration abondante et loulable;” however, the captain recovered and 12 years later walked around his estate at Ploitou with the help of a cane. Although this was not the first example of surgical intervention, it was the first report containing data from a definitive long-term follow-up review. Louis’ paper included several examples of battle casualties and unsuccessful surgical attempts at decompression or reduction.
The analogy between surgery on the head and spinal cord was fundamental to the early treatment of SCI. By the end of the 18th century, Chopart and Desault recommended trepanation of the spine, even in cases in which there was no evidence of fracture or dislocation, in an effort to relieve compression by blood or scar. Ten years after Vice Admiral Nelson sustained his fatal wound, a report by George Hayward described a surgical procedure performed by Mr. Cline, Jr., at St. Thomas’ Hospital. Mr. Cline performed surgery 1 day after injury in a patient rendered paraplegic after a fall from a balcony. Cutting into the spinous processes of the thoracic region, Cline removed bone fragments with a rongeur and sawed off the transverse processes to reduce the dislocation. The patient failed to improve and died 5 days later, but Hayward believed that the spine could “bear very considerable violence without any dangerous consequences.” He added that, in the next patient, Cline would use the chisel with even less caution in an effort to reduce the dislocation. Cline never performed another laminectomy. Similar to the contemporary treatment of head injuries, these mixed messages resulted in two radical views concerning surgical intervention. Some surgeons, such as Sir Astley Cooper, lectured that it would be “unmanly” to refuse to perform an operation, although in his one effort, Cooper terminated the procedure prematurely. Others, such as Charles Bell and Benjamin Brodie, condemned aggressive surgeries and referred to inaccurate diagnoses, careless techniques, and incomplete follow ups usually based on hearsay.

Alban Smith’s widely disseminated report in 1829 was a good example. A Shaker farmer had fallen and fractured his lower cervical spine. The despair of the patient led Smith to operate several months after the injury by using a Hey’s saw-and-tooth forceps to remove the lamina, pedicles, and transverse processes of the upper thoracic vertebrae. After an attempt to reduce the dislocation, Smith sutured the remaining fragments together. Somehow the patient survived and Smith, who believed in the beneficial influence of the spinal cord on skin viability, reported:

I saw him in a week afterwards. The ulcers in his gluteal muscles, which were produced by lying on his back, were healed up; and he had some additional sensation in his hands. Since then I have not seen him; but I entertain considerable hopes.

Medical officers either advocated conservative treatment or failed to address the problem. Surgeons in the Peninsular War did not mention SCI nor did Gross in his manual published in 1862. Williamon during the mutiny in India, or Hennen and Guthrie in their textbooks. Sir George Ballingall wrote that Mr. Blair, a former surgeon in the Royal Navy, had trephined the spine of a lower deck man, but Ballingall condemned the procedure as did the French Medical Service. Lidell reported 10 cases of gunshot wounds of the vertebrae without SCIs during the Crimean War. Four of the patients survived, whereas all 22 military personnel with SCIs died. The official medical history of the British Army during the Crimean War noted that infection of the “spinal marrow” resulted in death, even in casualties with fractures that only involve the spinous or transverse processes. The experiences of several medical departments corroborated reports in the civil practice of cord “concussion.” In another comparison to the brain, the spinal cord could be concussed without evidence of external trauma or surgical confirmation of a fracture or SCI. The paralysis, like unconsciousness, either improved or remained unchanged.

By the middle of the 19th century, infrequent and turgid case reports offered a pale glimmer of success in a formidable surgical arena, but resulted in contentious debates. For the most part, treatment was limited to the ancient methods of closed reduction and bedrest, or the occasional exploration and removal of a musket ball or bone fragments. Civil and military surgeons had little time to deal with an infrequent problem that promised few clinical rewards. A physiologist and another war would alter this point of view.

Defining the Problem

Charles Edward Brown-Séquard was 41 years old when he summarized his research into the function of the central nervous system in a series of lectures delivered to the Royal College of Surgeons in 1858. The talks, published in book form 2 years later, were successful and strengthened an already considerable reputation that originated from his earlier description of the sensory decussation in the spinal cord. The book included 12 lectures in which Brown-Séquard lucidly described cerebellar, brainstem, and spinal cord functions with animal experiments and clinical examples. At the end he addressed surgical intervention for fractures and SCI. First he showed that opening the spinal canal and exposing the meninges or cord to the air was in and of itself not dangerous, as he had done this many times during his animal research. Second, he claimed that death following spine fractures was due to pressure or “excitation” of the cord and was not due to direct injury. Here he stepped on unfamiliar ground as he speculated that skin sloughs or urinary infections were a result of this irritation, rather than local ischemia or bladder dysfunction. Most fractures contained bone splinters that irritated the cord and, hence, removal of the bone could improve the skin condition and bladder function. Third, reports of trepanation on the cord proved the usefulness of surgery. Brown-Séquard admitted that many descriptions, including that of Smith, were incomplete but at least some patients survived and showed improvement. He went on to observe that many experimental animals improved after section of the cord, suggesting a “reunion” and, finally, bone regenerated after removal, arguing against the potential hazards of spinal instability. These lectures presented a skilled blend of neurophysiology and clinical observation. Brown-Séquard was well known in the US, England, and France because he had various academic appointments in all three countries. His strong advocacy for surgical intervention was difficult to refute at any level.

By the time of the publication of Brown-Séquard’s book, America was involved in a war complicated by firearms, projectiles, and tactics that produced casualties by the thousands. The authors of the massive official American medical history obtained data from 20 military operations ranging from the Revolution in Paris in 1830 to the Russo-Turkish War ending in 1877. Excluding the Civil War, there were a total of 216,000 shot wounds (the Civil War...
War resulted in almost 246,000 shot wounds on the Union side alone. The introduction of the rifle Minie projectile increased the range and accuracy: round, grape, canister, or shrapnel shot achieved projectile velocities greater than 1500 feet per second with ranges up to 5 miles. The tactics of advancing troops over open ground in front of fortified defensive positions led to huge numbers of casualties. Later in the war, entrenchment resulted in the protection of the soldiers’ backs, but increased the number of injuries to the head and neck. Improvements in evacuation meant that at least some casualties with SCIs were transferred to larger general hospitals in the cities, and accurate records outlined specific wounds, clinical courses, and outcomes. Autopsies provided the ultimate answers.

American medical officers described their own extensive experiences before compiling the official history. In 1864, the surgeon John Lidell, who was in charge of the Stanton General Hospital in Washington, DC, published an article in which he described a series of casualties with SCIs. He divided patients with closed fractures into those with immediate cord compression by bone and those with a gradual onset of symptoms that were due to compression by blood from damage to the “meningo-rachidian” arteries. Dislocation without fracture was infrequent and usually occurred in the cervical region with complete disruption of ligaments and muscles. Gunshot wounds caused simple fractures or fractures with direct damage to the cord and leakage of CSF. Digital exploration of these wounds was mandatory: “for in them the highest interest of the patient and the reputation of the surgeon are deeply involved in the prognosis which he may give.” Lidell did not favor reduction of fractures, however, and recommended trepanation only in unusual circumstances. His prescient advice for the transportation and medical care in patients with SCIs is quoted at length:

Care should be taken at every step that the injury of the spinal cord be not increased by the employment of any unnecessary violence in handling or moving the patient. After the receipt of the injury, the coat, waistcoat, and shirt should not be removed by pulling them off over his head, as generally practiced; for, by taking them off in this way, there is a great risk of increasing the displacement of the fragments, thereby increasing the lesion of the cord; but the clothing should be carefully cut off from him with a scissors or a sharp knife. In all cases, of paraplegia produced by violence, the safest way will be to cut off from him with a scissors or a sharp knife. In all cases of removing the patient to his home or to the hospital, he should be carefully placed in a recumbent position upon a litter, or a door removed from its hinges. If the fracture be located in the cervical or superior dorsal region, his head should at the same time be carefully steadied by pillows or cushions placed on each side of it. At the hospital, he should be placed upon a water-bed, or, in its absence, upon a soft mattress, for treatment, with a view to lessen the tendency to the formation of bed-sores over the sacrum and the hips, a very strong tendency to which will be present on account of the diminished vitality of the paralyzed tissues. Bed-sores in such patients do not heal, and generally expedite the fatal result considerably. Special attention should always be paid to the bladder. From paralysis of that organ, the patient cannot pass any urine of his own volition. The catheter should therefore be regularly introduced at suitable intervals twice a day, and the urine drawn off. . . . Particular attention should be paid to cleanliness. The surgeon should every day see for himself that the genital organs, the nates, the hips, and the sacral region are perfectly clean and dry, and that there are no dark-red spots indicative of the beginning of bed-sores. . . .

John Ashhurst, who was a surgeon at the Cuyler General Hospital, approached the problem in a different manner. In 1867, he published what can only be described as an outcome analysis of cases culled from the previous literature. Beginning with Hildanus in 1646, Ashhurst included only those reports that contained accurate descriptions of injuries, treatments, and outcomes. In this fashion, he analyzed 394 cases of SCI from a variety of causes, although only 16 were due to gunshot wounds. In 208 cases the injuries involved the cervical region, in 106 cases they involved the thoracic spine, and in 37 cases they involved the lumbar region; the remaining cases involved mixed injuries. The incidence of mortality was highest in the cervical region (77%), followed by the thoracic region (63%), and, finally, the lumbar spine (59%). Lumbar injuries displayed the greatest tendency to improve. Ashhurst took particular care to write that 15% of patients with SCIs lived for longer than a month, but less than 1 year, whereas 4% of all of these patients lived longer than a year. He found that extension (with rotation or pressure) resulted in recovery in 30 of 44 cases, whereas general treatment (bedrest) resulted in only 13 recoveries in 117 patients. Resection failed to produce any recoveries in 24 patients, leaving a mortality rate of 75%, and thus could not be recommended.

Although valuable, these reports were overshadowed by the publication of the first volume of The Medical and Surgical History of the War of the Rebellion in 1870. The American Army Medical Department used their newly organized Army Medical Museum and the Surgeon General’s Library to supplement this monumental work of six volumes, each of which comprised more than 700 pages and was edited entirely by medical officers. Daily regimental and hospital reports, which had been mandated by 1863, along with surgical reports and detailed illustrations produced an accuracy that was applauded immediately in the US and Europe.

The history offered reports on 642 shot wounds of the spine; these represented 0.26% of all shot wounds and a mortality rate of 55% (Fig. 2). The chapter edited by Assistant Surgeon George Otis, who was the director of Surgical Records and worked in the Army Medical Museum, contained detailed descriptions of 133 cases, identifying the surgeon who contributed to each report. Otis included an additional 62 operations on the spine. There was an operative mortality rate of 43%; in 27 procedures performed to remove the ball, nine patients died and four returned to duty, whereas in 24 operations performed to remove bone, 10 patients died and seven returned to duty. All four patients who underwent arterial ligation in the cervical region died as a result of the surgery. The mortality rate dropped from 70% in cervical injuries to 46% in lumbar injuries; wounds through the chest and abdomen were fatal. The Surgeon General’s Library enabled the editors to include several long bibliographies on SCI and the Museum provided specimens on which to base engravings throughout the text (Fig. 3). Although the Confederacy was not allowed to have its own medical history, Otis readily acknowledged the contributions of his rebel
colleagues, particularly with regard to spinal concussion. Some of the clinical reports and their young surgeons-reporters were surprising. Many survivors with SCIs were transferred to Turner’s Lane Hospital in Philadelphia and were treated there by Assistant Surgeon William W. Keen. He described the case of Private Charles Cleland, from the 7th Wisconsin Volunteers, who was shot in the mouth through to the third cervical vertebra. The trooper was paralyzed in all four extremities, but the ball was removed with a Nelaton probe 1 week later and the patient improved enough to stay on as a hospital attendant. While at Turner’s Lane, Private Cleland kept spitting up bone fragments:

...nearly the entire body of the third cervical vertebrae has come away including the anterior half of the transverse process and the vertebral foramen. No injury to the vertebral artery has been disclosed. What supports his head, anteriorly, I can’t conceive.69

Assistant Surgeon John Shaw Billings performed surgery in a Confederate prisoner, Corporal W. A. Freeman, of Company B, of the 13th North Carolina regiment, at the Cliffburn Hospital in Washington. The wound, which was located in the upper dorsal region, was infected; Shaw explored the wound with his fingers and then made a transverse incision to remove pus and large bone fragments. The wound was left open and packed with lint that had been soaked in laudanum. Corporal Freeman did well and was eventually transferred to the Old Capital Prison.70

Both assistant surgeons moved on to successful careers, each in his own fashion.

Several obstacles had been overcome by the end of the American Civil War. Experience with SCIs expanded and improved; operative intervention was no longer a rarity. The expertise of military surgeons now superseded their civil colleagues, as army records testified to their accurate notes and follow-up reviews. Older reports had been summarized and a new more reliable literature outlined injuries and treatments. On the other hand, although it was true that both acute and chronic care improved, surgical intervention was still haphazard. Despite the influence of Brown-Séquard and dependable clinical observations, such as the negative prognostic signs of hypothermia and

Fig. 2. Table indicating Percentage of Fatality and Relative Frequency of Shot Wounds recorded during the War of the Rebellion. From Otis GA, Huntington DL: The Medical and Surgical History of the War of the Rebellion Surgical History, Part III, Volume II. Washington, DC: GPO, 1883, Table CXIX, p 691.

Fig. 3. “Lumbar vertebrae, with a cast-iron shot lodged in the canal.” From Otis GA, Huntington DL: The Medical and Surgical History of the War of the Rebellion Surgical History, Part I, Volume II. Washington, DC: GPO, 1870, Fig. 195, p 443.
priapism, most neurological examinations were primitive and incomplete. Nevertheless, 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.

NEUROSCIENCE, ACCIDENTS, AND WEAPONS

Innovations in basic and clinical neuroscience during the next half century resulted in significant changes in the treatment of patients with SCIs. Anatomists and neurophysiologists outlined nerve tracts and reflex arcs, demonstrating that the spinal cord showed distinctive reflex activity following disease and injury. The emergence of neurology as a specialty, although not regulated, provided a cadre of well-trained observers. New instruments, such as the esthesiometer, and techniques, such as lumbar puncture, added measurable data to the clinical examination as well as to the cache of scientific apparatuses and techniques by the bedside. Faradic or galvanic electrical stimulation determined the reaction of degeneration in damaged muscles and restored “trophic” influences on the skin that had been interrupted by SCI. By 1901, the innervation and various patterns of denervation had been described for the bladder and rectum.23,28

Discoveries by Lord Lister, von Bergman, G. W. Crile, and many other civil surgeons broadened the range of expertise in the operating amphitheater. In an article published in 1884, William Thorburn,81 a surgeon in Manchester, England, described the clinical picture of SCIs at various levels (Fig. 4). His recommendations for aggressive surgery in patients with compound fractures or compressive lesions stemmed from a large experience of 9000 patients with accidental injuries who were admitted every year to the Manchester Royal Infirmary. Thorburn preferred the new term, “laminectomy” rather than the older phrase, “trephining the spine” with its remote analogy to cranial surgery.16,18 In 1905, at the University of Pennsylvania Harte36 analyzed the cases of 95 patients who underwent operations for spinal tumors. Most of the neoplasms were “sarcomas,” although there were a variety of other lesions such as Echinococcus species, cysts, adhesions, or “fibromas.” The mortality rate was a foreboding 47%, but Harte allowed some leeway concerning this statistic because almost half the patients died weeks or months after surgery. By this time, osteoplastic laminectomies, which had been pioneered by Dawbarn and Urban in the late 1880s, lost favor.60 Harte recommended a simple midline incision and bilateral laminectomy, with careful preoperative localization so as not “to search for the growth too low down in the spinal canal.”36 Harte used whatever instruments were handy, including chisels and saws. He closed the dura mater “loosely” and drained all the wounds.

A decade after Harte’s paper, Charles A. Elsberg and Charles H. Frazier published their influential textbooks on spinal surgery. These surgeons devoted a great deal of space to SCIs. They recommended closed reduction for fractures, but if this failed, an open reduction was considered. Penetrating wounds of the spine with retained fragments of bullets or knives were explored, particularly if CSF continued to leak from the wound. Frazier noted from the literature that deaths more frequently occurred in patients who did not undergo surgery, whereas the incidence of surgical intervention was almost three times higher in the 38% of survivors who showed improvement. In his own cases that were managed prior to 1911, the rate of operative mortality was 20%: this figure dropped to less than 7% between 1911 and 1915.

Both surgeons used meticulous techniques and discarded chisels, saws, and osteoplastic laminectomies. Elsberg used a straight midline incision and Frazier made a semilunar incision and reflected a flap over the spinous processes. The dura mater was opened gently after a laminectomy and the cord was split in the midline to remove clots when appropriate. Following exploration, the dura was closed and the wound drained. The authors downplayed the innovation of spinal cord suture or myelorrhaphy. Frazier reported a summary of seven cases since Estes in 1889 and attributed the poorly documented recovery rate to a failure to recognize uninjured portions of the cord or segmental recovery of nerve roots above the lesion. “The burden of proof” he wrote,

is so overwhelmingly on the operator that any such statements may be well set aside unless there be a detailed description of his technique and findings in the examination. . . .

The plight of the patient with an SCI or a putative SCI influenced public opinion during this period. In 1866, John E. Erichsen, a prominent London surgeon later knighted, examined the disabilities of workers and passengers involved in railway accidents and developed the concept of “railway spine.”11,48,73 These patients demonstrated symptoms following their injuries that were similar to the spinal cord “concussion” described during the Civil War. The importance of this condition did not lie in the clinical phenomena—both Thorburn and Frazier condemned the lack of clinical signs and Erichsen’s speculation of a “molecular disturbance” in the spinal cord—but instead in the fact that the occurrence of symptoms was associated with litigation following the introduction of worker’s compensation laws. Whatever the motives and legal outcomes (courts generally ruled in favor of the defendants), the accidents galvanized public support for

Fig. 4. “Figure of the upper extremities of a patient with a complete transverse lesion of the cord at the level of the sixth cervical segment.” Picture adapted from Frazier CH, Allen AR: Surgery of the Spine and Spinal Cord. New York: Appleton, 1918, Fig. 193, p 410.
Medical care. Labor organizations lobbied, sometimes violently, for government regulations and subsidies. By 1914, legislation was introduced for most European countries and the US as accident victims became a public concern, rather than an individual tragedy.17

Military medicine had its own problems and surgical innovation was not one of them. Huge numbers of non-battle casualties during the Spanish–American and Boer Wars highlighted gross deficiencies in medical authority and sanitary regulation. The wars of the late 19th and early 20th centuries offered partial solutions to these concerns. The Franco–Prussian War demonstrated the effectiveness of an inclusive coordinated General Staff and the Russo–Japanese War reinforced the value of strict and pragmatic hygiene to dozens of military medical observers. Meanwhile, regular and reserve armies grew at exponential rates while the ascendance of machine guns and artillery eluded military planners.40

The medical services managed to collect their statistics and officers published their memoirs. Surgeon-General Longmore, in a comprehensive text published in 1877, counted 2586 spinal injuries among various armies from conflicts ranging from the Crimean War to the British Conflict in the Sudan in 1871. The average mortality rate was 32%, but ranged from 10 to 75%.53 Longmore was pessimistic about SCIs, but devoted little space to their treatment. Thomas Evans, in his experience with the American Ambulance corps during the siege of Paris from September 1870 to February 1871, recorded 247 admissions with a mortality rate of only 19%. There were five soldiers with spine injuries, four of whom died.21 The British experienced a 58% mortality rate among patients with SCIs during the Boer War. The War Office had hired nine civil consultants to inspect hospital facilities and institute standardized surgical care. One of these consultants, George H. Makins, who was later knighted, was a surgeon at St. Thomas’ Hospital in London and eventually became president of the Royal College of Surgeons. In his memoir, Makins wrote of SCIs that “these cases form one of the most painful and distressing features of the surgery of the campaign.”55-56 Fractures from falls or from hard-mantle small-caliber bullets were infrequent. Functional paralysis or “conussion” was not uncommon. Makins recommended surgery if one of the following three conditions was present: 1) if the patient was suffering severe pain in the region above the wounded segment; 2) if the patient showed some improvement following evidence of compression by bone fragments; or 3) if the patient showed improvement followed by evidence of compression by bullets or fragments in the spinal canal. Surgical treatment was delayed until the patient reached a general hospital, which sometimes was hundreds of miles away.13-64 None of the medical observers during the Russo–Japanese War (1904–1905) mentioned the treatment of SCI. Statistics on specific injuries were hard to come by and most observers were more concerned with the combatants’ integration of voluntary aid and sanitary procedures.51-56,79 The Balkan Wars (1912–1913) gave some hint of what was to come. Frazier reported a mortality rate of 94%. Surgeons remarked on the frequency of wounds produced by shells and the high incidence of infections. Casualties with SCIs were transported immediately to prevent the onset of decubiti or bladder infection due to the lack of nursing care at hospitals near the front.51

Statistics showed the medical services that the mortality rate for SCIs had increased during this period. Preventative medicine was a priority, but the authorities could not ignore the widening gulf between the expertise of civil and military surgeons. To some extent the introduction of consultants and contract surgeons narrowed the gap and allowed for greater wartime flexibility and improvements in care, but these were temporary fixes. The establishment of army medical schools, increases in pay and rank, and specialists’ appointments partially relieved a dismal recruitment; the development of a reserve component helped as well.

Both consultants and regular army officers knew that military medicine faced additional constraints such as effective evacuation during battle. Consequently, medical departments modified their tactics to adjust to the changes in war that occurred during the early 20th century. Zones of collection, distribution, and evacuation contained specific personnel, transport, and hospital facilities to ensure that wounded personnel would pass through the line rapidly and reach appropriate care. Efficient transport meant that increased numbers of severely wounded patients reached hospitals before dying on the battlefield. This, in turn, indicated that the mortality rate for soldiers admitted to the hospital would rise unless medical equipment and personnel improved and increased.

One innovation occurred quickly. Five months after William Roentgen’s submission to the Würzburg Physical Medical Society in December 1895, Lt. Col. Alvaro at the Italian Military Hospital in Naples obtained x-ray films in two soldiers wounded at the Battle of Adowa. One year later, skiagrams were used during the Greco–Turkish War on a routine basis, or at least as routinely as possible given the confusing collection of interruptors, commutators, coils, and fragile Crookes tubes. Tenacious medical officers (or quartermasters) lugged portable units through the Kyber Pass, Sudan, and Cuba. Lt. Bruce Smith, who would later become chief radiographer for the Royal Army Medical Corps, jerry-rigged an x-ray unit during the siege of Ladysmith in 1899. Although it was not easy, he managed to develop 200 x-ray films. Within 10 years, the use of x-ray studies became mandatory for trauma care.1,12,10,74

There remained a fundamental clinical issue specific to the patient with an SCI. Civil and military surgeons still agreed that surgery was useless in patients with complete injuries. The question was whether surgery was effective for patients with incomplete lesions and, if so, how to determine if an injury was incomplete. For punctilious neurologists, the appearance of any reflex, particularly the Babinski phenomena, indicated a partial lesion. Improvement in sensation no matter how vague or poorly localized, or bladder evacuation associated with any voluntary effort were positive signs.73 As a result, there was a potentially large population of patients with incomplete SCIs in whom surgical intervention was necessary if the spinal cord had been compromised by a bone or bullet. Another conflict would test this clinical assertion as well as the value of civil expertise, public awareness, and military medical preparations.
SURGERY AND DISABILITY DURING THE GREAT WAR

There was no shortage of human material during World War I. Wartime medical advertisements were constant reminders of casualties and disabling wounds (Fig. 5). Statistics were often incomplete, but American data were accurate for that country’s brief 4 months of active operations. There were 147,651 hospital admissions for missile injuries. A total of 12,192 patients died, providing a mortality rate of 8.2%. Five hundred ninety-eight (0.4%) of these patients sustained wounds to the spine, and 334 (55.9%) of them died. Three hundred thirty-one patients died of “unspecified” injuries, whereas 267 died of injuries caused by shells or shrapnel.55 The Ministry of Pensions in the UK published data on long-term care. In April 1919, there were 3531 military patients with “paraplegia;” injuries caused by shells or shrapnel.55 The Ministry of Pensions in the UK published data on long-term care. In April 1919, there were 3531 military patients with “paraplegia;” this was 0.3% of the disabled military personnel who required either inpatient or outpatient treatment. By 1923, 2481 (70%) of these patients sustained wounds to the spine, and 334 (55.9%) of them died. Three hundred thirty-one patients died of “unspecified” injuries, whereas 267 died of injuries caused by shells or shrapnel.55 The Ministry of Pensions in the UK published data on long-term care. In April 1919, there were 3531 military patients with “paraplegia;” this was 0.3% of the disabled military personnel who required either inpatient or outpatient treatment. By 1923, 2481 (70%) of these patients died or were discharged from military care.61 (In 1919, the totally disabled British soldier received £8 or the equivalent of $32/month in pension. The American soldier received $30/month, which rose to $95/month for soldiers with more than four dependents. This pension converts to approximately $1,200 to $3,800 a month in 2003 dollars.35)

The numbers, bad as they were, softened the reality. Spinal cord injuries were frequent occurrences in late 1914 and in 1918, during the periods of mobile war. The higher incidence in 1914 was attributed to enfilade fire into the flanks of advancing troops. Casualties in 1918 were caused presumably by a lack of cover, the use of rifles by German stormtroopers, and inaccurate indirect artillery fire. During the middle years of the war, trench stalemate and the development of sophisticated surgical care near the front line complicated the analyses of SCIs. Surgical perspectives differed between personnel at field hospitals and base hospitals along the Atlantic and Channel coasts, and the constant shifting of patients and staff hindered adequate follow-up review in these patients.

Many clinical observations occurred in the face of dramatic obstacles. Two regimental medical officers tried their best:

Case B.-Pte.-was completely cut across at the level of the second or third dorsal vertebra by a large piece of high explosive shell shaped like a knife-blade (longer than the blade of an ordinary bread knife and much heavier). . . . Examination of the trunk showed the knee-jerks to be present and distinctly brisk.

Pinching the inner side of the thigh caused the corresponding leg to be drawn up, and both urine and feces were voided . . . we regret that circumstances did not permit of investigation of the plantar response and ankle clonus.44

(The reader may forgive the officers for their failure to complete the neurological examination.) It was not surprising that the fog of war produced marked differences in surgical attitudes; consensus was difficult to achieve.

Early in the war, survivors with SCIs were transported to hospitals in the UK and prompted a flurry of clinical studies. At Queen Square F. M. R. Walshe reported several unusual findings. The presence of reflexes, including the Babinski phenomenon, were not associated with recovery, but part of a “paraplegia in flexion” that originated in the cord and was not dependent on efferent pathways from the cortex.45 Later, Henry Head (who was later knighted) and George Riddoch at the Empire Hospital demonstrated that intermittent bladder function was due to the increased reflex activity seen in some patients with cord transaction.46 Thorburn summarized these findings in his chapter on SCI for the official British medical history:

These observations show clearly then that the return of reflexes below the lesion is no evidence of returning function, and they incidentally remove the false premise upon which an estimate of recovery has often been based. . . . One is thus in the majority of cases faced by the impossibility of determining how far recovery is possible, and time alone will answer this question.45

Gordon Holmes, the most scientifically prolific neurologist during the war, rarely agreed with Riddoch42,75 and relied on the Babinski reflex as early evidence of a partial lesion. Following his work with Percy Sargent, a surgeon at Boulogne, Holmes delivered the Goulstonian lectures to the Royal College of Physicians of London in 1915.43 Using handwritten notes made on more than 300 patients with SCIs, Holmes described clinical signs of injury to the sympathetic chain, hypothermia, and the unusual occurrence of posttraumatic herpetic lesions in the upper margin of the sensory loss. He also described an incomplete lesion of the cervical region that presented with paralysis of the arms but spared the legs. He attributed this to cervical “softening,” with damage to the gray matter of the cord. Most importantly, he outlined a series of neuropathological changes that developed after the injury and demonstrated axonal swelling several segments away from the primary lesion (Fig. 6 upper). These distant lesions with small areas of necrosis and hemorrhage resulted in necrotic cavities in the central cord that were filled with cellular debris and degenerating axons (Fig. 6 lower).

Holmes made two points about these cases. The first was that spinal “concussion” was not always functional and that tissue changes occurred in causalities without external evidence of trauma such as troops buried by shell explosions. The diagnosis had to be confirmed by clinical evidence of cord damage. Second, the distant lesions accounted for clinical deterioration several days or weeks after injury. His data also indicated, although Holmes did not agree, that the neurological examination was not a reliable indicator of the extent of the injury. This meant that military surgeons had to rely on their own expertise and, during the war, their judgments varied a great deal. Marburg and Ramzi at the von Eiselsberg Clinic in Vienna

Fig. 5. Advertisement reprinted from the British Medical Journal, December 23, 1915, p 27.
Treatment of spinal cord injury in 19th and early 20th century

Fig. 6. Upper: “A cross section of swollen axis cylinders in one lateral column two and a half segments above the level of the maximal damage produced by concussion.” Reprinted from Holmes G: The Goulstonian lectures on spinal injuries of war. BMJ November 27, 1915, Fig. C, p 770. Lower: “A cavity in the left dorsal column three segments above a direct injury to the cord. It contains only necrotic detritus.” Reprinted from Holmes G: The Goulstonian lectures on spinal injuries of war. BMJ November 27, 1915, Fig. L, p 771.

waited at least 4 or 5 weeks before laminectomy, whereas Guillain and Barré in the French Fifth Army advocated immediate surgery on all SCIs. Donald Armour, an officer with the Canadian Army Medical Corps, wrote: “It is unfair to the patient and unfair to surgery to wait on and on till hope gives place to despair and then call in a surgeon as a last resource to perform the impossible.”

These opinions were generated from personal experiences at base hospitals. By 1917, the casualty clearing station had developed into a well-staffed and equipped, 1000-bed trauma hospital located 5 to 7 miles from the stationary trench line. During a rush, casualties arrived in the hundreds, between approximately 8 and 12 hours after injury. One of the most experienced medical officers in France was Colonel (Temporary) Henry Gray, another prominent London surgeon and consultant to the British Third Army. In July he summarized his pragmatic recommendations for field surgery in patients with SCIs. He believed that if a casualty had an obviously incomplete lesion with positive findings on x-ray films, then surgery should be performed before the patient was transported to another facility. Other indications for immediate surgery included severe radicular pain, increasing deficit after injury, or large, open wounds that could turn septic. All other patients were sent back to the base by hospital train. Gray disliked set operations, preferring to open the wound if it was near the midline or creating a counter incision if the wound lay to one side. The surgeon could debride the bone or bullet without a complete laminectomy. Local anesthesia with adrenaline supplemented by ether gave good results. Drains were common and the dura mater should be closed if possible. By the Armistice, many surgeons agreed with Gray, including American medical officers, although their experiences in field surgery were not as comprehensive. (Harvey Cushing, the Neurosurgical Consultant to the American Expeditionary Forces, focused his effort on head injuries and had very little to write about SCIs.)

Several changes went along well. To avoid false localization, x-ray films had to be obtained in two planes at right angles to the spine. The neurologists Pierre Marie and Gustav Roussy refuted the older principle that the absence of a “trophic” influence of the spinal cord resulted in cystitis, bedsores, and decubiti. They wrote that prolonged compression and ischemia, skin abrasion, and constant urinary or rectal incontinence produced these potentially lethal complications, and recommended simple measures similar to those described by Lidell during the American Civil War. Urologists such as Frank Kidd at the London Hospital developed aseptic techniques for intermittent or continuous bladder drainage. Mechanical bladder compression was used occasionally, whereas many surgeons at casualty clearing stations advocated suprapubic cystotomies. Kidd believed that it was important to begin drainage soon after injury to avoid stretching of the muscle fibers and potential loss of reflex activity, which could be used later to empty the bladder.

One discarded technique resurfaced and caused controversy. In late 1917, Colonel A. W. Mayo-Robson visited a Canadian hospital at Clivedon in his duties as consultant to the Southern Command in the UK. He learned that the medical officers had performed surgery in a paraplegic soldier a few weeks after injury. They had removed a bullet from a partially divided cord and had transplanted the spinal cord of a rabbit into the separated ends. Mayo-Robson approved of this procedure, as he had performed a similar procedure before and planned to use the technique in another patient. He wrote in the British Medical Journal that the procedure worked; the paraplegia was “passing off” and the result, “promises to be a brilliant success.” Percy Sargent, the urbane and successful surgical partner of Gordon Holmes, took less than 1 week to castigate Mayo-Robson in a letter to the editor. Colonel Sargent reminded Colonel Mayo-Robson that his original transplantations were performed on peripheral nerves; the Canadian soldier had a partial injury and it was too early to tell if the injury was complete. Sargent summarized his opinion as follows:

At the present time there exists neither experimental nor clinical evidence that an operation of grafting upon the spinal cord does offer even the remotest possibility of success, and it seems cruel to hold out to these unfortunate patients any hope whatever that, by submitting to a severe operation, by no means intrinsically devoid of danger, their condition may be benefitted.

One week later, the by now angry Colonel Mayo-Robson responded only by reiterating Sargent’s criticisms and limiting the operation to “incurable” cases—without defining the adjective.

After the war, the survivors required additional surgical attention. By 1919, Elsberg and others outlined opera-
tive indications for chronic traumatic lesions. Division of the posterior nerve roots was effective for intractable spasticity or radicular pain. Late deterioration of function could be prevented by exploration and lysis of adhesions, removal of new bone formation, or aspiration of old intraspinal blood clots or intermedullary cysts. Elsberg also entertained the possibility of nerve suture of the cauda equina and autotransplantation for bladder dysfunction. Although these indications were not new, the pathological findings made by Holmes and later by Thorburn added impetus to the expansion of surgical therapy.

Three years after the Armistice, Sir Robert Jones published his textbook, *Orthopaedic Surgery of Injuries.* Jones, who had apprenticed under his uncle, Hugh Owen Thomas, and practiced with Thorburn at the Manchester Royal Infirmary, was a leader in the effort to separate orthopedic surgeons from their 19th century reputation of bone setters and manipulators. In 1916, the British government established the Ministry of Pensions to deal with the massive number of casualties and the growing recognition of entitlements for conscripted soldiers. Jones saw his opportunity and developed the concept of a comprehensive military orthopedic hospital with physical "reconstruction" and "creative workshops" to rehabilitate the thousands of casualties with fractures and amputations. These large specialized hospitals contained separate facilities for surgery, electrical therapy, baths, exercise rooms, and training programs. Orthopedists controlled the staff of physical therapists, massage therapists, and various consultants. In the second volume of his book, Jones included chapters on head and peripheral nerve injuries as well as a chapter on SCI written by the omnipresent Percy Sargent and E. Farquhar Buzzard. Although the chapter was not particularly assertive, it was clear that injuries of the central nervous system fit into the grand scheme. Jones was successful during the war with the establishment of several dozen impressive demonstration hospitals around the UK, but his postwar plans languished as political and financial constraints forced hospitals into other functions.

The treatment of patients with SCIs in the UK never approached the ideal. Eventually their care was decentralized into smaller hospitals or homes funded by voluntary aid societies or the British Red Cross. One such domicile was the Star and Garter, an old hotel in Richmond that was converted to become a "Hampton Court Palace" for the totally disabled. The care was excellent, but rehabilitation was negligible. The Star and Garter was meant to be the soldiers’ "last home." Sixty-three beds were kept filled during 1919. Ten pensioners died, 19 were discharged to other facilities, and 28 were admitted to their final billets.

In the US, Jones’ concept of a unified comprehensive program for the treatment, rehabilitation, and reeducation of injured military personnel took hold, but the orthopedic surgeons, many of whom had trained under Jones in the UK during the war, failed to secure their clinical authority. Casualties with SCIs were sent to various general hospitals around the country close to their homes. Their treatment relied on neurosurgical or medical expertise. In 1921, the Veterans’ Bureau was created to reduce administration and consolidate various government agencies. Wartime obligations and progressive reform mandated rehabilitation and vocational training throughout hospitalization and aftercare (Fig. 7). The public commitment would continue into another war.

OUTCOMES

The treatment of SCI was never a priority for military medicine. Most military personnel with these injuries, such as Vice Admiral Nelson, were killed in action by injuries to other organs. The plight of the survivors, however, compelled civil and military surgeons to develop rational care, even in the face of permanent disability. Although the treatment for closed fractures changed very little, by World War I, a large number of casualties with penetrating SCIs who managed to reach sophisticated surgical care during battle, underwent increasingly aggressive intervention.

The new surgical outlook was the result of many factors. Reinforced by the experiences of military surgeons during major conflicts in the middle and late 19th century, the rapid development of neurology and civil surgery provided a clinical framework that matured during World War I. The integration of civil surgeons into the medical services brought expertise and surgical flexibility. Opinions on the treatment of SCI varied considerably but the approach was similar. Penetrating SCIs required active treatment that needed to be adapted to the requirements of the wounded and the conditions of war. Along with this change in attitude, there were adjustments in medical services leading to more efficient evacuation, improvements in x-ray studies and hospital facilities, and the ability to disseminate accurate (as much as possible) statistics and unfamiliar surgical techniques. The result was pragmatic and frequently successful operative care. Colonel Gray’s indications and techniques are, arguably, as relevant today as they were in 1917.

Improvements in long-term care paralleled those for acute treatment. Decubiti and bladder infections were no
longer thought to be the pathophysiological results of SCIs. Intermittent or continuous bladder drainage and strict attention to skin care reduced sepsis and increased survival in patients with SCIs. Government funding as a financial base for physical rehabilitation, occupational therapy, and vocational reeducation became a viable alternative to condescending charity and the inevitable result. To some extent, the early political developments arose from mixed motives, but changed the social landscape for casualties with serious disabilities. In the US the mobilization of rehabilitation personnel resulted in the establishment of organizations for physical and occupational therapists soon after the war. During the 1920s, professional societies promoted the recognition of neurosurgery as a specialty in the US and the UK. Put into perspective, these outcomes suggest that the evolution in the treatment of patients with SCIs owes a great deal to military conflicts in the 19th and early 20th centuries.

**EPILOGUE**

Paralyzed and bleeding internally, Nelson laid in cramped midshipmen’s quarters in the after part of the ship below the waterline. The attendants gave him lemonade as he watched Beatty work on the wounded, while the lower deck men cheered after each French ship was struck. Aware of his fatal injury, Nelson gave Hardy instructions for the care of his family and requested that his body not be thrown overboard. Hardy agreed and, after the engagement, interred the corpse in a leaguer, the largest shipboard cask, which was filled with brandy. Thus embalmed, Horatio Lord Nelson returned to England and a hero’s burial. A midshipman, John Pollard, killed the French marksman and Surgeon Beatty returned to the cockpit.85

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