The development of military medical care for peripheral nerve injuries during World War I

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Although the clinical and electrical diagnoses and treatments of peripheral nerve injuries (PNIs) had been described prior to World War I, many reports were fragmented and incomplete. Individual physicians’ experiences were not extensive, and in 1914 the patient with a PNI remained a subject of medical curiosity, and was hardly a focus of comprehensive care.

World War I altered these conditions; casualties with septic wounds and PNIs swamped the general hospitals. By 1915, specialized hospitals or wards were developed to care for neurological injuries. In the United Kingdom, Sir Robert Jones developed the concept of Military Orthopedic Centres, with coordinated specialized care and rehabilitation. Surgical appointments of neurologists and electrotherapists sharpened clinical diagnoses and examinations. Surgical techniques were introduced, then discarded or accepted as surgeons developed skills to meet the new conditions. The US Surgeon General, William Gorgas, and his consultant in neurosurgery, Charles Frazier, went a step further, with the organization of a research laboratory as well as the establishment of a Peripheral Nerve Commission and Registry.

Despite these developments and good intentions, postwar follow-up for PNIs remained incomplete at best. Records were lost, personnel transferred, and patients discharged from the system. The lack of a standardized grading system seriously impaired the ability to record clinical changes and compare outcomes. Nevertheless, specialized treatment of a large number of PNIs during World War I established a foundation for comprehensive care that influenced military medical services in the next world war. (DOI: 10.3171/2010.3.FOCUS103)

Key Words • peripheral nerve injury • World War I • military medical care

Sir Robert Jones, a respected British orthopedic surgeon and beloved teacher, waxed eloquent about the peripheral nerve in 1918. By this time, the central role of PNIs to his concept of comprehensive management of war injuries was apparent to the casualty, medical officer, War Office, and government; in fact, all the stakeholders in military medicine. Complex historical issues of specialization, which were not readily apparent in earlier wartime medical organizations, were important elements of this expansion.6,46,68,79 In this report I will outline the buildup of the sophisticated treatment of PNIs during World War I, even though these injuries seemed unlikely candidates for attention during a global war.69

The Unassuming Peripheral Nerve

Associated with the emerging specialty of neurology, a surprising number of elaborate investigations described the anatomy and clinical examinations of the peripheral nervous system during the 19th and early 20th centuries. Descriptions of the loss of motor power in muscles innervated by specific peripheral nerves were followed by various clinical reports of “trick” movements mimicking functional regeneration.9,17,62,63 Detailed studies of sensory loss and recovery were explained by sophisticated theories of collateral innervation, nerve anastomosis, or nerve growth from healthy, adjacent areas.6,25,26,56 Findings in studies of the fascicular structure of the peripheral nerve and of histological degeneration after PNI were confirmed by the introduction of the silver precipitation stain of Golgi and the methylene blue method of Ehrlich.18,64 The monogenetic or downgrowth of nerve regeneration had been established by investigators such as G. Carl Huber,29 who described the principle in simple terms:
The regeneration of the peripheral end (which always degenerates so that only the old sheaths of Schwann containing a band of nucleated protoplasm, developed from the hyperthropic [sic] protoplasm and proliferated nuclei of its fibers, are met with) is the result of an outgrowth of new axis cylinders from undegenerated axes of the central stump, the budding axes following paths of least resistance.

The diagnostic use of electricity for PNIs and disease began with the development of the faradic induction coil (alternating intermittent, nonsymmetrical current) and the galvanic battery (continuous current in the same direction over a sustained period), and culminated with Wilhelm Erb's textbook published in 1883. Erb's points and charts for the reactions of degeneration were diagnostic standards in the early 20th century (Fig. 1). Electrotherapists, such as Herbert Tibbitts, who organized the West End Hospital for Diseases of the Nervous System on Welbeck Street in London, were associated with a new School of Massage and Electricity, and gained medical credibility. The "nerve force" perhaps associated with electricity was still unsolved, but it was enough that the peripheral nerve and its connections could be accurately examined in health and disease, with a hint at rational therapy.

The development of surgical therapy for PNIs depended on the clinical advances during this time. According to Artico et al., attempts at repair probably began as early as 1596, and included Paget's description in 1847 of a successful primary suture of the median nerve, but remained stalled by concerns about sepsis, stricture, "neuritis," or convulsions. Primary suture was rare, and secondary exploration and suture were discouraged. Most closed injuries recovered on their own, and given the early description of nerve degeneration after injury, it did not make sense to attempt a suture that was doomed to failure.

The surgical revolution in the last half of the 19th century changed the indications for repair. Anesthesia, asepsis, better instruments, and the basic notion that the 2 ends of a cut nerve could be sutured allowed surgeons more creative leeway. Techniques proliferated as nerve ends were cut tangentially before suture, bound together, sutured to the skin or "a distance," and transplanted into noninjured nerves, either through slits in the epineurium or by partially dividing normal nerves and suturing one end to the distal stump. As described by Snyder, Edward Létiévant in 1873 described an ingenious "double nerve flap" that looked much like a modern exit ramp for an expressway (Fig. 2). Other methods for bridging nerve gaps included various conduits or tubes fashioned using bones, arteries, veins, plasma, blood clots, or fascia, with the stumps sutured at each end of the tube. According to Dellon, Dr. Charles H. Cargile, in Arkansas, began selling his preparations of ox peritoneum for either tubulization or as a wrap to protect the suture line.

Several surgeons attempted transplants with the patient's own nerves, stored human homografts, or "heterografts" from other species. In 1896, Mr. Mayo-Robson, the Hunterian Professor at Leeds, England, reported a graft in a 29-year-old gardener who had severed both ulnar and median nerves in the arm. Robson examined the patient 7 months later and described atrophy of all muscles, but preservation of sensation over the thenar eminence. There was no muscle reaction to faradic current, and a minimal reaction to galvanic current. Mr. Robson dissected the scar and all 4 nerve stumps. He used a stored rabbit's sciatic nerve to bridge a three-quarter-inch gap of

![Fig. 1](chart-based-on-wilhelm-erbs-reaction-of-degeneration-in-a-complete-and-permanent-nerve-lesion.png)

The voluntary power (P) of the muscle is lost immediately. The nerve's (N) response to faradism (F) or galvanism is normal for approximately the 1st week, and then declines until absent by the 3rd week. The muscle (M) response to faradism is similar to the nerve, whereas its response to galvanic current (V) falls in the 1st week, rises to above normal for the next 37 weeks, and then slowly declines until absent by approximately 2 years after the lesion. (Reprinted from Gowers WR: A Manual of Diseases of the Nervous System, ed 2. Philadelphia: P. Blakiston's Son & Co, 1899, Vol 1, p 56 [Figure 36].)

![Fig. 2](drawing-of-lethievants-double-nerve-flap.png)

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the ulnar nerve, but ran out of nerve for the 3-inch gap in the median nerve. An assistant came in, killed a rabbit, and dissected out the spinal cord, which was sutured to both ends of the patient’s median nerve. Within 10 days, sensation returned in the palm, and within 3 months there was movement in the flexors of the forearm. The patient was lost to follow-up until 6 years later. Examination at that time revealed good muscle tone and intact function of the hand and forearm. The reaction to faradic current was normal. Although the report met with skepticism, the influence of the prestigious British Medical Journal carried the day.55

All these articles suggested a certain enthusiasm for the repair of PNIs, but they lacked surgical credibility. Civilian injuries were few in number, and the reports were scattered, occasionally unclear or ill thought out, and with insufficient follow-up. Consequently, military surgery might have a great deal to offer during this period. However, with one exception, this was not the case. The celebrated investigations of PNIs recorded by Silas W. Mitchell, George R. Morehouse, and William W. Keen at the Christian Street and Turner’s Lane Hospitals in Philadelphia were the first to systematically describe, examine, and offer therapy for wartime PNIs. The American official medical history, The Medical and Surgical History of the War of the Rebellion, described multiple PNIs, but the descriptions were not specific, and follow-up continued only until the soldier was pensioned. The author, Assistant Surgeon George A. Otis, 57 gave full credit to the work by Mitchell and his collaborators.35–47

Despite the popularity of Mitchell’s work, there was no large-scale effort to include PNIs in the medical literature during the wars in the late 19th and early 20th centuries. Head and coworkers25,26 recruited casualties from the Second South African (Boer) War for their studies on sensory loss. American24 and British26 medical observers during the Russo-Japanese War focused on military sanitation, whereas Hashimoto and Tokuoka24 described a technique in which arteries were used for tubulization. In the Balkan wars, German24 described a technique which arteries were used for tubulization. In the Balkan wars, German scientists described a technique in which arteries were used for tubulization. However, with one exception, this was not the case. The celebrated investigations of PNIs recorded by Silas W. Mitchell, George R. Morehouse, and William W. Keen at the Christian Street and Turner’s Lane Hospitals in Philadelphia were the first to systematically describe, examine, and offer therapy for wartime PNIs. The American official medical history, The Medical and Surgical History of the War of the Rebellion, described multiple PNIs, but the descriptions were not specific, and follow-up continued only until the soldier was pensioned. The author, Assistant Surgeon George A. Otis, gave full credit to the work by Mitchell and his collaborators.35–47

The Medical Services’ Dilemma

Every account of World War I stresses the reader with the number of casualties. By 1915, more than 1500 casualties with PNIs swamped the Val-de-Grâce Military Hospital in Paris alone.55 Although military diagnostic codes did not specifically list PNIs, some idea of the extent of the problem can be calculated. Perhaps the most accurate data were reported in 1920 by Lieutenant Colonel Charles Frazier, head of the American Peripheral Nerve Commission. By that time, there were 3000 patients with PNIs in American hospitals. He assumed that 15% of the casualties had been discharged, so that with a total 208,000 casualties, there was a 1.6% incidence of PNIs.15 This was in line with other estimates of 1.5–2%, and suggested that the French Service de Santé may have treated approximately 30,000 PNIs, although this was probably an underestimate.16 Athanassio-Benisty2 thought that 20% of all wounds involved PNIs. Sir William Thorburn,20 in a chapter on PNIs in the British Official Medical History of the Great War, estimated that 20% of “severe” casualties sustained PNIs, but he did not define “severe.” Using Frazier’s 1.6% estimate in the 2,497,400 British battle casualties during the war who did not die of wounds, approximately 32,079 sustained PNIs.48 By 1918, many military surgeons had published articles on PNIs, with series of more than 100 cases and a few with more than 500 patients.

Whatever the numbers, the wounds were a mess. Artillery accounted for 60%; bayonets for less than 1%. Primary suture was very rare. Gas gangrene (and other bacteria) caused septic wounds, and by 1915, these wounds were left open and irrigated continuously with a variety of antisepctic solutions. While this technique reduced mortality rates and risk of amputation, it resulted in months in bed and healing by secondary closure or slow granulation. Secondary suture was associated with massive scarring. Nerves were contused, twisted, shattered, partially sliced, trapped in broken bone or scar; sometimes they appeared normal and yet didn’t work. Even after the initial wound closure and healing, the surgeon had to deal with “flare.” This was a recurrent infection when opening the old wound. Consequently, patients received antitetanus serum and underwent wound manipulation or massage prior to exploration. This was an apparent effort to aggravate the bacteria, which were lying in wait for the surgeon and his scalpel. Occasionally, it was effective, but then the patient had to wait for another chance. Thus, the surgery of PNIs during the war meant dealing with the most difficult of injuries, far more disastrous than those in civilian life, while developing indications, timing, and surgical techniques for complex surgical wounds. And there were thousands of patients!

First Impressions

This early period was confused; casualties were transferred to field or base hospitals without histories, records, or even identification. To make matters worse, wounds were complicated, usually infected, and required experienced medical officers. A few articles in the medical journals published prewar reviews, but it wasn’t until 1915 that early reports attempted to sort out the injuries and treatment. Blunt injuries were left alone and seemed to recover on their own. Penetrating injuries were septic and allowed to heal. If surgery was required, it would have to be performed after the infection had cleared.54,55

When surgery was performed, military surgeons faced injuries that they were unprepared to handle in any standard fashion.
Several patterns emerged throughout 1915. First, all the military services began to concentrate casualties with neurological injuries, including PNIs, in specialized wards or hospitals. The French Service de Santé established 12 “Services Neurologique” around the Paris region, with more than 200 beds in each. Dozens were organized throughout the country. Second, the timing of surgery became a critical issue. The neurologist and his electrodiagnoses were the gatekeepers for surgical intervention. Clinical examination and the Erb reaction of degeneration indicated when it was time to explore the injured nerves. Various coils, condensers, and so on were cumbersome and sometimes unreliable, so efforts were made to standardize equipment. Casualties with “hysterical paralysis” began to stumble into the centers. Their behaviors could mimic PNIs to an uncanny extent. Faradization along the western front. Immobility combined with tactile futility produced large numbers of casualties in small areas, described today as a massive force-space ratio. The Allied Medical Services responded to these operational conditions with rapid triage and comprehensive frontline surgery, followed by appropriate transport to base hospitals in France or general hospitals in the UK. (A similar system developed for the Central Powers.) Medical officers were faced with broken but salvaged limbs, and PNIs that required sophisticated operative decisions.

The results of surgery and nonoperative intervention were areas of contention. Theodore Tuffier reported on 250 cases in 1915. Tuffier, who would become the Inspector General of the Surgical Services of the French Army and President of the Interallied Surgical Conference, was an influential, internationally known surgeon. His report was simple: in 250 cases of PNI, nerve suture was performed in 19. None of these operations restored useful function. On the other hand, Otto Hoffman in Germany reported 70–80% “positive” results for nerve sutures, 75% in his own series of less than 50 cases. British surgeons emphasized delayed surgery on clean wounds, with various techniques of nerve suture. Hoffman and the British sutured nerve endings, but suggested that follow-up required several years, which is an eternity in wartime.

Two critical reports were published in 1915, the first by Paul Hoffman, a physician and physiologist, and the second several months later by Jules Tinel, a neurologist with the French Third Army at Le Mans (Fig. 3). Both reports described the “signe du fourmillement” in PNIs. Although misinterpreted during the war (and later), a “tingling” when pressing on the area of nerve injury or above the injury that gradually extended down the nerve indicated regeneration at least for sensory fibers. Pain was not an accurate sign, and the tingling did not predict the return of voluntary movement. The eponym “Tinel’s sign” took priority, not so much because of France’s victory, but due to Tinel’s later publication of a text that would have significant influence during the war. His experience with PNIs was extensive; he was the first to describe ischemic paralysis associated with arterial injuries, as well as his rapid, reproducible clinical sign to judge the success of conservative or operative therapy. The accurate prediction of sensory fiber regrowth, presumably earlier than motor regeneration, was a valuable clinical tool in lieu of the time-consuming, but perhaps more accurate electrical examination. Both Tinel and Hoffman would go on to distinguished careers—Hoffman with his H-reflex and Tinel with his extensive publications and collaboration with the resistance during World War II.

A Rough Consensus: Sir Robert Jones and William Mackenzie

The war became a stalemate, with a static trench line along the western front. Immobility combined with tactical futility produced large numbers of casualties in small areas, described today as a massive force-space ratio. The Allied Medical Services responded to these operational conditions with rapid triage and comprehensive frontline surgery, followed by appropriate transport to base hospitals in France or general hospitals in the UK. (A similar system developed for the Central Powers.) Medical officers were faced with broken but salvaged limbs, and PNIs that required sophisticated operative decisions.

Tinel spoke for the French neurologists—left alone, approximately 60% of PNIs would recover. Other authors agreed with the conservative approach, writing that spontaneous recovery could sometimes occur 7 or 8 months after injury. Many medical officers were not patient enough to wait, although it did not appear that the results of delayed surgery were a great deal different from early operations. There were, however, several reasons for rapid intervention. First, there was less scarring, and technically that made for easier surgery. Second, if the nerve was injured, there would be less time for nerves and muscles to degenerate, and finally, hospitals were overburdened with casualties waiting for surgery. An arbitrary time frame of a 2- to 3-month delay in surgery developed. If there was
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TABLE 1: Anatomic Location of 2,390 PNIs in United States Peripheral Nerve Centers during World War I *

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Total</th>
<th>Operated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial plexus</td>
<td>516</td>
<td>132</td>
</tr>
<tr>
<td>Musculospiral</td>
<td>551</td>
<td>269</td>
</tr>
<tr>
<td>Median</td>
<td>298</td>
<td>482</td>
</tr>
<tr>
<td>Ulnar</td>
<td>252</td>
<td>551</td>
</tr>
<tr>
<td>Sciatic</td>
<td>107</td>
<td>395</td>
</tr>
<tr>
<td>External popliteal</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td>Internal popliteal</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>


Evidence of a complete nerve injury and if there were no signs of clinical or electrical recovery, surgery would proceed. This management required frequent examinations made by skilled neurologists familiar with electrodiagnosis. The Tinel sign could serve as an alternative clinical maneuver to demonstrate nerve recovery. 

Along with the indications for surgical intervention, surgeons had to determine how to repair the various lesions that they encountered at operation. Some techniques were generally agreed on, although opinions differed occasionally. A sterile operative field, large incisions, thorough dissection, complete visualization of all the injured nerves, direct palpation, and the use of fine curved needles became standard. General or local anesthesia, the use of tourniquets, and the type of sutures were always debated. Intraoperative judgment, however, was critical; skill and experience were necessary to repair complex PNIs adequately. Consequently, surgery was increasingly limited to individuals trained in these techniques.

Table 1 shows the location of PNIs treated in the US during World War I. The table, developed by Captain Charles Frazier for the AAMD, indicated that 53.1% of PNIs were in the upper extremities. Sciatic and radial nerve injuries were the most common. One other series in the British Official Medical History indicated that 5.5% of PNIs involved the brachial plexus, and approximately 8.1% were “combined” injuries. Table 2 gives some idea of the problems the surgeons faced in the operating room. Approximately one-third of the nerves were severed, with bulb neuromas and encasement in scar. Another third had neuromas in continuity; the remainder were partially severed, contused, or compressed by an adjacent aneurysm or bone. Approximately 1% appeared normal but were physiologically inert. The French also described “sclerosis,” or a lengthy, diffuse intraneural scar.

First the French learned what not to do. Létiévant’s “suture á lambeaux” (see Fig. 2) only created more scarring and was useless. Suture “á distance” was without effect, as was “nerve implantation.” Although some surgeons disagreed, most gave up pedicle flaps or “bypass” operations.

What to do was more complicated. For example, fine chromic or waxed silk epineural sutures, with identification sutures to match fascicular structure, were used for end-to-end anastomoses. The suture line was protected with fat, fascia, or was transposed to acceptable sites. Bulb neuromas had to be resected until “normal” fascicles were seen. External neurolysis or “liberation” was used to free up nerves that had been encased in scar or bone, although Tinel advised surgeons that “a good resection is better than a bad liberation.”

Internal neurolysis or “capsulectomy” was performed reluctantly, and only if the fascicular structure was visualized clearly (Fig. 4). Lateral neuromas or notching were resected and sutured, leaving a normal portion of the nerve intact (Fig. 5).

Gaps in nerve endings required considerable ingenuity. Acceptable techniques used transposition, flexion-relaxation of the limb, or external neurolysis to remove tension at the suture site. Limb shortening was discouraged. Some advocated 2-stage stretching. Dr. Robert Kennedy, in Glasgow, used his homemade nerve “stretcher” to torture the nerve into position (Fig. 6). Nerve grafting was common. Autografts, homografts, or heterografts were used, but by the end of the war, rabbit spinal cords were
abandoned, despite another case reported by the indefatigable Mr. Mayo-Robson. In 1917, Langley and Hashimoto demonstrated the potential of suturing specific “bundles” of fascicles through a cable graft, thereby increasing the potential of accurate axonal regeneration. Intraoperative bipolar stimulation was used to delineate sensory fascicles in the proximal stump (Fig. 7) or motor fascicles in the distal stump to increase the accuracy of reconstruction. Tubulization remained a common practice and was performed using tubes made from all available materials.

“Irritative” nerve lesions, such as stump pain or causalgia, were treated surgically. The former condition was treated successfully with the resection of the neuroma, suture of the nerve ending, and injection of absolute alcohol into the nerve proximal to the suture. Although the role of the sympathetic nerves and the pathophysiological mechanisms of causalgia had been investigated, treatment was limited to repair of the nerve and stripping the epineurium to destroy the sympathetic nerve endings, or the injection of 60% alcohol above the injury, presumably to destroy only the sensory fibers. These maneuvers, however, were usually ineffective, although an occasional patient would experience partial relief.

An increasingly lengthy war of attrition pulled in government policy and public concern. Conscription, large numbers of crippled citizen-soldiers, and novel pension schemes demanded a sea change in medical care. The idea of an all-inclusive center for hospital care and workshop training was a rational extension of the prewar recognition of the need for some type of physical therapy in patients with PNIs. The German Lazarettenschule and French efforts toward comprehensive care for disabled soldiers had been in place since 1914. Now the focus of efforts became reconstruction, and its champion was Robert Jones, who trained (and lived) with his uncle, Hugh Owen Thomas. He developed his interest in orthopedic surgery treating crippled children in Liverpool, followed by an appointment as surgeon to the Manchester Ship Canal Project. In 1916, while pushing for his military orthopedic centers, he became the Inspector General for Military Orthopedics in the Army Medical Service. Later that year, he established his first hospital at Shepherd’s Bush in London. He was joined there by King Manuel, recently deposed from the throne of Portugal, who was an energetic advocate for curative workshops, and later by an Australian, William Mackenzie, who helped to develop the muscle reeducation program. Mackenzie was awarded his fellowship from the Royal College of Surgeons of Edinburgh, and worked
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Fig. 7. In the drawing labeled “B”, a stimulator is placed on a fascicle after dissection of the epineurium of the proximal stump. Motor branches arise from the distal stump. Stimulation of the distal stump was usually ineffective. (Reprinted from Ney KW: Technique of nerve surgery, in Weed FW [ed]: The Medical Department of the United States Army in the World War, Vol 11, Part 1. Washington, DC: Government Printing Office, 1927, p 962 [Figure 152].)

Fig. 8. Advertisement for “Active and Passive Machines” for the physical treatment of war injuries. (Reprinted from the journal Recalled to Life, April 1918.)

The Americans: Charles Frazier and Robert McKenzie

By the time Congress declared war on Germany in April 1917, the AAMD knew a great deal about the war. Military observers had traveled throughout Europe and had reported on the medical developments.22,42 By June, a new division in the Surgeon General’s Office, called Surgery of the Head, started collecting abstracts for the manual War Surgery of the Nervous System, one-third of which dealt with PNIs.54,58 The rapid buildup of the American Expeditionary Force and the equally rapid Armistice meant that most casualties with PNIs were transported back to the US. Surgical indications, techniques, treatment, and aftercare mirrored the allies’ management, so that various specialists had to be recruited and trained. Hospitals had to be constructed, and ancillary personnel were necessary for effective management. It was the Surgeon General of the Army, William Gorgas, to whom the responsibility fell in the creation of a system for the treatment of crippled men. Gorgas, the son of Joshua Gorgas, Chief of Ordnance for the Confederate Army, was
Fig. 9. Photograph of setup for a machine delivering interrupted galvanic current to muscles in case of injury to the external popliteal nerve, with footdrop. (Reprinted from Crane AG: Physical reconstruction and vocational education, in Weed FW [ed]: The Medical Department of the United States Army in the World War, Vol 11, Part 1. Washington, DC: Government Printing Office, 1927, p 151 [Figure 67].)

an internationally respected sanitarian, who had made his reputation in Havana and the Panama Canal. He was a scientist and field worker, hardly an administrator, and he depended on a cadre of mostly East Coast consultants for much of the build up.

Numerous organizations crowded into Gorgas’ office in 1917. Members of the American Orthopedic Association (founded in 1887), American College of Surgeons (founded in 1913), American Association of Electrotherapeutics and Radiology (founded in 1890 as the American Electrotherapeutic Association), committees of physical therapists, the newly minted National Society for the Promotion of Occupational Therapy, the huge American Red Cross, and of course representatives selected for their expertise in brain surgery enthusiastically offered their services.21,22,23 Robert T. McKenzie, a Canadian who had trained with Dr. James Naismith at McGill University, joined the Division of Physical Reconstruction. McKenzie was the head of the Department of Physical Education at the University of Pennsylvania, and worked on staff for Sir Alfred Keogh, Director General of Medical Services for the British Army, as inspector for remedial physical education. In 1918, he published Reclaiming the Maimed, a book that became a manual for the AAMD and outlined the equipment, personnel, and function of a rehabilitation program.24

Gorgas could never “bell” all these specialized cats. It took more than a year to organize the Divisions of General Surgery, Orthopedic Surgery, and Physical Reconstruction, and a section of brain surgery under the Division of Surgery of the Head. The orthopedic surgeons, many whom trained under Jones, lost their bid for specialized hospitals under their control. The returning troops with PNIs would be treated in 12 peripheral nerve centers, with each center commanded by a medical officer experienced in neurological surgery, associated with a consulting neurologist. The centers were usually located in general hospitals, with reconstructive facilities shared by orthopedics and staffed by electrotherapists and physiotherapists.25,26 The neurosurgical victory, of sorts, was due to Charles Frazier’s political clout in Philadelphia and along the East Coast. Frazier was Professor of Clinical Surgery and former Dean of the University of Pennsylvania’s Medical School. He was well known for his work in neurosurgery and PNIs, having studied under S. Weir Mitchell. Gorgas made him consultant in neurosurgery to the Surgeon General, an appointment that carried considerable authority in the development of rehabilitation work in the US.27 As senior consultant, Frazier was also appointed head of the Peripheral Nerve Commission, which was to report on the treatment and outcomes of PNIs after the war. Finally, both Gorgas and Frazier recruited G. Carl Huber at the University of Michigan to organize the second neurosurgical laboratory to investigate problems associated with PNIs. Although the research fit Huber’s prior histological studies in nerve regeneration, the contract surgeon Huber, the son of Swiss missionaries, reluctantly accepted the appointment. Over the next year, Lieutenant Colonel Dean Lewis, Major J. Corbitt, Major B. Stookey, and Major T. Roberg worked with Huber or Walter Ransom at Northwestern University.28,29 Both the first and second army laboratories were examples of the funding of medical research by the military services during World War I. Details of Huber’s 278 animal experiments, along with an extensive review of the literature, were published in 192 pages of the official American medical history. Huber used pyridine silver stains to study various techniques to bridge nerve gaps and the formation of stump neuromas. His research justified the use of autografts or homografts; heterografts were unacceptable. Dr. Cargile received a boost. His “alcoholized” membranes were successful for protecting the suture line. Tubular grafts uniformly failed and were not recommended. Nerves sutured under tension failed to regenerate, whereas alcohol injections limited the formation of amputation neuromas.20,30

Eventually, the American system developed according to Jones’ concept. Large military centers with trained, experienced personnel and elaborate equipment for electrodiagnosis and therapy (Fig. 9), gymnastic training, and vocational reeducation created win/win situations for the casualties, pension systems, and civilian population. Specialization was an essential element, although the issue of professional control created difficulties, particularly in the US. Both Frazier and Huber had lobbied for the neurosurgeons. Huber defended his bias, writing:

The nervous system consists of independent anatomic units. The neurons related to each other by contiguity and not by continuity. The peripheral nervous system is therefore on anatomical and functional considerations a part of the central nervous system and its surgical treatment should be recognized as such.21 (Emphasis mine. –W.H.)

In Britain, Jones organized freestanding orthopedic centers, whereas in France, the prewar influence of the neurologists resulted in medical control over surgical therapy. Despite the administrative differences and historical judgments on pension concerns and government intrusion, these were reasonable, progressive responses to overwhelming problems.
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After the Armistice

The [surgical] rule should be radical nerve exploration, but conservative nerve operation.

Brian Stokey

Following the war, there was a flurry of articles concerning PNIs and surgical therapy. Frazier was the Surgeon General’s representative at the Interallied Surgical Conference in 1920, and he chose to speak on PNIs. K. Winfield Ney, a 70-day brain surgeon, who trained during the war under the AAMD, started his career with his experiences in PNIs and later became Professor of Neurosurgery at New York Polyclinic Medical School. Lewis Pollock, who would become chairman of the Department of Nervous System and Mental Diseases at Northwestern University, wrote Clinical Signs of Nerve Injury and Regeneration and several chapters in the American official medical history of World War I based on his wartime experiences. In 1933, he and Loyal Davis published a well-known textbook on PNIs. Brian Stokey, who worked as Huber’s subordinate, wrote his first report condemning nerve flaps for bridging nerve defects and later authored one of the first definitive texts on PNIs while an assistant professor of neurosurgery at the New York Postgraduate Medical School. The influence of these decidedly neurological surgeons did not parallel the postwar experience in the UK. Although the British Journal of Surgery was crammed with articles on PNIs in its last postwar editions, many of these were written by general surgeons, such as Henry Souttar, Percy Sargent, known for his work on head injuries with Gordon Holmes during the war, investigated suture materials for PNIs and was appointed a member of the “Committee Upon Injuries of the Nervous System” for the Medical Research Council that published its first report in 1920. Sargent coauthored the chapter on head injuries for Jones’ textbook, but chapters on PNIs were written by various orthopedic surgeons who had worked with Jones in his military hospitals. Sir William Thorburn, a Manchester general surgeon, who achieved considerable prewar recognition for his work on spinal cord injuries and PNIs, wrote the chapter for the British Official Medical History of The Great War. Thorburn’s colleague, Harry Platt, an orthopedic surgeon at Manchester and President of the Royal College of Surgery in 1954, developed a reputation for treatment of PNIs.

While the surgeons trumpeted their technical success, Jones’ idea for centralized orthopedic centers throughout the UK died a financial death during the 1920s. Moreover, the Royal College of Surgeons was not too thrilled with the idea of an orthopedic takeover of surgical care, particularly for injuries that had been treated by general surgeons during the war. Jones eventually transformed his vision into a smaller group of orthopedic hospitals for civilian injuries and crippled children, but the comprehensive model at Shepherd’s Bush never got off the postwar ground. In 1926, the center was taken over by the Ministry of Pensions. Long-term follow-up of veterans with PNIs failed through loss of interest or records, discharge, and the lack of a centralized system. The Medical Research Council’s report never analyzed surgical outcomes.

Similar failures plagued the AAMD, despite Frazier’s attempt to concentrate PNIs in the appropriate hospitals. A report by one military surgeon described the problem with characteristic understatement:

Careful preliminary study, operations and appropriate cases and prolonged and systematic follow-up, with massage, bath­ing, electro-therapy, proper splinting, and frequent examina­tions for evidence of returning function, constituted the treat­ment at this hospital. No conclusions can be reached, because of the transfer of this group of cases to another hospital.

By 1921, the Veteran’s Bureau had taken over treatment of patients who were under active care or who were compensable. Records and patients disappeared. In a short chapter in the American official medical history, Frazier summarized the results in 470 of approximately 1414 operations as 34% “good,” 36% “mediocre,” and the rest “failures.” He admitted that the definitions were “loose” and subject to the skill of the examiner. There were records on 60 transplants; none was successful. Showing his frustration, he wrote: “Considering the total number of cases and the results as recorded, the employ­ment of the transplant, either ‘auto’ or ‘homo’ as a practi­cal method of bridging defects in peripheral nerves has proven to be a dismal failure in the hands of the surgeons of our country.” There the matter rested.

Lessons Learned

It could be argued that prewar developments would have resulted in similar changes in medical care for PNIs without the influence of World War I. That is possible, but doubtful. War has a tendency to focus one’s attention, and the changes over a very short period of time were not specific to one technique or specialist, because they were part of a system of coordinating medical expertise to accomplish specific goals. However flawed in achievement, the practical value of the process seemed to take effect.

Twenty-one years after World War I, a second global war resulted in another large population of casualties with PNIs. The lessons learned from their medical management in World War I were underplayed but critical. The American official medical history in 1959 clearly stated the impact:

It is extremely unfortunate that the Official History of the U.S. Army Medical Department in World War I was not made readily available to military surgeons in World War II. It should have been required reading for them and for other military surgeons. It contains fundamental information on peripheral nerve anatomy and on technical methods of nerve exposure, mobilization, transplantation, and suture…”

Generally speaking, no important technical advances were made in the surgery of peripheral nerve injuries in World War II, with the possible exception of the introduction of tantalum wire sutures and tantalum cuffs. The striking improvement in results rested more upon a fuller appreciation of the principles of nerve repair than upon mechanical or surgical advances in technique.

The AAMD established 12 peripheral nerve centers during the war, along with a new Peripheral Nerve Com-
mission and Registry. R. Glen Spurling and Barnes Woodhall, both neurosurgeons, headed up the American effort. The British organized 5 nerve injury centers as part of their Emergency Medical Services. Not unexpectedly, orthopedic surgeons, such as H. J. Seddon and Harry Platt, supervised medical care.

Although the lines of authority were clear on both sides of the Atlantic, by this time it was obvious that the treatment of PNIs required the coordinated efforts of multiple specialties that now included plastic surgery and hand surgery. Lengthy rehabilitation was designed into the system, and after the war, as the veterans’ facilities expanded, long-term follow-up data were available that had been absent after World War I. In 1954, the British Medical Research Council published Special Report No. 282 on PNIs. This monograph detailed 3-year follow-up examinations on almost 1500 PNIs. Risk factors, such as location of sutures or time to surgery, were independently examined, along with the results of 67 autologous nerve grafts. Twenty-eight of these showed outcomes that were equivalent to primary suture at the same level. Surgical treatment of brachial plexus injuries was discouraged. Two years later, Woodhall and Gilbert Beebe, a statistician, published a report sponsored by the Veteran’s Administration and the National Research Council on a 3-to-5-year follow-up in 3656 PNIs in casualties from World War II.

The authors of both studies took care to acknowledge the work of their predecessors during World War I. As the first to “stand on guard” over nerve regeneration, they deserved this respect.

Disclosure

The author reports no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Dedication

This report is dedicated to the memory of Dr. Robert Tiel, a student of PNIs and a good friend.

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Peripheral nerve injuries during World War I


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