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Biomedical Technology: Supporting Movement

Petros Katsioloudis
Old Dominion University, pkatsiol@odu.edu

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Biomedical Technology: Supporting Movement

By Petros J. Katsioloudis

The main goal of these devices—to aid individuals with physical disabilities—remains the same, and their importance to humanity will remain vital.


Credit: Prof. Sankai, CYBERDYNE, Inc., University of Tsukuba.

Hybrid Assistive Limb (HAL®) system created by CYBERDYNE®.

Earlier this month, in a little-noticed ceremony in Japan, the world's first fully functioning robotic exoskeleton was launched. It is called the Hybrid Assistive Limb (HAL®) system, created by CYBERDYNE®, and will endow the wearer with abilities and strength he or she could previously only have dreamt of (Hornyak, 2008). According again to Hornyak (2008), the robotic suit® moves only when you want it to move, and it works by using sensors applied to the skin that detect the faint electrical currents sent by the brain through the nervous system when it commands a particular activity. These sensors are connected to a computer that interprets the signal and then sends its own command to electric leg and arm braces. Upon detection of the appropriate electrical nerve signal, HAL® moves a split second before the leg muscle itself. Along with the Hybrid Assistive Limb, several other discoveries that have the same purpose—to minimize the problems related to physical disabilities—have been on the rise.

Disability is a public problem (Gusfield, 1981) as well as a deeply personal one; functional loss necessitates the construction of artificial prosthetic devices and related research. According to the National Institute on Disability and Rehabilitation Research, an estimated 8.5 million children 21 years and younger have a disability (Jans & Stoddard, 1999). Loss of a limb is one type of disability. Of the estimated 1,285,000 amputees (excluding fingers and toes) in the United States in 1996, an estimated 70,000 were under the age of 18 (U.S. Department of Health and Human Services, 1999, p. 93). Amputations typically result from accidents with motor vehicles, lawn mowers, farm machinery, commercial machinery, gunshot wounds, or are secondary to burns or vascular insufficiency following fractures (Letts & Davidson, 1998). There are three main types of deficiencies that lead to the need for amputation and the use of prosthetics.

Congenital limb deficiencies are limb deficiencies that occur prenatally and are apparent at birth. It has been estimated that the overall incidence of limb deficiencies is approximately 6.0 per 10,000 live births, with upper limb deficiencies being three times more common than lower limb deficiencies (Wilson, 1998).

Meningococcal-induced *purpura fulminans* are sepsis-induced infections following viral, bacterial, or rickets infection (Adams & Hobar, 1998). Children who survive these kinds of systemic infections are at risk for microvascular injury as a result of the toxin buildup in the tissues. Removal of dead tissue prior to attempting limb reconstruction is recommended. Typically, the infected limbs are amputated. One report suggested that 46% of the children who survived the disease require amputations of two or more limbs (Adams & Hobar, 1998).

Malignant bone tumors of the extremity, particularly osteosarcoma and Ewing's sarcoma, are the most frequent cause of amputation and limb salvage surgeries in children and adolescents (Ries, Smith, Gurney et al., 1999 as cited in Nagaranjan, Neglia, Clohisy, & Robison, 2002).

Prosthesis is an artificial body part that helps where some function is lost or impaired, including anything from false teeth to aid in chewing to artificial joints to aid in walking. Prosthetics are man-made materials constructed to replace or augment diseased or damaged body parts in a safe, reliable, economical, and physiologically acceptable manner (Ravi & Alyar, 2006). Pictorial examples of splints and various assistive devices can be found among early civilizations, including ancient Egypt and Greece. The earliest known written reference to an artificial limb was made around 500 B.C.—Herodotus wrote of a prisoner who escaped from his chains by cutting off his foot, which he later replaced with a wooden substitute. Prosthetic care goes back to the fifth Egyptian Dynasty (2750-2625 B.C.); archaeologists have unearthed the oldest known splint from that period. The development of math, science, engineering, and technology of splinting and brace making, now referred to as the field of orthotics, paralleled developments in the field of prosthetics.

Technological Evolution

The technological evolution of prostheses for the lower limb took a long time. Prostheses were built almost exclusively by the exoskeletal method since most components were made of wood (Mora, Beratni & Pedrotti, 2006). In the early 1970s electromechanical prostheses with myoelectric control were available for the upper limbs. After about a decade, with the development of new and sophisticated materials (aluminum alloys, titanium alloys, and carbon fibers) and the integration of electronics, it was then possible to significantly improve the performance of prostheses, built with the so-called endoskeletal (or skeletal-modular) method (Mora, Beratni & Pedrotti, 2006).

There are several characteristics of materials that determine their suitability for use in prosthetics and orthotics. Table 1 lists the most important of these characteristics.

Table 1. Important Characteristics of Prosthetics and Orthotics Materials

Strength	Maximum external load
Stiffness	Stress/strain or force to displacement ratio
Durability	Ability to withstand repeated loading
Density	Weight per unit volume
Corrosion Resistance	Resistance to chemical degradation
Ease of Fabrication	Equipment and techniques needed to shape it

Note. Adapted from Shurr, G., & Michael, W. (2002). *Prosthetics and Orthotics.* NJ: Pearson Education, Inc.

Photo by Randy Montoya. Credit: Sandia National Laboratories.

FANCY FOOTWORK— Sandia liaison Mort Lieberman examines the latest version of a prosthetic foot created by U.S. private industry and checked by Russian nuclear weapons scientists—a cooperative project originated by Lieberman.

Prostheses for the upper limb can be classified as follows: passive prostheses (e.g., cosmetic hands), lightweight and simple to use, and active prostheses. There are three kinds of active prostheses: myoelectric prostheses, activated by electric signals produced by muscular contraction; kinematic prostheses, activated by bodily energy; and hybrid prostheses, which combine a myoelectric control of the hand function and a kinematic control of the elbow function. The main components of a prosthesis for the lower limb are: socket, liner (interface between the skin and the socket), knee (in prostheses for tight amputation), adapters, feet, and cosmetic finishing (Reykjavik, 2005).

As mentioned above, lower limb prostheses are built in two different ways: the exoskeletal method and the endoskeletal method. In the endoskeletal method the prosthesis has a carrying structure, inserted between socket and prosthetic feet. Prosthetic knees are classified on the basis of the mechanical or electronic control of flexion and extension. Knees with mechanical control have some limitations because they require continuous control by the patient. In prosthetic knees with electronic control, the device that generates the movement is controlled by a microchip. This kind of knee offers higher performance than a mechanical knee with regard to speed and safety. The exoskeletal method has now almost been completely abandoned. This kind of prosthesis is strong, lasting, and requires little maintenance but it cannot generally satisfy the functional needs of patients.

Researchers have been developing functional electrical stimulation systems for restoring lower extremity function in persons with paraplegia for many years. FES provides supportive forces for standing and propulsive forces for walking by exciting the intact peripheral nerves, causing paralyzed muscles to contract. Stimulation systems using surface or implanted muscular electrodes are capable of restoring mobility in the form of back and side stepping, walking, and stair climbing (Marsolais & Kobetic, 1988).

The reciprocal gait orthosis (RGO) is among the most widely used orthotic devices for the restoration of standing and walking in persons with paraplegia (D'Ambrosia, Solomonow & Baratta, 1995). This sophisticated mechanical orthosis provides a rigid exoskeleton that stabilizes both the trunk and lower extremities and permits reciprocal gait through mechanical linkages.

Prosthetics Today

Advanced neural prostheses are nothing like the past generation of prostheses, in which no interaction between the prostheses and the body's natural systems occurred. Current prostheses actually communicate with the electrical signals of the body and can help train or retrain the nervous system by transmitting signals to natural receivers inside the brain and nervous system. The human body can integrate neuroprosthetic technology to enable remarkable recovery.

Army 1st Lt. Ferris Butler takes a lap around the traffic circle just inside Walter Reed Army Medical Center's 16th Street gate before heading for Charlotte, NC, on May 20, 2008. Butler, who lost half of his right foot and his left leg below the knee in a bomb blast, was one of several wounded warriors who embarked on the 480-mile Road 2 Recovery bike ride.

Most of current research activity in motion restoration of paralyzed patients is related to functional electrical stimulation (FES). FES provides or improves functional movements of an abnormal neuromuscular system by the application of electrical pulses to the efferent or afferent peripheral nerve fibers. These pulses are supplied by either surface, percutaneous, or implanted electrodes, and they are externally controlled. In addition to immediate functional motor effects in some patients, FES may also improve volitional motor control of the paretic extremity and reduce spasticity even after electrical stimulation is discontinued. In cases of clinically complete paralysis, no improvement of volitional motor control can be expected, but daily electrical stimulation increases the contractile force of the hypotrophy muscle (Vodovnik et al., 1985).

Computer-Assisted Navigation

Computer-assisted navigation for total knee arthroplasty is a technology that is in its infancy in terms of development (Buehler, 2008). Since the introduction of this technology, it has continually evolved and grown into an important tool for modern orthopedic surgery. Its development was the result of collaboration between surgeons, engineers, and computer scientists. Because familiarity was generated with the use of computers in the operating room, a natural evolution occurred with its application in spine surgery (Picard, et al., 2004). Basic concepts eventually applicable to orthopedic surgery were identified, such as anatomic-based registration, use of intraoperative optical sensors, and a guiding system to aid surgeons in localization (Lavallée, et al, 1995).

Design Initiative for Students

As a part of this activity, students will fabricate, fit, maintain, and repair artificial limbs, plastic cosmetic appliances, and other prosthetic devices, according to specifications and under guidance of the instructor, who in this case will serve as the patient needing the prosthetic. To be able to complete this activity, students need to be able to read technical specifications to determine the type of prosthesis to be fabricated and materials and tools required in the production of appliances; therefore, a week of research on the related topic is suggested.

Starting this activity, students will receive the prescription from the patient explaining the type of disability so they can identify the appropriate prosthetic to be made. As a second step they will lay out and mark the dimensions of

Table 2. Correlation with *Standards for Technological Literacy*

The Nature of Technology	Technology and Society	Design
Standard 1: Students will develop an understanding of the characteristics and scope of technology.	**Standard 4:** Students will develop an understanding of the cultural, social, economic, and political effects of technology.	**Standard 8:** Students will develop an understanding of the attributes of design.
Standard 2: Students will develop an understanding of the core concepts of technology.	**Standard 5:** Students will develop an understanding of the effects of technology on the environment.	**Standard 9:** Students will develop an understanding of engineering design.
Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.	**Standard 6:** Students will develop an understanding of the role of society in the development and use of technology.	**Standard 10:** Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
	Standard 7: Students will develop an understanding of the influence of technology on history.	

Note. Adapted from the International Technology Education Association. (2000/2002/2007). *Standards for Technological Literacy: Content for the Study of Technology.* Reston, VA: Author.

parts necessary by using precision measuring instruments and templates. Once templates are made, students will saw, carve, cut, and grind wood, plastic, metals, or fabrics to make the parts, using rotary sawing and cutting machines, and hand cutting tools. Adhesive materials consist of glue, welding, bolts, and sewing to form prostheses. Students will make wax or plastic impressions of the patient's amputated area (given to them from the instructor), prepare a mold from the impression, and pour molten plastic into molds to form the cosmetic appliances, such as artificial ear, leg, or hand. Next, they will assemble layers of padding over the prosthesis to fit and attach the outer covering, which could be leather or fiberglass. When the appliance is ready to be painted, they will mix paints to find the right pigmentation color and then polish the finished device, using grinding and buffing wheels.

Students will use a number of different instruments and fixtures to test the prostheses just produced for freedom of movement, alignment of parts, and biomechanical stability. They may attach the prostheses to the patient's stump, applying their knowledge of functional anatomy, and may even instruct the patient on how to use the prostheses.

Activities such as the one described here are easy to correlate with *Standards for Technological Literacy: Content for the Study of Technology(STL)* (ITEA, 2000/2002/2007). See Table 2 for correlations with the *STL* standards.

Summary

As we look at the new inventions and innovations in the technology of medical prosthetics and orthotics, we can see that, through the years, they are becoming more technologically advanced. We see examples such as the Hybrid Assistive Limb (HAL ®), where sensors are applied to the skin to detect the faint electrical currents sent by the brain through the nervous system and transform them into movement; however, the main goal of these devices—to aid individuals with physical disabilities—remains the same, and their importance to humanity will remain vital.

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Petros J. Katsioloudis, Ph.D. *is Ambassador to Cyprus for the International Technology Education Association. He is an assistant professor in the Department of Occupational and Technical Studies at Old Dominion University in Norfolk, Virginia.*