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JRRD Guest Editorial

As history repeats itself, unexpected developments move us forward

As long as our country has been involved in war, men and women have sacrificed life and limb serving this great nation in the pursuit of freedom. The unwavering commitment to enter battle comes with a trust in their fellow soldier and the peace of mind that in the event of injury, our great nation will provide the very best for our veterans. The Departments of Veterans Affairs (VA) and Defense (DoD) have a long history of being the leaders in medical care and research in the quest for the most effective treatment interventions and devices with the mission of caring for those who have served.

The benefits for veterans of the United States dates back to 1636, when the Pilgrims of Plymouth colony were at war with the Pequot Indians and a law was passed by the Pilgrims which stated that any disabled soldier would be cared for by the colony. In 1776, the Continental Congress authorized half-pay pensions for life for those with loss of limb or other serious disability. Only 3,000 Revolutionary War veterans ever drew any pensions [1].

The Civil War was the bloodiest war in U.S. history with over 30,000 Union soldiers and 40,000 Confederate soldiers losing limbs during the 4 years between 1861 and 1865. Prior to the war, only 500 of the 11,000 Northern physicians and 27 of 3,000 Southern physicians had performed surgery. Most had 2 years or less of medical school and learned to perform surgery through on-the-job training. Because more than 70 percent of the Civil War wounds were to limbs, countless wounded overflowed field hospitals after battle, and because of doctors' limited surgical skills, amputations were the treatment of choice, especially because the average procedure took less than 10 minutes [2]. The mortality rate from a primary amputation was 28 percent; however, if a secondary amputation was performed, the mortality rose to 58 percent. If infections such as "pyemia," or "pus in the blood," occurred, the mortality rate was over 90 percent [3].

The post-Civil War era pushed the Government to embrace the care of soldiers returning home since every family in the United States had been touched in one way or another by the war. Accordingly, the VA's motto is taken from President Lincoln's second inaugural address in 1865, where he asked Congress "to care for him who shall have borne the battle and for his widow, and his orphan." However, not until 1873 did Congress authorize the revision of disability pensions to be paid based on the degree of disability rather than rank, establish the National Home for Disabled Volunteer Soldiers, and decide that Arlington National Cemetery would be the place for burial of honorably discharged veterans [1].

The postwar opportunities ushered in the age of entrepreneurship that was sparked by "Great Civil War Benefaction," or the U.S. Government commitment to provide prostheses to all veterans. The most famous was a

young engineering student, J. E. Hanger, who lost his leg above the knee early in the war serving in the Confederate Army. Discontented with his prosthesis, he set about to improve the function of his artificial leg. He obtained an exclusive contract to provide limbs to Confederate amputee veterans and was constantly in competition for Federal contracts with another firm founded by Dr. Douglas Bly of Rochester, New York. Both companies claimed to offer veterans the lightest prosthetic limb, weighing just less than 12 pounds. The U.S. Patent Office received numerous prosthesis designs, most of which could be worn by only a select few amputees. With just over 200 prosthetic clinics serving veterans throughout the United States, many extraordinary claims were made about the capability of a prosthesis, few were comfortable, and most veterans found crutches to be a more efficient means of ambulation [4]. Many prostheses were provided by traveling salesmen who scouted potential amputee customers from newspaper articles, local hospitals, or word of mouth. Others used the large manufacturer in New York, A. A. Marks, where measurements were taken and the artificial limbs were purchased from mail-order catalogs: some veterans just had to visit their local barbershop to be measured for a new limb, which would arrive in the mail a few weeks later [5].

D. W. Dorrance, whose right arm was amputated following an accident in 1909, was, like most amputees before him, dissatisfied with the artificial limb he received. A typical upper-limb prosthesis during this time consisted of a leather socket, which absorbed perspiration and thus had a distinct odor, and a heavy steel frame with a choice of three types of terminal devices: a heavy cosmetic hand that was covered with a leather or cotton glove, a mechanical hand that was clumsy with poor function, or a passive hook that could be used to lift and carry objects but did not allow for prehension. He introduced the double or split hook that could be opened by means of a strap across the back which was anchored to the opposite shoulder and closed by heavy-duty rubber bands about both hooks [6].

As the United States entered World War I (WWI) in 1917, Congress established a new system of veterans' benefits that included programs for disability compensation, insurance for active military and veterans, and vocational rehabilitation for the disabled. Of the 4.7 million Americans who served during WWI, 53,500 lost their lives, with approximately 204,000 Americans wounded and 4,403 returning with amputations from the relatively short participation in the War. Late 1918 brought the armistice and the conclusion of the war. Within 6 months, over half the American forces returned home to find jobs scarce and the United States depleted of resources and with little ability to care for the returning veterans, especially the wounded. With the Great Depression looming and no central Government program like the VA to take responsibility for the veterans, a champion for wounded soldiers was needed. On Christmas Day 1919, Judge Robert Marx initiated the concept and within a year formed the Disabled American Veterans (DAV), an organization to which 741,000 disabled veterans were eligible for membership. Since its inception, the DAV has led many of the National Service Offices (NSOs) in working with Government to create legislation, education, research, and programming for veterans with disabilities and their families [7].

During the 1920s, the various benefits were administered by three different Federal agencies: the Veterans Bureau, the Bureau of Pensions of the Interior Department, and the National Home for Disabled Volunteer Soldiers. As a result, in 1921 Congress created the Veterans Administration and authorized the Administration to operate hospitals and provide vocational rehabilitation for those with disabilities. This expanded further as veterans returned from WWI and World War II (WWII). With the Depression of the 1930s, the Federal Government began to assist in the rehabilitation of the handicapped.

Because of the economic depression and the need for the Government to provide the bare essentials to veterans and their families, little research or innovation occurred in prosthetics during the 1920s to 1940s. Those who could afford or tolerate wearing a prosthesis during this time purchased them through mail-order companies or local limb makers who often made artificial limbs for friends as an aside to some other job.

The scars of WWII brought about the massive and concerted effort of scientific research to aid those who had lost limbs. There were 14,912 soldiers with amputations: 10,620 lower limb and 870 bilateral lower limb from the U.S. Services and over 1 million worldwide. Because of these historic numbers, in 1945 the National Academy of Sciences–National Research Council, at the request of Norman Kirk, Surgeon General of the Army, established the Committee on Prosthetic Devices, later known as the Prosthetic Research Board. The impetus for the intense focus on prosthetics was the vigorous protest by the returning veterans about the prosthetic devices they were receiving.

Representative Edith Nourse Rogers of Massachusetts, ranking member of the House Veterans Committee, had been visiting the veterans since WWI. Mrs. Rogers brought in busloads of amputees from Walter Reed Army Medical Center (WRAMC) in Washington, DC, to meet with members of Congress to illustrate that their prosthetic limbs were heavy and hurt constantly. She wanted the members of Congress to see firsthand the people for whom they were representing and voting, because numerous bills for veterans were being discussed during this time and the future of many veterans lay in the decisions that Congress was making [8].

As amputees were discharged from the Army and Navy hospitals, complaints of prosthetic care prompted a congressional subcommittee hearing in 1945 regarding the Veterans Administration's practice of purchasing prosthetic devices from the lowest bidder. During the same year, in response to the need for better care for the veteran, General Omar Bradley, Veteran's Administrator, initiated the Prosthetics Appliance Service, which led to the significant research contributions in prosthetics, orthotics, shoes, and aids for those who are hearing and vision impaired.

Major General Paul Hawley, Director of the Veterans Administration Medical Department, recruited Dr. Paul Magnuson from Chicago to develop the prosthetic research program. Dr. Magnuson introduced a program of rehabilitation and research within the Veterans Administration that is best illustrated by the story of a young veteran with bilateral shoulder disarticulations who was invited to the White House. While being received in the Oval Office, Dr. Magnuson asked President Harry S. Truman if he would like to see the young veteran with no arms get into and out of his prostheses by himself. The President did not see how this would be possible.

The veteran with no arms, who was standing in the Oval Office, said he would show him, but was afraid of scratching the President's desk. "Never mind the desk!" said President Truman with intent interest, sweeping aside his papers. After watching the boy wriggle out of and back into his prosthetic arms, tears were reported to have rolled down the President's face [8]. The cost for research and development of the prosthetic's program was justified over and over again with moments like this across the country. Congress appropriated prosthetic funds to the Veterans Administration which, in turn, generated the greatest research effort ever in the field of prosthetics and orthotics.

In 1945, WRAMC was admitting 1,500 soldiers with amputations per month from the European Theater [8]. Amputees were also cared for at Brooke Army Medical Center, San Antonio, Texas; Fitzsimmons Army Medical Center, Aurora, Colorado; Valley Forge Army General Hospital, Phoenixville, Pennsylvania; and the U.S. Naval Hospitals in Oakland, California, and Philadelphia, Pennsylvania. Because of overcrowding at WRAMC, the Army transferred the prosthetic research program to the University of California education system. The human biomechanics and gait laboratory was located at the University of California San Francisco, the lower-limb program at the University of California Berkley, and the upper-limb prosthetic program at the University of California Los Angeles (UCLA).

In the summer of 1945, Howard Eberhart, a military engineer, was setting up a research project on B-29s' landing gear. Late one evening, Eberhart's left leg was crushed beneath one of the testing trucks. The Naval Surgeon Dr. Verne Inman performed his amputation. As part of Eberhart's occupational therapy, Dr. Inman introduced him to another engineer, Eugene Murphy. Together the trio received a $50,000 research grant, seed money for what would become one of the greatest research collaborations in rehabilitation history [8]. Together with a team of notable researchers, they were the first to describe

the biomechanical events of gait cycle, developed the Solid Ankle Cushioned Heel foot, ankle rotators, total contact sockets, the patellar-tendon-bearing socket, the quadrilateral socket, and numerous other contributions to modern-day prosthetics.

By the mid- to late-1940s, numerous teams throughout the country worked on multiple areas of research related to the amputee beyond just prosthetic devices. For example, Dr. William Levy and Dr. Gilbert Barnes were funded and reviewed hundreds of skin disorders of the residual limb, related materials, socket environment, and physiological changes as the result of amputation. Their work is the foundation for dermatological care in amputees today.

By 1947, the Advisory Committee on Artificial Limbs was formed and multiple research facilities were organized through the Veterans Administration and the Armed Services. The program was financially supported by the Veterans Administration, the Navy, the Army, and the Office of Scientific Research and Development. The responsibility of the Committee was to review potential research projects in the field of artificial limbs and advise the Veterans Administration when, in the Committee's opinion, a device or technique had reached the point that it should be offered to Veterans Administration beneficiaries.

In 1948, Representative Edith Rogers pushed Public Law 729 and congressional funding of $1 million annually was provided for the development of artificial legs and arms, hearing aids, and aids to those who are blind. The Veterans Administration was charged with the administration of the funds and established the Research and Development Program. Dr. Eugene Murphy was appointed Chairman of the Prosthetic Research Department with the headquarters located in the New York City Veterans Administration Center [9].

Partnerships with private business were essential to the success of the prosthetic research program. The Veterans Administration awarded financial support to Northrop Aircraft Corporation, which teamed up with the UCLA Biotechnology Department. The goals were to replace the traditional carved wood and leather prosthetic devices and develop the application of lightweight metals, multistrand control cables, plastics, and artificial hand mechanisms that would be comfortable, strong, and efficient. The results of the research and development group would benefit upper-limb amputees for decades to come and are still incorporated in most upper-limb prosthetic components today. The next two decades would bring enhanced socket-and-suspension designs, Bowden cables, lighter weight terminal devices, cosmetic hand covers, and numerous other developments that improved function and returned the veteran to work. Professor John Lyman also introduced the very first microprocessor prosthesis with integrated circuits, with accurate actuation of the arm's mechanical parts. One of the most significant developments was laminate plastic, which was much lighter than wood and easier to shape. It quickly became the standard for all upper- and lower-limb sockets until the 1980s and remains widely used today. Moreover, special training programs were established at New York University (NYU) and UCLA to bring limb-fitting personnel for an intensive 12-week training course that led to certification for applications of the new technologies to Veterans Administration standards [10].

Cineplasty is a method of operating an artificial hand or hook by the flexing of a muscle directly attached to cables. Muscles such as the forearm flexors and extensors, biceps and triceps, or pectoral muscles were surgically prepared with a soft tissue tunnel or flap. A detachable plastic ring ran through the tunnel and the amputee was taught to contract the muscle to control the prosthesis. The benefits included no restricting harnesses and greater proprioceptive feedback [11]. By 1952, over 70 procedures had been performed at WRAMC in the Army Prosthetics Research Laboratory (APRL) under the direction of Lieutenant Colonel Maurice Fletcher. Reports suggested "The hands perfected at the laboratory [APRL] are now able to grasp a delicate eggshell without crushing it, or to lift a 50-pound weight without dropping it" [12]. The next generation of upper-limb prosthetics included the introduction of microprocessors to assist with control of the prosthesis. Research collaborations were created between International Business Machines (IBM) Corp. and its subcontractor Alderson Research Laboratories in New York City to further the development of the myoelectric arm.

The Veterans Administration expanded its prosthetic research program in 1956 when it began to support a Prosthetics Research Laboratory (PRL) at Northwestern University through the work of orthopedic surgeon Dr. Paul Magnuson and Dr. Clinton Compere. Dr. Compere had been chief of an army amputee service during and after WWII as well as his amputee clinic at the Rehabilitation Institute of Chicago, and Dr. Paul Klopsteg was already funded at the time by the Veterans Administration for prosthetic studies; together, a long tradition of engineers and clinicians working together at the PRL was initiated. To this day the VA continues to fund research and education at Northwestern University PRL [13].

Rehabilitation of the amputee was acknowledged as being critical to the success of veteran amputees and, while countless prosthetic developments were being introduced, so were advanced rehabilitation procedures. In 1952, Dr. Magnuson, while Medical Director of the Veterans Administration, personally raised private funds in the amount of $250,000 and in less than 10 weeks started the Rehabilitation Institute of Chicago. After serving as a physician at Mare Island, Dr. Henry Kessler further understood the need for rehabilitation and opened the Kessler Institute of Rehabilitation in Orange, New Jersey. Dr. Howard Rusk of New York, a consultant to Washington, worked tirelessly with veterans of WWII but pointed out that during the same time that the war resulted in 17,000 amputees, trauma and disease resulted in 120,000 amputees in the civilian population. He raised funds for the Institute of Physical Medicine and Rehabilitation of NYU and was one of the first to stress the need to offer civilians the same level of prosthetic care and rehabilitation techniques being offered to the veteran. Before WWII ended, Rusk's system of getting people out of bed as quickly as possible, usually within 3 days, was instituted in 253 hospitals and 12 rehabilitation centers across the nation [8].

In 1958, the Congress formally recognized medical research as one of the missions of the Veterans Administration and authorized a portion of the Veterans Administration's annual budget for research. The Veterans Administration's mandate was to contribute to the nation's knowledge about disease and disability by carrying out medical research in connection with the medical care and treatment of veterans.

Although certificate programs were offered since 1952 at UCLA, Northwestern, and NYU, not until 1963 was the first undergraduate curriculum leading to a Bachelor of Science degree in Prosthetics and Orthotics inaugurated at NYU [14]. All three programs received their initial funding and maintained some form of support from the Veterans Administration for many years. Today Northwestern is the only original school still enrolling students. The reduction and in most cases elimination of Government subsidy contributed to the closing of some prosthetic and orthotic educational programs, leaving the nine remaining prosthetic programs to employ a variety of funding mechanisms to remain in operation.

Between 1961 and 1975, the Vietnam war resulted in 5,283 amputations, with 1,081 soldiers suffering multiple amputations [15]. By 1968, the number of amputees in military hospitals was growing because of the increased involvement of the United States in the Vietnam war; likewise, the prosthetic developments continued to be a part of the Veterans Administration funding mission for research. In 1968, the *Bulletin of Prosthetic Research* was first published, reporting on new developments in prosthetics, sensory aids, and assistive technology. Today the publication is the *Journal of Rehabilitation Research and Development*, now more well known as *JRRD*.

In 1964, Prosthetic Research Study (PRS) was founded in Seattle with Veterans Administration funding by Dr. Ernest Burgess. Many innovative areas of development included the transtibial posterior flap surgical procedure, immediate postoperative prosthetic, and in 1984, the first "energy storing" prosthetic foot known as the Seattle Foot. Some of the products developed at PRS were distributed through private manufacturers as the Veterans Administration continued its relationship with private industry such as the Seattle Limb Systems. PRS also introduced the use of computer-aided design/computer-aided manufacturing methods for prosthetics and later the Automated Fabrication of Mobility Aids systems with New York VA Medical Center (VAMC) and Northwestern University/Lakeside VAMC. Dr. Burgess

used many of these developments to provide the poorest of civilians in Vietnam and Cambodia with prosthetic care [16]. Today PRS is one of the only self-supporting research centers in prosthetics and orthotics, preserving the mission of Dr. Burgess.

Hans Mauch, a brilliant German scientist, was brought to the United States toward the end of WWII to continue his work with the U.S. Air Force at Wright Field in Dayton, Ohio. His areas of expertise, among many, were hydraulics, pneumatics, and mechanics. He developed dozens of important contributions such as the V-1 rocket, ME 262 jet-propelled fighter, remote-controlled missiles, the first climate-controlled flight suite, and airfield cranes. While working for the U.S. Air Force, he was encouraged to pursue prosthetic research during his spare time. Together with another German scientist, Ulrich Henschke, and a financial contract with the Veterans Administration, the two worked on a hydraulic knee for the transfemoral amputee in Mauch's home basement. Although the first prototype of the swing-and-stance control was produced in just a few months after the initial Government request, satisfying the list of items that Mauch believed the amputee would want the knee to do as well as the list of things that they would not want the knee to do took 12 years: in his words, "just making refinements so it will do everything the amputee wants it to do and nothing he doesn't want it to do." After 11 years as a contractor with the U.S. Air Force, he retired to concentrate on the knee unit, and in 1968, Mauch introduced the hydraulic knee control, which is still the most widely used high-activity knee in the world [8].

In 1967, a small group of Vietnam veterans with amputations came together to extend their rehabilitation beyond the walls of WRAMC and get back to sport. They skied prior to losing their limbs in Vietnam and chose to call themselves the National Amputee Skier Association. They quickly broadened the sports in which they participated or helped others with disabilities enjoy, and through the years they finally became know as Disabled Sports USA (DSUSA). Today DSUSA and several other well established disabled sports organizations with Vietnam veterans still at the helm provide venues for recent returning war veterans to relearn competitive and recreational sports from certified instructors and athletes with disabilities.

In 1973, with the reorganization of the Veterans Administration, Rehabilitation Research and Development became part of the new Research and Development Office. The rehabilitation research budget had only modest growth since 1948 and was expanded as areas of research focus were identified [9].

On March 15, 1989, President George Bush renamed the Veterans Administration the VA, as the 14th department in the executive branch, ranking second in size to the DoD. The three major programs remained healthcare, benefits, and cemeteries.

By 1989, the VA supported an estimated one-third of all physician-investigators in the United States with less than 2 percent of the Federal biomedical research budget [17]. Currently, the Medical and Prosthetic Research annual budget for fiscal year 2007 is over $412 million. The VA currently supports over 5,100 researchers, of whom 76 percent are practicing clinicians who provide direct patient care to veterans. As a result, the Veterans Health Administration (formerly Veterans Health Services and renamed in 1991), which is the largest integrated medical care system in the world, has a unique ability to translate progress in medical science directly to improvements in clinical care [18].

Over the past two decades, the model of prosthetic care shifted from fabrication services being provided within the VA hospitals to private commercial prosthetic companies under contracts providing prosthetic care to veterans. The primary cause for loss of limb across the health community is no longer trauma, but rather diagnoses related to diabetes and dysvascular disease. As a result, the VA shifted research efforts to examine prevention of amputation related to dysvascular disease. In Seattle, Washington, the VA Center of Excellence in Amputation Prevention and Prosthetic Engineering has examined causes of amputation, interventions, and the comfort and mobility of veterans with amputations. The VA's Preservation-Amputation Care and Treatment (PACT) program was established in 1993 to meet the changing needs of the veteran population, reducing the number of amputations performed each year at VAMCs from 9,000 a year to fewer than 5,500 a year [19]. The PACT program has provided a model of care for people

considered to be "at-risk" for amputation that is now implemented in medical centers worldwide.

As Operation Iraqi Freedom/Operation Enduring Freedom veterans began to fill Ward 57 at WRAMC, the VA and DoD have once again come together to blaze the research trail into the newest frontier of prosthetics and into neuroprosthetics. Current microprocessor prosthetics and bionic technology are offered to returning soldiers. Teams of researchers are currently investigating methods to improve the interface between the human anatomy and prosthetic devices far beyond cineplasty and myoelectric arms with surface electrodes. Electrical signals are now received from electrodes surgically implanted within muscle tissue that allow thought-generated nerve impulses to control the upper-limb prosthesis. Thought-control prosthetics is moving even closer to development of neuroprosthetics where an amputee may one day simply think of a movement and the prosthetic action will occur without hesitation. A surgical procedure known as "osseous integration," first developed in Sweden, where direct skeletal attachment of a lower-limb prosthesis occurs, eliminating the need for a plastic socket, is now being investigated in the United States. In addition, research related to evidenced-based amputee rehabilitation is determining the most judicious therapeutic training to maximize both physical and prosthetic function. Without reservation, the most ambitious and potentially the most significant contribution to rehabilitation care is currently being developed through the VA's Polytrauma System, which has created a pathway of comprehensive care that is designed to address the physical and emotional needs of returning veterans requiring cutting-edge multidisciplinary rehabilitative care.

War is an unfortunate reality, sometimes without tangible results. One consistent consequence of war is improved medical care and the development of prosthetic technology. The loss of limb is devastating and life-altering, requiring young men and women returning to their homes to carry on in their altered bodies. The adjustment necessitates assistance with both emotional and physical healing. Since the times of the colonies, citizens of the United States have mandated that our Government be accountable for the care of our returning sons and daughters. Time to heal the physical wounds is relatively short compared with the time to restore a life back to what it once was. Providing substitute limbs and training that will afford veteran soldiers the ability to resume a quality of life thought to be lost is a challenge that many dedicated scientists and clinicians have enthusiastically embraced, often with the most simplistic of goals, seeing the pleasure on the face of someone whose life may have just become a little better.

The hard truth is that providing innovative prosthetic technology requires considerable funding, which can rarely be shouldered by private industry. As a result, Government funding for development and research is essential. The developments in prosthetic and rehabilitation training, initially focused on the military and veterans, always benefit the civilian population. In return, the prosthetic innovations developed by the private sector have served the military and veterans as well. In other words, a long-lasting partnership between the Government and private industry has always been productive.

Funding from the VA and other Federal programs has produced the knowledge and technology that can be found in the prostheses fabricated by prosthetists, in the rehabilitation programs prescribed by physical or occupational therapists, and in the medical care of an amputee provided by physicians. Together, the VA, DoD, civilian clinicians, and manufacturers worldwide have, over generations, developed the highest level of care for people with limb loss. What the future holds still lies in the imagination of the many dedicated researchers and developers.

George Bernard Shaw once wrote, "If history repeats itself, and the unexpected always happens, how incapable must Man be of learning from experience." The fact is with every war thousands lose limbs, Government funding spawns new developments never expected, and ultimately each generation of prosthetic devices and training further enhances the quality of life for the returning warrior and the civilian population. For some, this may be little solace, for others, the realization is that a government of the people has never stopped working for the people.

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