Patients with spinal cord injury (SCI) were generally considered untreatable for most of human history and were associated with a high mortality rate. However, worldwide military conflicts in the 20th century produced a significant number of injured soldiers and necessitated improvements in SCI care; treatment has accordingly progressed significantly over the past century. In present-day military conflicts, increased use of improvised explosive devices (IEDs) and unconventional guerrilla warfare have resulted in high rates of SCI among soldiers. These injuries are of a severe and complex nature, distinct from spinal trauma seen in the civilian population, and often occur in association with damage to multiple organ systems. Nonetheless, lessons learned from treating SCIs on the battlefield have been transferable to the civilian context and have led to significant advancements in care.

In this review, we present a historical overview of treatment for SCI, focusing on the progress spurred by military conflicts (Fig. 1). An appreciation of the evolution of SCI interventions can help one to better understand the foundations of the modern-day approach to SCI treatment and to consider novel therapeutic paradigms for future patients.

Pre–20th Century

The earliest documented description of traumatic SCI is found in the Edwin Smith Papyrus, an Egyptian medical treatise dating back to the 17th century BC. The papyrus details 48 medical cases, 2 of which describe SCI, labeling it “an ailment not to be treated.” This dire conclusion set the stage for the treatment of SCI for a millennium. In the 5th and 4th centuries BC in ancient Greece, Hippocrates described SCI caused by dislocation of vertebrae in his text On Joints, noting a poor prognosis, including severe neurological complications and a high rate of mortality, but arguing that conservative treatment can work for some mild cases.

Management of SCI remained challenging through the 19th century. The medieval surgeon Theodoric Borgogni (1205–1296/8) described the classification of SCI as partial or complete injury based on the neurological examination, noting the important influence on prognosis and death. Decompressive surgery and laminectomy to treat SCI was proposed as far back as the medieval period, albeit limited by the anesthetic and surgical tools of the time, and open reduction of fractures was introduced in the 16th century.

ABBREVIATIONS  IED = improvised explosive device; SCI = spinal cord injury; WWI = World War I; WWII = World War II.
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The famed Renaissance surgeon Ambrose Paré of France (1510–1590) described removal of bone fragments for spinal injuries.8 Still, despite some enthusiasm for aggressive intervention, many considered surgery “hopeless” due to the poor prognosis.7 The esteemed British naval commander Lord Admiral Sir Horatio Nelson (1758–1805) provides a famous example of the impact of SCI on soldiers. Aboard the HMS Victory at the Battle of Trafalgar in 1805, a musket ball tore through his ribs and lung and transected his spinal cord at T6, resulting in paralysis below the chest.10,11 The ship’s surgeon, Sir William Beatty, was summoned to his side, and Nelson adamantly remarked, “You can do nothing for me. I have but a short time to live. My back is shot through.” An emotional Beatty replied in the affirmative, “My Lord, unhappily for our country, nothing can be done for you.”12 Although the British were ultimately victorious, Nelson succumbed to his injury 3 hours later.13 Describing his final moments, Beatty wrote that “his extremities and forehead became soon afterwards cold,” yet “he retained his wonted energy of mind and exercise of his faculties” and expressed “heart-felt satisfaction … in the most emphatic language” upon hearing of the British victory.14 Beatty attributed Nelson’s death to hemorrhage from injury to the pulmonary artery but noted that the spinal injury too would have proven fatal within days.12

**World War I**

Treatment of SCI underwent a profound transformation during World War I (WWI) and World War II (WWII), declining from a mortality rate of more than 80% in WWI to less than 10% by the conclusion of WWII.18 A crucial early development was the formation of specialized neuro-rehabilitation treatment centers, pioneered by Robert Tait McKenzie (1867–1938), George Deaver (1890–1973), and Harry Botterell (1906–1997), among other physicians.15 They demonstrated that intensive physical and occupational therapy regimens could improve outcomes and even help paralyzed soldiers return to civilian society.

A professional athlete and gymnast, McKenzie developed an interest in physical education and was appointed the first professor of physical therapy in the US upon joining the faculty at the University of Pennsylvania in 1904 and emphasized scientific rigor to develop exercise regimens for both healthy and disease states.15 In 1915, he joined the British Royal Army Medical Corps in WWI, where he introduced physical therapy regimens, occupational therapy, and vocational retraining for injured soldiers.16 His manual *Handbook of Physical Therapy* was referenced by American, British, and Canadian armed forces to establish physical rehabilitation efforts.15 McKenzie described the use of graded exercises and hydrotherapy to restore function after nerve injuries and achieved recognition for his success in returning wounded soldiers to military service.16 He emphasized precision in measuring strength, range of motion, and exercise dose to monitor recovery and illustrated specialized equipment for physical rehabilitation.15 Deaver, considered the “grandfather of rehabilitation medicine,” was a medical student of McKenzie who served with the YMCA Expeditionary Force and applied McKenzie’s techniques to rehabilitate thousands of American and British soldiers.15,16 Later in his career, Deaver studied rehabilitation for SCI and focused on improving the self-sufficiency and independence of disabled patients.17 However, wartime efforts at rehabilitation were largely centered around soldiers experiencing peripheral nerve injury, and SCI treatment remained lacking.18 Facilities were established to house the growing numbers of paralyzed soldiers, and although these homes offered comfort to war veterans, there was little expectation of functional improvement.19,20

The pioneering neurosurgeon Harvey Cushing served in Europe from 1917 to 1918, performing surgical procedures in frontline medical units and treating wounded soldiers, including at the Battle of Ypres (Fig. 2). Nearly
a decade earlier, Cushing had classified SCI cases into two groups: those with complete transection in which operation was contraindicated, and partial lesions for which surgery could help. He found that WWI soldiers with SCI faced a grim prognosis, estimating that “fully 80% died in the first few weeks after SCI.... The conditions were such, owing to pressure of work, as to make it almost impossible to give these unfortunate men the care their condition required.” Lack of knowledge in the proper care for paralyzed patients resulted in bed sores and bladder and bowel infections, accounting for the high mortality rate. Only 10% of paralyzed soldiers who returned to the US lived longer than 1 year.

Nonetheless, the establishment of specialized care centers and the importance of physical therapy would be the catalysts for advances in care during WWII. After WWI, physicians began making strides in caring for SCI-associated complications, such as pressure sores and neurogenic bladder. In 1935, Boston neurosurgeon Donald Munro (1889–1973) described tidal drainage for paralyzed bladders, in which the bladder is filled with irrigating fluid to a predetermined intravesical pressure and emptied using siphonage and gravity flow, reproducing the bladder’s natural filling and emptying. Munro advocated urgency in inserting catheters and securing a tidal drainage apparatus adjusted to the needs of each patient, noting that genitourinary infections are a common cause of death after SCI. Munro also recommended moving patients each hour and keeping their bedding dry to avoid the development of sores and infections. He treated patients with multidisciplinary teams and inspired the establishment of SCI centers for wounded soldiers by the Veterans Administration. Munro signaled a change in the attitude toward care of patients with SCI, writing that “a defeatist attitude on the part of everybody concerned must be avoided.” Instead, Munro noted that even for patients with complete transections, “an active self-supporting wheelchair life ... and ambulatory activity with the aid of splints” should be considered the goals of care.

**World War II**

The lessons from Deaver and Munro influenced many physicians in the WWII era (1939–1945), including Harry Botterell and Al Jousse. Botterell joined the war effort as a neurosurgeon in the Royal Canadian Army Medical Corps and organized teams of neurosurgeons, nurses, and physical therapists to treat soldiers with SCI. His unit at Basingstoke, England, was successful in reducing and treating postinjury infections, preventing pressure sores by frequently turning patients and using innerspring mattresses, and managing bowel and bladder dysfunction. Botterell’s experiences influenced Captain John Counsell, a patient who sustained a gunshot wound during the war, to develop Canada’s first SCI rehabilitation center at Lyndhurst Lodge in Toronto in 1945. Al Jousse, a physician with experience in neurology and psychiatry, was appointed medical director of the Lodge.

The trio of Botterell, Counsell, and Jousse published landmark papers on SCI treatment and endorsed a revolutionary view advocating for a return to daily activities. At Lyndhurst Lodge, they used physical rehabilitation, education, mat and wheelchair exercises, and gait training to encourage a full return to civilian life. In their 1946 paper “Paraplegia following war,” they wrote that “the primary purpose of treatment ... is to return the patient to independent life beyond the confines of hospital.” They were met with significant pushback and skepticism. Additional advances in the care of SCI patients were led by the German-British neurologist Dr. Ludwig Guttman, who established the National Spinal Cord Injuries Centre, the first specialized unit for SCI treatment, at Stoke Mandeville, England, in 1944. Guttman pioneered the division of SCI patients into “complete” and “incomplete” injury categories, which helped with treatment, decision-making, and providing more accurate prognoses. He also made significant strides in treating patients with bed sores and urological complications, such as replacing indwelling catheters with sterile, intermittent catheterization.

By the end of the war, the philosophical approach to SCI treatment had undergone a foundational paradigm shift. Laminectomies were increasingly performed for decompression and pain relief (Fig. 3), although treatment patterns were heterogeneous, and surgeons debated the need for early versus late decompression. Despite the
improvements in care, General George Patton, who led the Allied forces to victory in Europe, sustained a cervical SCI and quadriplegia sustained in a car crash in Germany after the war’s end in 1945. Patton was immediately transported to a hospital in Heidelberg and leading neurosurgeons were summoned. The consensus was that surgery was not indicated, and tongs were applied in the skull for traction. This method was originally described by Crutchfield in 1933 for treatment of a traumatic C2–3 fracture in a 23-year-old woman, with the apparatus refined over the decade. Crutchfield tongs were safer than manual reduction popular in the era. However, the tongs kept slipping from Patton’s skull, and therefore fishhooks from a local shop were instead placed beneath the zygomatic arches with traction applied. A similar technique was described by Neubeiser in 1933 using a large fishhook connected to a spreader bar with traction, and several reports in the literature indicated success using this method. The fishhooks were removed the following week after radiographs demonstrated anatomical alignment. Unfortunately, General Patton did not improve neurologically and died 12 days after his injury, likely from a pulmonary embolus. Pressure stockings and anticoagulants were not yet available.

The Korean and Vietnam Wars

The Korean War (1950–1953) saw a decrease in mortality associated with overall war wounds due to increased use of antibiotics and bandaging. First-echelon mobile teams provided early neurosurgical treatment to soldiers, who were then evacuated by helicopter to Tokyo Army Hospital, dramatically increasing access to care. SCI mortality fell to 3.6% during the Korean War, whereas it was a death sentence only decades earlier. The use of reinforced armored vests also contributed to reduced frequency of thoracic injuries. Greater attention to bladder care, prevention of decubitus ulcers, and rigorous physical therapy improved functional outcomes.

Treatment of SCI during the Korean War was summarized by Major Gordon Wannamaker, who reviewed the care of 300 soldiers at Tokyo Army Hospital (Table 1). Lam inetomies were performed on all patients with penetrating SCIs, as well as closed injuries with fracture-dislocation of the spine. Patients were turned every 2 hours to prevent pressure ulcers, long metal back braces were fitted for patients with thoracic and lumbar injuries, and early ambulation was encouraged. Despite the advances in care, only 18% of soldiers were operated on urgently within 24 hours of injury, partly due to the large influx of casualties. Still, Wannamaker reported improvement in 48% of patients in the postoperative period, with patients with cervical SCI experiencing the best improvements, and a low mortality rate of 1% providing encouraging evidence for the use of early laminectomies and decompression. The benefits of early laminectomy and decompression were corroborated by Boshes et al. in a study of 35 patients from the Korean War, who noted the importance of following every step involved in the coordination of care of paraplegic patients, such that “any lapse is promptly reflected in a regression of the patient’s condition.”

SCI accounted for nearly 1% of all American casual-
of the general population. These deaths often occurred years after the initial injury, illustrating the persistent challenges faced by veterans with SCI.45

Modern Military Conflicts (1989–2022)

The US invasion of Panama in 1989 resulted in a high rate of spinal injury compared with prior conflicts, with a nearly 6.3% incidence among all wounded soldiers.46,47 Moreover, spinal trauma accounted for nearly 30% of all fatalities. Schoenfeld et al. attributed this high rate to a large number of injuries sustained in the initial nighttime parachute operations.46 Two years later, the Persian Gulf War marked the first major conflict in which body armor was provided to all American soldiers. These synthetic fabric Kevlar vests were effective in blocking shell and grenade fragments and bullets from some common handguns and shotguns.48,49 Consequently, spinal injuries declined, representing only 1% of all war casualties, consistent with the rate of the Korean and Vietnam Wars, although airborne operations still represent a leading cause of SCI.50

The subsequent decade witnessed two major long-lasting military conflicts in Iraq (2003–2011) and Afghanistan (2001–2021). The reported incidence of spinal injuries among war casualties rose from approximately 1% in

TABLE 1. A summary of Major Gordon Wannamaker’s review of treatment options for soldiers with SCI at Tokyo Army Hospital during the Korean War

<table>
<thead>
<tr>
<th>Type of SCI</th>
<th>No Surgery</th>
<th>Laminectomy</th>
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<tbody>
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<tr>
<td>Partial lesion</td>
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<td></td>
</tr>
<tr>
<td>Closed</td>
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<td>—</td>
</tr>
<tr>
<td>Penetrating</td>
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<td>—</td>
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<tr>
<td>Complete loss of function</td>
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<td></td>
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<td>Thoracic</td>
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<tr>
<td>Transitory long tract signs or nerve root involvement</td>
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<td></td>
</tr>
<tr>
<td>Closed</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>Penetrating</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Partial lesion</td>
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<td>—</td>
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<tr>
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<tr>
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<td>—</td>
</tr>
<tr>
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<tr>
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</table>

This table illustrates the adoption of laminectomies, particularly in patients with penetrating injury. Modified from Wannamaker GT. J Neurosurg. 1954;11(6):517-524.40 © AANS, published with permission.
Vietnam to 11% in Afghanistan and Iraq due to unconventional guerrilla warfare. IEDs represented the most common cause of death for service members, estimated at nearly 75%–80% of combat casualties. These weapons result in blast injuries that can affect multiple organs simultaneously and can cause complex, uncommon spinal fractures such as chance fractures, which injure the spinal cord and cause severe neurological deficits. A 2009 review of 12 soldiers in Afghanistan who were admitted with thoracolumbar fractures found that chance fractures represented 38% of the fractures.

The hierarchical systems of care developed in Korea and prior conflicts have expanded into five echelons. Echelon I includes battlefield first aid, Echelon II includes the forward surgical team, and Echelon III consists of hospitals within the theater of battle. Because of the limited resources and concern for implant infection, decompressive surgery is generally only performed in Echelon IV facilities, or overseas hospitals, and Echelon V facilities, located within the US. Surgery can be performed earlier in select cases, such as hemodynamically stable patients with progressive neurological deficits, but dedicated spine surgeons and advanced imaging technologies are not always present in such facilities. Decompressive laminectomies were once nearly impossible in early 20th-century conflicts, but soldiers in later periods such as the Korean War generally received surgery in a delayed fashion. In contrast, present-day soldiers can often arrive at Echelon IV/V facilities within 24–48 hours after injury.

Given the novel mechanisms of SCI experienced by soldiers in the wars in Iraq and Afghanistan, reassessments of prior treatment strategies are warranted. In 2010, Klimo et al. recommended early laminectomy for soldiers with incomplete injuries, cautioning that soldiers with complete injuries are unlikely to benefit from decompression, although the authors highlighted the controversial nature of the topic. A 2018 meta-analysis of 245 patients with penetrating SCI indicated no observable benefit from decompressive laminectomy compared with conservative treatment of SCI due to shrapnel injuries. Wannamaker’s findings concerning the benefits of decompression and laminectomy may be less relevant for the 21st-century battlefield.

Compared with prior eras, modern rehabilitation efforts require larger teams and active communication among healthcare professionals due to the polytrauma and injury severity sustained in modern conflicts. In 2004, Congress legislated the development of specialized healthcare systems to provide rehabilitation to wounded soldiers. The Department of Veterans Affairs maintains an active nationwide network of SCI centers to provide multidisciplinary specialized rehabilitation following surgical stabilization. These efforts draw on the legacy of Botterell, Counsell, and Jousse by emphasizing functional recovery without surgical intervention.

Surgical care was developed in the 1970s, allowing for detailed visualization of osseous structures, and current guidelines for combat casualties require its use for cervical spine clearance. The introduction of MRI in the 1980s transformed the workup of SCI, allowing high-resolution imaging of cord tissue, edema, and ligamentous injury. Although MRI is widely used in the civilian setting, its availability in military hospitals, particularly Echelon I–III facilities, can be limited and is contraindicated in soldiers with concern for retained metal. Moreover, an improved understanding of the ischemic secondary effects of SCI lent support to the use of vasopressors to augment mean arterial pressure to 85–90 mm Hg, thereby improving spinal cord perfusion pressure. Evidence-based guidelines for acute SCI, first published in 2002 and updated in 2013, formally recommended such hemodynamic management in the first week after injury. Guidelines also promote the use of heparin for anticoagulant thromboprophylaxis within 72 hours of injury to prevent deep vein thrombosis and pulmonary embolism, the cause of General Patton’s death in 1945 and a leading cause of SCI mortality. Patients with high bleeding risk, often seen in polytrauma, can also receive mechanical prophylaxis.

**Treatment Recommendations**

Despite substantial progress over the past century, soldiers sustaining an SCI face high morbidity and mortality. Advances in military care and treatment of SCI have allowed more soldiers to survive the initial injury, and efforts are needed to improve neurological recovery and integrate service members back into civilian life. As the nature of warfare continues evolving, new treatments should be explored while management guidelines are reappraised and revised (Fig. 4). Protective armor and helmets should continue to be improved, and their use should be mandatory among military personnel engaged in combat. MULTIDISCIPLINARY teams should be assembled to care for the complex polytrauma seen in soldiers with SCI. After hemodynamic stabilization, soldiers with SCI should undergo imaging to evaluate injury locations and trajectories. Early laminectomy and decompression should be performed in the case of incomplete injuries from nonblast causes where there is evidence of ongoing neural compression or spinal instability. Efficacy may be limited for complete injuries from explosions or missiles. Following surgery, early aggressive rehabilitation should be performed with multidisciplinary teams, including neuropsychologists and physical and occupational therapists, and care should be taken to prevent decubitus ulcers. Importantly, it must be remembered that soldiers with SCI live with a lifelong chronic condition. Rates of posttraumatic stress disorder are high in veterans with SCI, and care should be directed toward providing support as soldiers return to their communities.

**Conclusions**

The history of military conflicts offers informative lessons for the treatment and care of patients with SCI. Until the last century, regaining function after SCI was the exception, not the norm. A revolution in treatment occurred over the course of the two World Wars. Multidisciplinary
teams began coordinating care of soldiers, antibiotics were prescribed for infection prevention, care was taken to prevent pressure ulcers, and rehabilitation specialists worked to improve ambulation and neurological function. Soon thereafter, the benefits of early decompressive laminectomies were recognized and mortality declined. However, recent conflicts have seen new modes of fighting, such as IEDs and blast explosions, which have both increased the incidence and severity of SCIs and limited the efficacy of surgical intervention. As the nature of war continues to evolve, so too must treatment paradigms for soldiers, veterans, and civilians with SCI.

References


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Dr. Theodore receives royalties from and owns stock in Globus Medical. He is a consultant for Globus Medical and has served on the scientific advisory board/other office for Globus Medical.

**Author Contributions**

Conception and design: Theodore. Acquisition of data: Hersh, Davidar, Weber-Levine, Raj, Alomari. Analysis and interpretation of data: Hersh, Davidar, Weber-Levine, Raj. Drafting the article: Theodore, Hersh, Alomari, Judy. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Theodore. Administrative/technical/material support: Theodore. Study supervision: Theodore, Judy.

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