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Carnage remembered: prosthetics in the US military since the 1860s

The Iraq War is so far removed from the experiences of American Civil War soldiers that it brings to mind the Polish cavalry riding out to meet German tanks early in the Second World War. Changes in ordnance and materiel over the last 150 years have been dramatic. Of equal importance to the weaponry are dramatic changes in the level of medical knowledge and practice, especially in the field of trauma care. One measure of the enormous change in battlefield experience is illustrated by the survival rate from combat injuries. During the American Civil War, mortality from combat injury was 33 per cent, compared with 30 per cent in the Second World War and 10 per cent in Iraq.[1] With each war, as the destructive power increased, mortality was reduced. Combat mortality rates only represent a piece of the history of war's mischief with the marrow of human existence.

The elusiveness of past wars has attracted novelists, historians and curators who speculate on everything from the provocation behind the first Palaeolithic stone aimed at the head of an enemy to the interior life of blogging infantrymen in Iraq.[2] For those tasked with trying to explain the cultural and material impact of wars and armed conflicts in the nineteenth and twentieth centuries, the record is deep and abundant with tactics and weaponry but also overflowing with the shadowy memories of scarred veterans, bomber pilots with reminisces best left buried, and relationships interrupted by military service and forever haunted by 'what if?'. Scholars of modern wars have a wealth of documents, graphic images, ephemera and souvenirs, and letters from the front. War's materiality is collected, traded and re-enacted. But these are incomplete measures of the impact of slaughter and havoc on human lives. The physicality of war is not so easy to capture and analyse.

The intangible and tragic aspects of past wars often lay hidden in technology. Yet a study of the weaponry alone masks the spoliation of the combatants' bodies. Bodies cut to pieces by rapidly moving projectiles need never be considered when interpreting the technology of a breech-loaded rifle or the numerous systems that support an F-16. The corporeal experiences of war are hard to retrieve and infelicitous to discuss. Medical intervention and subsequent rehabilitation illustrate the immediacy of war's carnage. Examination of the medical record can temper the tactical and strategic record of what happened in a skirmish or hostile encounter. But the corporeal evidence is most real in the scars on an injured soldier's body. And no matter how unreliable memory may be, a prosthetic device is a cold, hard, irrefutable fact.

Prosthetic devices illustrate both the human cost of war and the uneasy intimacy of technology and flesh.[3] The history of military prosthetics can be approached from several angles – material culture, history of technology, history of disability and the body, history of medicine, gender and masculinity. Prosthetics are difficult to separate from the wounded soldier and society's complicated cultural relationships with nationalism, manhood and power, and concepts of health and physical wholeness. It is nearly impossible to avoid linking prosthetics with national recuperation, modernity and masculine redemption because prosthetics are such compelling icons for empire and rehabilitated masculinity – the most popular tactics of scholars studying prosthetics.[4]

This essay is intended as an admittedly eccentric and incomplete survey of the history of the relationship of the military to the development of prostheses, beginning with the American Civil War. It is incomplete because the field is sadly underdeveloped, with so much yet to learn, and eccentric because of the heavy weight given to the collections at the Smithsonian's National Museum of American History and the interests of the misfit curator authoring this piece.

The American Civil War: a market emerges

The history of prostheses in the military proceeds in parallel with changes in both the destructiveness of military technology and in the treatment of the wounds it inflicts. A comparison of the Civil War (1861–65) and the Spanish–American War (1898) dramatically illustrates the changes in treatment and survival of casualties, which in turn affected use of prostheses. Three-quarters of all Civil War operations were amputations, compared with about two-fifths in 1898, and surgical mortality rates were 26.3 per cent versus 0.4 per cent.[5] There were several reasons for the improved rates experienced by soldiers between the 1860s and 1898. By the end of the century, surgeons had a basic understanding of asepsis and antiseptic surgery, and germ theory was widely accepted. Battlefield kits made triage more effective. Although X-ray technology was still being perfected, surgeons who used X-ray equipment instead of their fingers to probe for bullets no doubt prevented countless fatal infections.

Most of the casualties in the Spanish–American War (91 per cent) were in Cuba and from disease, largely typhoid fever (80 per cent).[6] Consequently, this war put little pressure upon prosthesis makers. The American Civil War, on the other hand, was a watershed moment for limb prosthetics. It was significant not so much in terms of initiating design innovations – limbs and eyes looked pretty much the same before and after the war[7] – but in terms of the immense

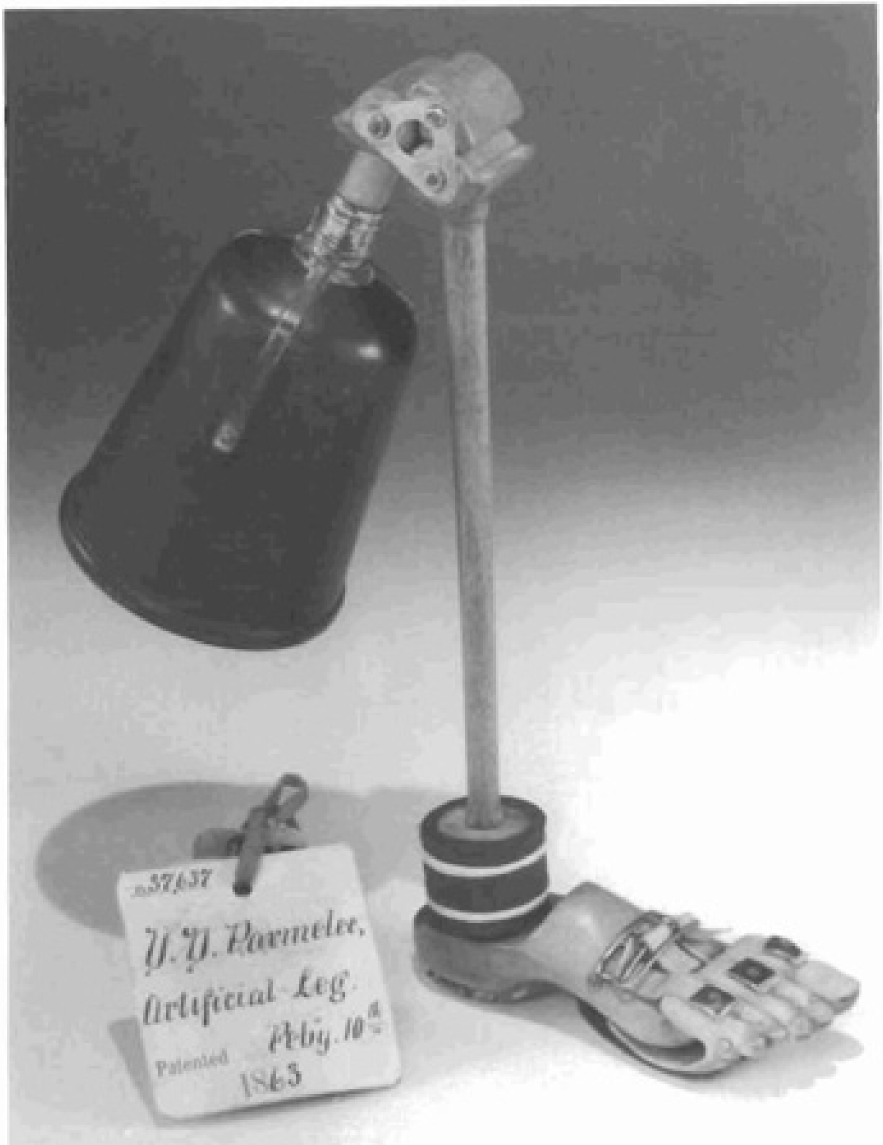

Figure 1 This 1863 prototype leg was submitted by D D Parmelee along with his patent application. The innovation points in nineteenth-century artificial legs were flexion (ankle and knee joints) and attachment. This leg has an ingenious knee design and a complicated toe attachment. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

increase in availability of commercially produced legs. Artificial limbs made the transition from custom or home-made one-offs to marketed commodity (Figures 1–4).

There were multitudinous war injured. Surgeons' preferred method of managing battlefield casualties was amputation. They performed amputations on about 60,000 soldiers during the war, of whom about 35,000 survived.[8] To care for these men, state and federal governments supplied prostheses for them.[9] Congress passed a law in 1862 that granted one artificial limb to each honourably discharged soldier or sailor who needed one. Another federal law passed in 1871 gave a new limb every five years to veterans, followed by an 1891 law providing a

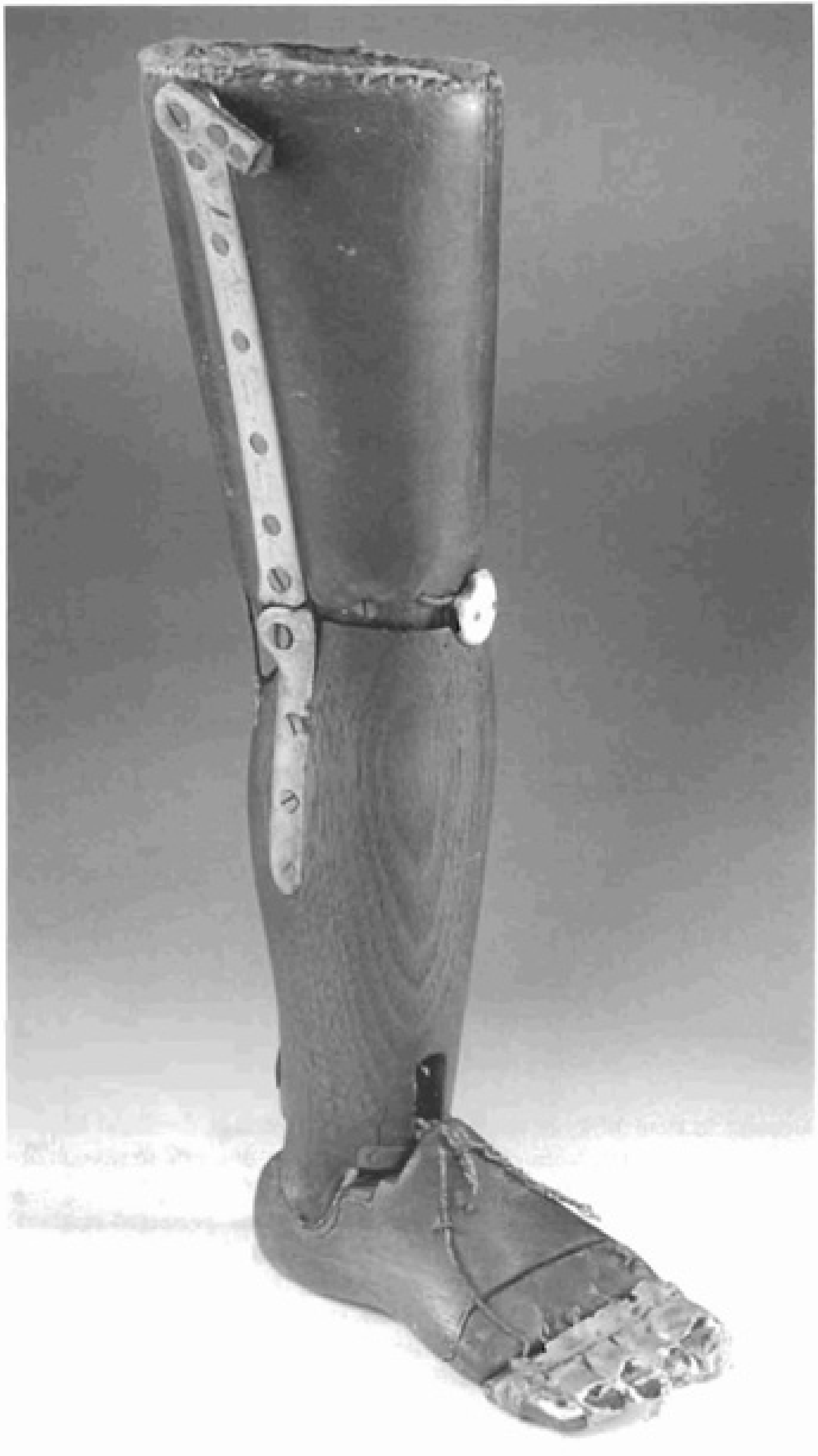

Figure 2 The maker of this 1863 wooden patent model attempted to solve the problem of ankle movement and provide for toe flexion, essential for maintaining balance on uneven terrain. Catgut was often used for the joint tendons but was affected by humidity and degraded over time. Silk was a better alternative. Sockets made the stump more comfortable and provided a better interface between body and device, but were not well developed in the nineteenth century. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

Figure 3 Most battlefield limb injuries are to the lower extremities, which explains why the majority of existing artificial limbs and prosthesis literature and ephemera relates to legs and feet. This is Douglas Bly's 1866 patent model for a below-the-knee appliance. Bly was among the many manufacturers competing for the government contracts for veterans. Note how Bly sculpted the toes and slope of the ankle. The rigid joints would have made for a noticeably stiff gait. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

Figure 4 Nineteenth-century peg-leg patent model, made of leather, wood and metal. Until the twentieth century, available materials were limited to wood, metal, rubber and leather. Willow and cork were commonly used for lower-extremity prostheses. This design attached over the shoulder and fastened over the stump with a lace. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

limb every three years. Limb manufacturer A A Marks was awarded federal contracts for limbs and expanded his business, selling them through his catalogue, then fitting them in person if there was a problem. Otherwise, the wearer did the measuring and fitting.[10] Rival James E Hanger of Staunton, Virginia, started making artificial legs after he lost his own while serving in the Confederate Army. Until the flood of manufactured limbs for Civil War veterans, limbs were usually simple home-made pegs attached with a leather harness. A wearer ensured that a limb would last for many years by padding the socket with cloth as the stump changed shape with the seasons and as the wearer aged.

Benjamin Palmer had given commercially produced limbs a boost with his widely lauded designs (Figure 5). Palmer's several patents (1846, 1849, 1851) marked steady changes – not necessarily improvements. Palmer's second patented leg, in 1849, won first prize in London in 1851, making him a minor celebrity. It had a steel knee joint, catgut cord tendons at the ankle and a painted wood shank. The Bly leg and others also competed for amputee business through attempts to improve upon the peg design, as well as to simulate the look of a real leg. J E Hanger added his rival design after the Civil War by introducing a cordless ankle and a wooden socket (Figures 6 and 7).[11]

But in some communities, notably in the South, not wearing a prosthesis valorised one's identity in a positive manner. An ex-soldier's stump was viewed as a mark of courage in glorious service to community. War wounds without a compensatory prosthesis were

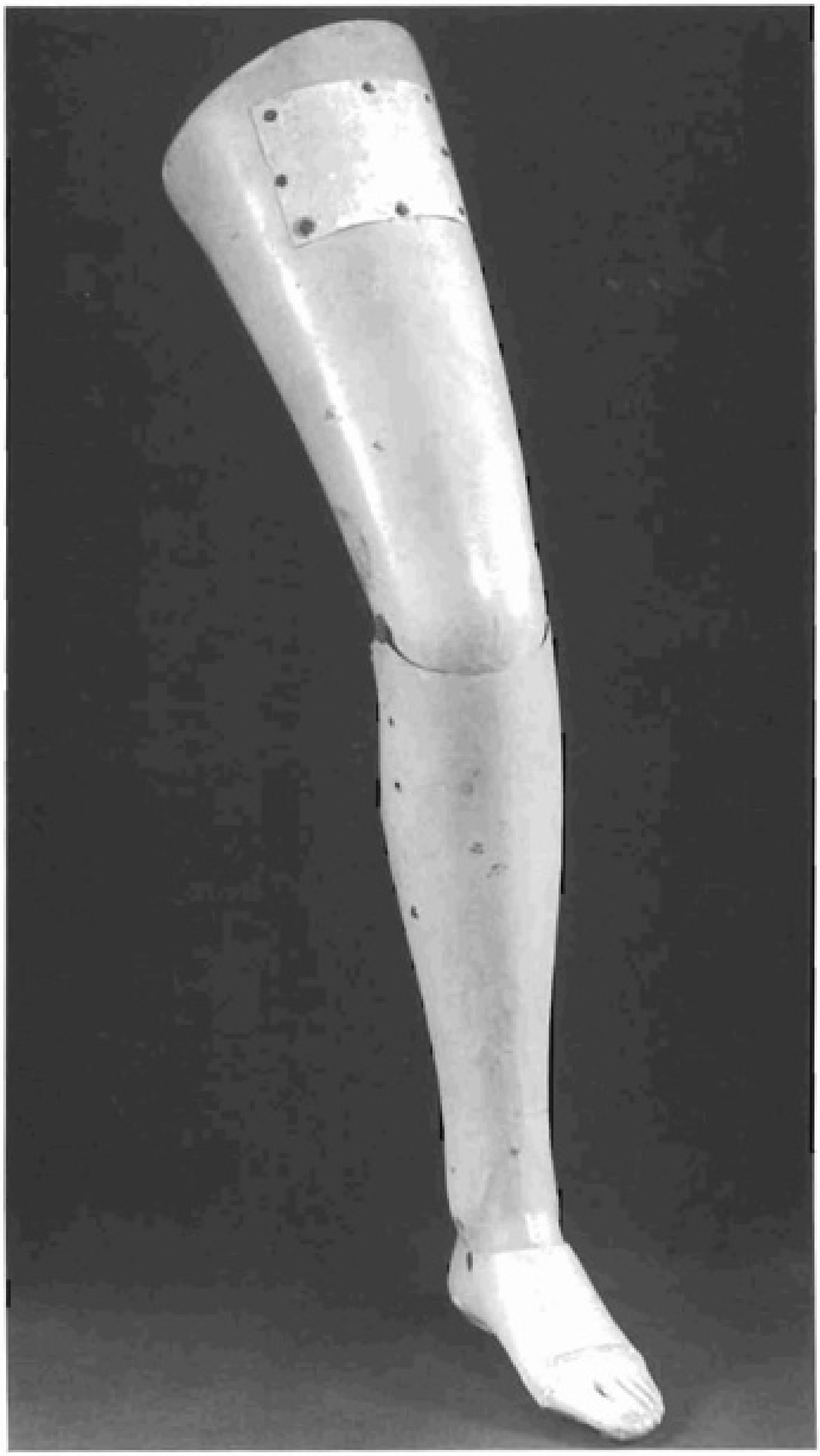

Figure 5 Benjamin Palmer's 1849 design was the gold standard for many years. The US Civil War created a robust prosthetics marketplace once the US government passed legislation to provide amputee veterans with artificial legs. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)


The Salem Leg,
Patented June 21 and July 22, 1862, and October 4, 1864.
Leg Amputation.
Thigh Amputation.
Leg Amputation.
MANUFACTURED BY THE
SALEM LEG COMPANY, SALEM, MASS.

Figure 6 This advertisement from the 1860s for the Salem leg does not show much technical detail but illustrates the growing emphasis on realism in limb design. The Salem leg was supplied to soldiers by the US government. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

memorialised in soldiers' poems and songs.[12] For veterans who chose to wear an appliance, by the end of the century, limb design had gone about as far as it could go, given the limitations of wood, metal and leather.

The First World War: some international comparisons

The First World War affected US prosthetics most notably through the services created to aid wounded soldiers. The Army created the Division of Physical Reconstruction for injured soldiers. There was also a civilian Federal Board for Vocational Education active in prosthetics work. In 1918, the Vocational Training Law for Disabled Soldiers was passed (Figure 8).

The US government paid veterans based on the part of the body disabled. Germany, on the other hand, paid military disability according to rank. In Germany, until around the time of the First World War, there were two basic designs for upper-extremity prostheses: a Sunday arm that was a cosmesis, not functional but resembling a real arm, and the work claw. Only the wealthy could afford more complicated arms and other terminal devices. The Carnes arm was a popular import from the United States until national pride motivated German orthopaedists to create an alternative. During the First World War, German hospitals and clinics were overwhelmed by the number of injured. Eventually, German officials came to believe that restoration of function was necessary for the rehabilitation of the worker. Consequently, only work-specific arms were created and the

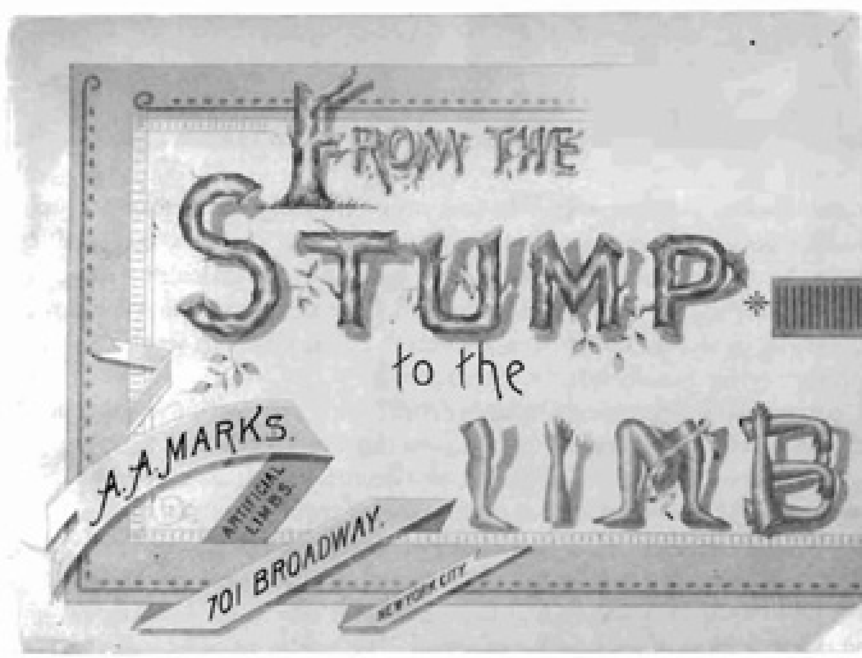

Figure 7 The cover of an A A Marks pamphlet on artificial limbs. Established in 1853, by the end of the nineteenth century, Marks was the largest limb-maker in the country. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

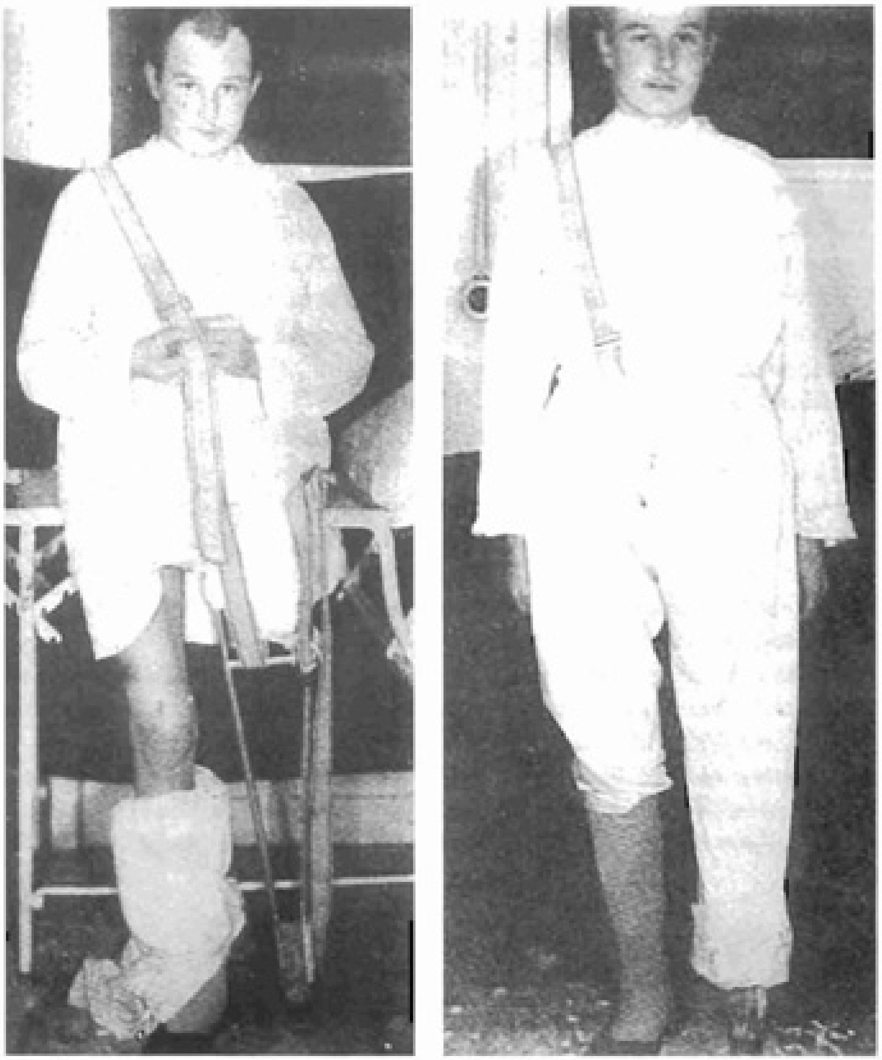

Figure 8 This First World War soldier demonstrates the temporary appliance given to him. Soldiers wore temporary and crudely fabricated appliances while their more durable limb was being made and their stump was healing. A stump changes shape and size while healing, especially if it is shedding shrapnel, as is often the case with blast injuries.[13]

cosmesis, or cosmetic arm, was discontinued. Of course, workers still wanted cosmetic arms and hands, but only 'head workers' received them. Note also that the influence of the American efficiency expert Frederick Winslow Taylor was strong in German prosthesis-making, as well as in German industry. By about 1917, German workers were producing Taylorised standard arms.[14]

Although designs for prosthetics had barely changed, the speciality of orthopaedics was largely created during the First World War by American, British and German physicians. Roger Cooter has explained the development of orthopaedics from the1880s to the 1940s as an expression of the emerging ideologies of power embedded in corporatism, rationalisation and statism. Cooter focused on crippled children, soldiers and industrial workers in his analysis of the organisation of care and treatment. The economic and political systems taking shape at the turn of the twentieth century heavily influenced how disabled veterans became integrated into civilian society.[15] For whatever reason, the rehabilitation of soldiers to occupations suited to their changed physical condition grew into a thriving, although small, sector.

The most significant changes in actual prostheses that resulted from the First World War were advances in facial restorations. The First World War was the impetus behind serious attention being given to the techniques for repairing and, lacking that, restoring lost tissue through artificial parts. Medical war work produced the first generation of plastic surgeons, such as Varaztad Kazanjian and Vilray Blair, who went on to train hundreds of younger surgeons in the techniques they had developed in military trauma units. The success of the war's innovative plastic surgeries fuelled the rise of cosmetic and aesthetic facial surgery in the 1920s, as peacetime surgeons learned of the techniques.[16] Surgeons established the American Association of Plastic Surgery in 1921 and began to build a consumer market for cosmetic surgery. Successful surgical repair of maxillofacial injuries, sometimes leading to the need for facial prostheses, was made possible by general medical advances during the war, such as the development of anticoagulants for blood products and understanding of blood types. Facial restorations and surgical repair for soldiers focused on the need to foster economic independence for men. Medical specialists emphasised normality of appearance, both of the face and in mobility, to enable men to be successful in earning a living.

The Second World War: creating a speciality

Despite the maturation of orthopaedics and the evolution of facial prostheses and slowly improving amputation techniques, on the eve of the Second World War the design of limb prostheses still remained much like that of 100 years earlier. An artificial leg was the common plug-fit wooden socket with a conical exterior. One bright spot in the 1930s that would later prove influential in the area of prosthetics was the establishment of the field of rehabilitation medicine as a result of the emergence of physiotherapy (or physiatry in the US). Physiotherapists had begun to refine their ideas several decades earlier, when most physicians who practiced physical medicine were either in electrotherapy or radiology. Over time, physical medicine drew physicians from other specialisms who were interested in rehabilitation and disability. The American Medical Association recognised physiotherapy as a speciality in 1947. Physiotherapists sought to habilitate injured soldiers to their new body and changed circumstances rather than train them back into their former bodies and lives.

Howard Rusk, a Missouri physician and one of those early activists, created a plan for Army Air Corps Convalescent Centers. Then in

1946 he went to New York University Medical Center, where he was instrumental in creating the modern discipline of rehabilitation. His revolutionary approach, refined during his service in the Army Air Force Medical Corps, was to focus on the whole patient by integrating injured or disabled people into the spectrum of life's activities. In 1948 he founded the Institute of Physical Medicine and Rehabilitation at NYU, with $1 million donated from Bernard Baruch. Physiotherapy was on the map.

The work of Rusk, Mary Switzer, Henry Kessler and others resulted in standardised prosthetic devices and treatment protocols, which in turn fostered the creation of post-war veterans' hospitals with large rehabilitation units. Mary Switzer furthered this work as the first administrator of the Social and Rehabilitative Services Administration of the United States Department of Health. Henry Kessler was a surgeon who served in the Pacific theatre. He had extensive experience in performing guillotine amputations. This was a straight-off cut and the common technique for limb amputation after shrapnel wounds, effective in preventing gangrene. Unfortunately, the stump left after a guillotine amputation was not good for fitting a prosthesis. Kessler's dissatisfaction with available options led him into extensive work with kineplasty – the use of muscle contraction to power the prosthesis that had been introduced in 1939.

Kessler worked at Mare Island Naval Hospital in California for a few years. The Smithsonian has several prototype limbs from Mare Island and other veteran hospitals of this era. They document the work of the US Artificial Limb Program, which contributed to understanding of biomechanics and functional anatomy.[17]

In 1945, the National Academy of Sciences (NAS) convened a conference of surgeons, scientists and prosthetists to improve the amputation–prosthesis interface. The NAS oversaw an intensive two-year research programme, called the US Artificial Limb Program, with subcontracts from universities and industrial research laboratories.[18] Northwestern University, the University of California at Los Angeles and at Berkeley, and Oakland Naval Hospital received study grants under the programme. For the first time, physicians, surgeons and engineers coordinated their efforts to work with a large amputee patient population. The labs made notable contributions to knowledge of the biomechanics of gait and both upper- and lower-extremity locomotion. The results fuelled the creation of a new field of study and also helped to invigorate ergonomics as a valid approach to human engineering.

Northrup Aviation also received a government contract under the US Artificial Limb Program. It initiated Project 17 with the funding received (Figure 9). Northrup engineers adapted Bowden steel-wire cable, used for aeroplanes, to replace the leather thongs that manipulated limbs. They also invented a device to mechanically lock

Figure 9 This prosthetist and soldier were part of Project 17, funded by the US government at the end of the Second World War, to study the biomechanics of locomotion and improve the design of prostheses. Here the technician is aligning a pylon and socket during fitting for a prosthesis. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

the elbow joint by using a shoulder motion. Project engineers visited the Limb Fitting Centre at Queen Mary's Hospital in Roehampton, UK, where the suction socket was popular. They also travelled to Sunnybrook Hospital in Canada and a few other sites in search of ideas to adapt. Overall, the US Limb Project resulted in several advances in limb design, such as the introduction of thermosetting resins to replace wood and leather, and plastic laminating. These innovations led to the biomechanical (total-fit) socket designs used today.

As in the First World War, survival rates of battle injury in the Second World War had improved over the previous war, which created another large pool of soldiers in need of prostheses.[19] General medical advances, such as the ability to batch penicillin in huge tanks and its widespread use with infections, chemical methods to increase the shelf life of bottled blood, and the overcoming of long-standing reluctance to retract the heart to perform cardiac surgery for bullet wounds, contributed to improved outcomes.

An interesting, although minor, advance in prosthetics brought about by the Second World War was the advent of plastic artificial eyes. Previously, there had been few plastic artificial eyes to be found. Techniques for working plastic were not perfected and the demand was not there. The transition to acrylic eyes was a direct result of wartime pressure.[20]

The dependence of American eye-makers, also known as ocularists, upon German glass (the preferred glass for artificial eyes) became increasingly uncomfortable after 1933. During the mobilisation of German industry for war, the Nazis forbade exportation of many products and raw materials, including glass. Among the Allies, glass shortages became acute and supplies of artificial eyes and glass tubing disappeared. Although the need of eye tubing was critical, consumers comprised a small niche market. As had happened during the First World War, when supplies dwindled, American glass manufacturers did not find it cost effective to put their scarce resources into research for perfecting glass-eye tubing. It was left to Army medical officers to search for alternatives.

Where and by whom the first successful acrylic eye was made is a subject surrounded in dispute and confusion. Plastic eyes first began to appear in the late 1930s in Britain, and word of mouth slowly spread news of their existence. Three Army dentists, Milton Wirtz, Stanley Erpf and Victor Dietz, have been credited with producing the first acrylic eye in 1943. What they actually did was adapt existing materials and techniques to create a system for mass production of acrylic eyes. The three men had been experimenting with acrylic eyes in their own labs and were dispatched together to Valley Forge, Pennsylvania. Since they were dentists, they turned to common denture-making processes, instruments and substances. They achieved success with acralain, also known as methyl methacrylate, the thermoplastic from which dentures were made. Acralain was easy to mould and harden, although the process took a few days. Plastic dentures had evolved from the rubber ones popularly used in the late 1800s. An international trust controlled the rubber market of the time and set prices exorbitantly high, so dentists searched for alternative materials. They first used celluloid with good results and then switched to methyl methacrylate in the 1930s, after it became commercially available. Acrylic plastic came into its own during the Second World War, when war researchers studied its potential use in aerodynamics, automobiles and elsewhere. By then, methyl methacrylate was readily available, its chemistry was well known and a cadre of dentists existed who were experienced in working with it. Since the Second World War, most of the artificial eyes made and worn in the United States have been of acrylic.

Iraq: the impact of body armour

The Iraq War has once again brought social and political pressure upon military prosthetics labs to rehabilitate injured soldiers. National wars reawaken politicians and citizens to the desideratum to care for those wounded in service to their country. The black-powder, low-velocity, large-calibre bullets of the 1860s are only found in museum gift shops now. High-velocity bullets actually cause more damage to tissue than the old, large lead bullets. The speed of impact means the bullets penetrate further and the force is displaced into surrounding tissue, producing a large area of destruction.[21]

In Iraq, blast injuries are most common. Soldiers' bodies are well protected, largely thanks to Kevlar and other body-armour materials, but head and extremities remain vulnerable. Consequently, those areas take the brunt of damage. During the twentieth century, most battlefield deaths occurred before the injured soldier received medical assistance. The medical response chain for injured soldiers has been streamlined so that field medics are immediately on the scene and administering clotting agents. They evaluate, stabilise and transport the injured to the proper facility.[22] The result is the lowest mortality rate of any war.[23]

Reduction in time elapsed between injury and treatment has improved survival rates, which in turn results in more mangled soldiers in need of prostheses.[24] The soldiers who require prostheses are sent to Walter Reed Medical Center in Washington DC, where they begin rehabilitation with their hi-tech devices. The Department of Defense first supplied amputee soldiers with microprocessor-controlled legs in 2003, after land-mine casualties began to occur during the Afghanistan campaign, called 'Operation Enduring Freedom'.[25]

Before microprocessing computers, radical improvement in function of lower-extremity prostheses was at a dead end (Figure 10). In the 1970s, the Blatchford or endolite knee was the first significant innovation. Its drawback was that it had to be locked in place. Blatchford was followed by the microprocessor-controlled C-leg. Otto Bock developed the C-leg in the mid-1980s and introduced it in the United States in 1999. The C-leg is the state-of-the-art prosthesis currently given to Iraq War soldiers. The plastic socket is designed with computer assistance (CAD/CAM) technology so that it exactly fits the patient's stump. The microprocessors monitor the terrain, speed and pressure placed upon the appliance through a force-sensing pylon as the wearer moves. The signals make minute adjustments to the user's gait. Gait is smoother because the wearer does not swing the leg forward, as with more conventional legs.[26]

Figure 10 This shoulder-harness, cable-activated, upper-extremity prosthesis with a split-hook terminal device dates from the Vietnam War era. It is made of canvas webbing and leather, metal, moulded plywood and thermosetting resins. (Collections of the Division of Medicine and Science, National Museum of American History, Smithsonian Institution)

The upper-extremity prostheses used at Walter Reed are a new generation of myoelectric arms, such as the Utah arm. These appliances operate in response to amplified electrical signals initiated by muscle movement. Myoelectric prostheses have been in use since the 1940s, but have only become popular through microprocessing engineering and lighter plastics. Upper-extremity prostheses do not take the pounding and battering of lower limbs and so have lent themselves to more delicate mechanics. It remains to be seen how long the Iraq War and its aftermath will continue to influence the development of prostheses.

In 1839, Edgar Allen Poe created the character of a Brevet Brigadier General grievously injured in sharp and savage Indian battles. Without the enhancement of his prosthetic appliances, General Smith was 'a large and exceedingly odd looking bundle of something' on the floor of his dressing chamber. After the general's valet helped him into all four of his limbs, bosom and shoulders, scalp, teeth, palate and one of his eyes, he became 'a truly fine-looking fellow' who could pass for absolutely normal.[27] Poe's imagination was well ahead of technical realties. His dubious achievement is that readers today can still easily understand General Smith. The many wars since Poe's time have created thousands of disabled soldiers who continue to look to physicians, technicians and engineers for repair. Let us hope that readers will one day find Poe's General Smith to be inscrutable.

Notes and references

1 Gawande, A, 'Casualties of war – military care for the wounded from Iraq and Afghanistan', *New England Journal of Medicine*, 351 (9 December 2004), p2472

2 I wish to acknowledge my debt to Audrey Davis, for many years a curator in the history of medicine and my predecessor at the National Museum of American History. Davis's path-breaking curatorial work in collecting artefacts related to disability laid the groundwork for much of this essay.

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6 Cirillo, V J, note 5, pp31–3

7 It is useful to distinguish between prostheses and orthotics. For the purposes of this essay, a prosthesis is an external appliance used to restore function and/or for cosmetic effect. It is different from an orthosis, which is a device that does not replace, but supports a part of the body having limited function. The distinction between prosthesis and orthosis is not always clear, however. These are general definitions and there is overlap between them – such as where cochlear implants, artificial hips and artificial larynges fit within this typology.

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