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SYMPOSIUM: RESEARCH ADVANCES AFTER A DECADE OF WAR

Extremity Injury and War: A Historical Reflection

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Introduction

Medical research and science in the 20th century have transformed the gruesome realities of war: Whereas before, a battlefield injury was associated with a high likelihood of death, most injured combatants now survive their injuries. However, even as advances in orthopaedic surgery have improved the lives of those injured in war, it is fair to say that the necessities of war have advanced the specialty. David LeVay, the prominent British orthopaedic surgeon and historian of orthopaedics, has argued that, "Orthopaedics was initially the surgery of war, fostered by war and the province of general surgeons" [13].

In fact, so many surgical advances seem to be associated with wars that some even compile a medical balance sheet of war [7], weighing its costs and benefits in a bizarre social calculus. War is a horrible failure of social and political responsibility and a social disaster of the first magnitude. As terrible as it is, however, war often serves as a sort of forcing function in medicine, accelerating changes already in queue because of the number of sick and injured as well as the number of medical personnel involved in similar war-related activities. The great 19th century Russian military surgeon, Nikolai Pirogov, is credited with calling war "an epidemic of trauma" [21]. Pirogov is correct.

Historians often note that the practice of medicine and/or standard of care at the beginning of a war is different from the practice of medicine and/or standard of care at the end of the war [1, 4, 8, 10, 14, 18, 20, 22, 26]. By reflecting on the key wars from before the 20th century to the war in Vietnam, we can potentially gain a better understanding of this transformative process.

Experiences and Developments Before the 20th Century

One of the clearest examples of war transforming musculoskeletal care is the experience of the 16th century military surgeon, Ambrose Paré. For more than 1000 years, fractures were treated by essentially similar methods—with splints and binding the wound when the wound is associated with the fracture. In the presence of such a wound, the fractured limb frequently became inflamed and generally required amputation. The introduction of gunpowder weapons created yet-more-severe wounds, exhibiting more severe inflammatory responses. Consequently, gunshot wounds were believed to be poisoned. By 1513, Juan da Vigo could summarize the standard of care as using boiling oil in gunshot wounds to combat the poison. Paré used oil

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until, in a battle at Turin, he ran out of oil and discovered that gunshot wounds healed better without further iatrogenic trauma from boiling oil. To substitute for the oil, Paré used the same egg and flour "digestive" he used routinely on compound fractures, including one used on his own lower leg in 1561 [11]. However, Paré's general practice, especially in the field, was to amputate compound (now called open) fractures, calling attention to the need to always amputate through healthy flesh [24].

By the 18th century, Pierre Desault recognized empirically that the introduction of devitalized tissue and foreign objects into the wound contributed to the inflammation. He recommended that débridement be performed by the surgeon before bandaging the wound. His student, the great Napoleonic military surgeon Dominique Jean Larrey, extended these teachings to answer the seemingly eternal question: early or late amputation for compound and comminuted fractures? Larrey argued that amputation was the best approach to avoid further complications. However, his conclusions were shaped by the ease of postamputation evacuation of the expeditionary wounded as much as the postoperative data [16].

Statistical Analysis for Complex Clinical Questions

In those days, every surgeon had his own records and no two surgeons recorded data the same way. Therefore, empirical answers were idiosyncratic, and surgeons had difficulty answering complex clinical questions with the available data in the early 19th century. Neither systematic records nor mathematical tools for record analysis had been agreed on. However, the situation was changing as a result of preventive medicine in both military and civilian life. The Royal Society of London led an effort to use numbers and data to answer questions about smallpox variolation in the 18th century, but too many parameters were unknown to satisfy all parties. The US Army Medical Department introduced systematic published disease records in the 1820 s and British public health reformers, led by Edwin Chadwick and William Farr, began to use statistical analysis of workhouse sickness data to answer medical and social questions.

By the middle of the 19th century, data from war in Crimea and the American Civil War were being used in surgical debates. At the same time common agreement to standards was still important. For example, the Dutch military surgeon, Antonius Mathijsen, introduced plaster of Paris casting in 1851. It was used widely by surgeons on both sides in the Crimea (1854–1856) because it was easy to apply and dried quickly. Mithijsen also noted it could be bivalved easily when necessary. Despite the affirmations in French, English, and Russian literature, plaster of Paris was not added to the supply table of either American army in the 1860 s, largely from the fear that civilian practitioners who volunteered for war service would use it on open fractures, introducing contamination. Of course, plaster casting was the least controversial of the innovations of the mid-19th century. The great changes of anesthesia and antisepsis proved controversial because they required a shared understanding of fundamental science and clinical application, a common professional goal not achieved in any Western country by that period.

An Improved Hospital Environment

Wars–along with the injuries arising from the new, hazardous industrial mines, factories, and railroads–called for more specific discussions of standards in the medical professions, and these were conducted in the climate of rising humanitarianism occurring in the Victorian era. Physicians, surgeons, and apothecaries each had different traditions in European countries. In the United States, sectarian strife between the regular or allopathic physicians and now historical practice communities such as homeopathic physicians and botanics (those committed to using only vegetable or natural remedies) prevented common standards. The then 20-year-old discussion regarding the value of anesthetics is a perfect example: What was the physiologic function of pain? Did pain elicit the healing power of the body? If it did, then did reducing the pain of operation slow healing? Such an academic discussion could rage while most practitioners resolved it empirically. The major wars of the midcentury led to widespread use of ether and chloroform without an obvious adverse impact [17].

The work of Claude Bernard and the mechanistic physiologists of the late 19th century held a shared understanding of the rule of physiology for the first time. A similarly shared understanding of germs was necessary for bacteriology to expand as a medical science. By the end of the century, almost all jurisdictions had some form of science-based examination to certify that probationers met a minimum standard. The United States introduced licensing examinations between 1875 and 1900. In the United Kingdom, the 1886 Conjoint Examination brought medicine, midwifery, and surgery together as a baseline for entry into practice.

A broader and deeper science base practitioners and researchers devoted to the issues concerning orthopaedics—better understanding of infection and improved hospital environment—all combined to see considerable progress in academic centers, where in the first decade of the 20th century, management of the open fracture reached new levels of success. In some European centers, the science of bone healing and the management of fractures that

failed to unite began to be studied. The development of the radiograph was moving rapidly and its use in orthopaedics was becoming more common. Still, considerable debate remained. On the whole, the community seemed poised for progress as we approached World War I.

Management of Extremity Wounds in World War I

Like in previous wars, soldiers on both sides of the conflict suffered exposed extremities, fractures (both open and closed), traumatic amputations, and vascular injuries during World War I. Those who did not bleed to death before help arrived remained on the field of battle for a period of time, often more than Friedrich's golden 6 hours (the average time for bacteria to move from the wound to the bloodstream and systemic infection) [9]. Medical personnel rightly feared infections would kill those with exposed extremities despite efforts to repair their limbs. Extensive débridement precluded vascular repair and antiseptics were infused almost constantly, but amputation rates remained high for all open fractures. Orthopaedic injuries were not widely understood by most physicians and there was no weightbearing femoral splint available in any army supply system when the war began. Consequently, femoral fracture mortality reached 60% (even as high as 80% in some hospitals) in the first months of the war [6].

Robert Jones was the best known orthopaedic surgeon in England in 1914 and was asked to serve as a consultant in orthopaedics to the British Army. He was a nephew by marriage to the apprentice-trained surgeon and bonesetter, Hugh Owen Thomas, who had assisted in Jones' training in orthopaedics. Thomas developed a steel splint to immobilize the knee in case of tuberculosis of the joint while still allowing the patient to perform the normal activities of daily living. The "Thomas splint" could be used to manage femoral fractures and Jones pushed its use on the British forces. By 1918, femoral fracture mortality was less than 10% among the British wounded. As the war progressed, the splint was adapted to other leg and arm fractures. Jones also advocated a rear-area hospital of orthopaedic injuries to assure appropriate postamputation care and prosthetic rehabilitation. He continued his advocacy for amputees and other severely injured patients after the war [25].

For fracture treatment, assuming infection could be controlled, traction remained the mainstay with Balkan frame wards dominating every base and general hospital. Weight and pulley traction allowed effective nursing, infection control with Carrel Dakin irrigation, and healing of the fracture. There were isolated attempts by experienced orthopaedic surgeons to use plates and intramedullary nailing, especially early in the war, but few had the experience or the materials to continue the effort. Appropriate nursing care remained also a constant struggle.

Many surgeons used casting, leaving the wound exposed for daily dressing and antisepsis, frequently producing nonoptimal casts for bone stabilization, but fear of infection and failures to understand traction methods led surgeons to try approaches they thought they understood.

Hiram Orr, an American surgical consultant from Nebraska, was aware of and appalled by France's poor infection rates and fracture management techniques. His review in November of 1918 of 4000 cases of open fracture in his rear-area hospital found approximately half had fenestrated casts, approximately 30% required further treatment in the hospital, whereas the remaining 20% had proper splinting. (The other half was not casted.). When he returned to Nebraska after the war, he began work on his "closed technique." It was simple—"Rest for the wound means infrequent dressings. Rest for the injured part means protection against movement…" [15]. In essence, he concluded that stabilization of the fracture required priority. Of course, if débridement was incomplete, the process needed to start over, but in Orr's hands closed casting, often for weeks, worked well.

More than any single advance, World War I illustrated the profound difference that existed between a knowledgeable and skilled, academically oriented orthopaedic surgeon and even a well-trained general surgeon when it came to management of complex extremity wounds involving fractures. It also sent a message to the orthopaedic community—we needed to further study fracture management.

The Management of Extremity Wounds in World War II

When Josep Trueta (1897–1977, was the chief of trauma services in Barcelona, Spain, during the 1930s) moved from Madrid to London in 1940 and published *Treatment of War Wounds and Fractures,* his Spanish Civil War experiences, he captured the attention of the military and orthopaedic communities. He followed Orr's closed technique with vigorous advocacy of radical exposure, débridement and épluchage, and recommended routine trimming of the bone wound to make sure débridement was complete. The wound was packed with petroleum jelly-impregnated gauze and dusted with the new sulfa powder using an insufflator for antisepsis. The wound and fracture were enclosed in the cast and left alone for weeks. He published pictures of bloody and pus-stained casts; when the odor became too offensive, he recommended a rubber bag to contain the stench [23]. Evidence of his impact was seen in Hawaii in December of 1941 when the open fractures were packed with sulfa, eliciting compliments from Isidor Ravdin, the Surgeon General's consultant, who

visited in early 1942 and was extremely complimentary of the low infection rates. It is, of course, more likely that the regular army surgeons, led by Major Leonard Heaton, had practiced effective wound toilet and the wound healing was unrelated to the sulfa dusting. In 1944, sulfa dusting would be forbidden [3].

The continuing education challenge was replayed in the rush to rapid subspecialty preparation of orthopaedic surgeons in 1942. The residency and board certification system had not prepared enough orthopaedists to staff the military needs. As a result, short courses lasting generally 3 months were established to introduce partially trained practitioners to the various subspecialty subjects. The academic orthopaedic community had enjoyed considerable success with a new external fixator introduced by veterinarian Otto Stador in 1931 and adapted to human use at Bellevue Hospital in 1937. The military bought thousands of them in 1942. In experienced hands it was a useful tool, but in the hands of a novice, misalignments and infections were common. By mid-1943 the Army Surgeon General forbade external fixation in deployed hospitals [5].

In the early campaigns in the Pacific and Mediterranean, infection rates went up, but as consultants made the rounds and reviewed practice patterns, infection rates eventually fell again. Adequate wound management was difficult to learn without actual experience. By late 1943, infection rates were falling again but consultants worried about the medical groups preparing to support the invasion of Europe in 1944. Fortunately by late 1943, a new antibacterial drug, penicillin, was reaching the deployed hospitals and by 1944, the drug was widely available.

As the war came to an end, the importance of the skilled surgery was even more apparent than it had been a generation earlier. The United States rushed to complete the work begun in the 1930s of establishing training programs for graduate medical education. The Veterans Administration and the National Institute of Health supported training in civilian institutions, which led to an exponential increase in graduate medical education slots in the late 1940s. The Navy (in 1946) and the Army (in 1947) opened orthopaedic and other residency programs in their larger hospitals. Research in orthopaedics, prosthetics, and vascular surgery progressed in these training programs. The country was in such a rush to demobilize that special efforts were needed to assure the postwar care of the wounded soldiers, sailors, airmen, and Marines.

Nevertheless, the world still had conflict—the Soviet Union, allies of convenience in the war, was pushing its borders in eastern Europe and the Pacific and, in retrospect, had perhaps irrational but great fear of Western intervention to stifle their view of a communist state. A quasi or cold war emerged, but it heated up suddenly on the Korean peninsula in June of 1950.

Management of Extremity Wounds in the Korean and Vietnam Wars

Partially trained residents, pulled from residencies in the second or third year, meant that the Korean conflict had a higher percentage of specialized orthopaedic skill than any conflict in history, and it showed. The introduction of body armor reduced the number of fatal thoracic and abdominal wounds; statistically this reduction increased the percentage of extremity wounds among the evacuees, but the advances in surgical care with forward blood, new antibiotics, and aeromedical evacuation dropped amputations to the lowest rate in history. Forward care had reached a high point in the Auxiliary Surgical Units in the European Theater in World War II and during the late 1940s, the war experience had been used to create a new forward hospital unit, the MASH (mobile army surgical hospital). Designed with complete nursing care and patient-holding capacity, these new hospitals were expected to be staffed by certified specialists, the initial deployments were staffed with those partially trained, but they were backed up by experienced consultants. The senior consultants were familiar with war wounds from their recent World War II experience and failures of débridement were uncommon in Korean forward hospitals. Perhaps most importantly, the Walter Reed Hospital Surgical Research Team entered Korea in 1952 to prove vascular surgery practical in forward-deployed hospitals. For the extremity patient, the introduction of the helicopter evacuation unit, in Korea from the Casualty Clearing Station, was immeasurably important because it reduced the pain, potential complications resulting from handling, and the time before the casualty received definitive care [19].

What Korea started, the Vietnam War raised to a high art. The new helicopters moved patients from the point of wounding directly to hospitals with highly skilled specialty care. Unfortunately, these advances were offset by changes in enemy equipment and tactics—higher velocity Kalashnikov rifles created cavitation that destroyed bone; land mines and booby traps caused terrible extremity injuries—which increased lower extremity injury rates by 300% versus World War II [2]. More than 5000 American service men lost limbs in Vietnam. Despite the number of amputations, the orthopaedic care improved dramatically—it was specialty care from the beginning to the end. Although there were failures of wound management, they were few. Closure was delayed, but not for a prespecified time period; rather, primary closure was elective and performed only when medically indicated, because the military medical leadership trusted the individual surgeon's judgment. The civilian experience of the 1950s and 1960s highlighted the importance of fasciotomy or fasciectomy to allow exposure of muscle compartments. The surgeon in Vietnam learned

that high-velocity bullet wounds increased the chances of compartmental pressure and ischemia. Venous repairs were undertaken by the Walter Reed Surgical Research Team led by Maj. Norman Rich, and venous injury, especially popliteal vein injury, often increased compartment pressures. There were challenges of continuity of care as aeromedical evacuation took the wounded to stateside hospitals close to their home of record, often to hospitals without complete orthopaedic and rehabilitation medicine teams. This socially mandated scattering of patients made long-term followup for anything beyond personally published series of patients almost impossible to reconstruct. Consequently, our belief in the overall excellence of care may be slightly overstated [2].

Technological and Philosophical Advances in Prosthetics

As the number of veteran amputees increased, so too did the maturation of rehabilitation medicine and progress in prosthetics. The development of biomechanical engineering led to the shift from exoskeleton prosthetics (hollow, fitting over the stump with weightbearing on the outside skin) to endoskeletal prosthetics with interior weightbearing rods and light plastic exteriors giving body shape. This change in material and design allowed surgeons to revisit stump formation and take advantage of the body's remaining musculature to assist in future movements [12]. Such equipment allowed the patient with an amputation to do much more with greater ease, which fit well into the evolving philosophy of rehabilitation medicine. As Paul Brown noted in his history of rehabilitation in Vietnam, "Leaders and innovators in the field were asking the question–'Where does treatment cease and rehabilitation start?' The true significance of this basically rhetorical question lay in the implication that treatment and rehabilitation were indistinguishable…" [2].

Although this philosophy had almost always been expressed as an ideal, it was impractical in previous wars where specialty staff were limited and patients were legion. However, the wealth of medical resources applied in the Vietnam era led to its actual implementation in many cases. By the late 1960s, understandings from multidisciplinary approaches to rehabilitation led to a realization that the professional tactic of preparing the patient to deal with loss of function had undermined motivation. Psychology and social work introduced a new paradigm: teach the patient to appreciate what they could do, especially through recreation. At Fitzsimons Army Medical Center in Colorado, the rehabilitation team engaged ski instructors to give amputees a new activity, providing a means of restoring pride and confidence in wounded men and women. There was nothing magic about skiing; the magic was in motivation of the patient to return to a full and robust life [2].

With an obligation to simultaneously prepare for war and serve as a healthcare system for service personnel and their families, military medicine increasingly conformed to civilian standards while trying to preserve its capacity to deploy and treat large numbers of cases far from home. Compensation increases were awarded for board certification and graduate medical education and research career paths were developed.

The key components revealed by previous experience were easy to see: interdisciplinary teams, sophisticated evacuation technology, and standards to get people to definitive care, and, most importantly, adequate numbers of well-educated, highly trained specialist surgical personnel prepared to go into harm's way with the soldier, sailor, airman, and Marine. Protecting the readiness of the easily seen components required, and requires, constant vigilance.

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