FROM THE EDITORS’ DESK

Development of Upper Limb Prostheses: Current Progress and Areas for Growth

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Abstract
Upper extremity prosthetic technology has significantly changed in recent years. The devices available and those under development are more and more able to approximate the function of the lost limb; however, other challenges remain. This article provides a brief perspective on the most advanced upper limb prostheses available and the challenges present for continued development of the technology.

Background and Recent Technological Advances

Compared with lower limb amputations, major upper limb amputations are relatively uncommon, representing approximately 3% of amputees in the United States. Nonetheless, they primarily occur in people that are otherwise healthy and productive in society because 83% of major upper limb amputations are the result of trauma. People with amputation as a result of trauma tend to be younger, with 72% of them being <65 years of age. In recent years, injured soldiers have become an important portion of this population. As of July 2011, military facilities had treated 1286 major limb amputations (of which 21% were major upper limb amputations) as a result of Operations Iraqi Freedom and Enduring Freedom.

For many soldiers injured in the most recent conflicts, the upper limb prosthetic systems available were inadequate and did not allow them to return to the high level of function to which they were accustomed. Based on the need for a more functional upper limb prosthetic system for soldiers, the Defense Advanced Research Project Agency launched the Revolutionizing Prosthetics program in 2006 and funded the development of advanced upper limb prosthetic solutions.

As a result of these efforts, 2 prosthetic arms are under development: the DEKA arm, a myoelectric system to be controlled by noninvasive methods, and the modular prosthetic arm, a system with the potential to be neurally controlled. The DEKA arm was developed to be a strap and go system that includes more degrees of freedom (compared with previously available myoelectric systems), a new control scheme, multiple grasp options, and the ability to accommodate multiple amputation levels.

The primary goal of the second arm developed, the modular prosthetic arm, was to create an artificial hand/arm modular system with the potential to be neurally controlled and capable of restoring motor and sensory capabilities to people with upper extremity amputations. The design of this modular arm includes 17 motors with onboard motor controllers, sensor conditioning, and digitization resulting in 26 degrees of freedom. It also includes 21 absolute position sensors, 10 contact sensors, 14 torque sensors, 17 joint temperature sensors, 3 accelerometers, 3 force sensors, and 17 additional sensors. This system is still being optimized and is not commercially available.

From an engineering standpoint, the devices produced as a result of the Defense Advanced Research Project Agency initiative have movement capabilities that are close to those of a healthy arm. In spite of these advances, barriers still exist to exploit the full potential of these cutting-edge prosthetic devices. The main technological challenges that remain include the following: (1) controlling the prosthesis in a way that allows for seamless and intuitive use of the device to its maximal potential and (2) optimal suspension of such devices.

Device Control Mechanisms

Research on control systems has focused on both central and peripheral nervous system control of prosthetic devices. Recent
animal-model research has demonstrated that it is possible to capture brain signals to control a robotic arm.6 Similar studies in humans have demonstrated the potential of harnessing brain signals to control external devices. People with tetraplegia are able to control a robotic arm just by thinking of moving the paralyzed arm.7 Current technology requires invasive surgery to implant in the brain the electrodes to capture signals, and the durability of the electrode arrays is of concern.

For amputees, brain surgery for prosthetic control might not be acceptable. As such, research should concentrate on noninvasive brain signal capture or on capturing those signals at another point in the nervous system. The possibility of capturing signals from peripheral nerve terminals remaining at the amputation site is under study. Traditional myoelectric prostheses are controlled by contraction or cocontraction of residual muscles at the amputation site. The use of antagonistic muscles to control the device limits the number of activities that can be controlled simultaneously. In an attempt to capture nerve signals for prosthetic control, targeted muscle reinnervation surgery was developed. This surgical procedure reroutes the nerves that formerly transmitted motor signals to the distal limb to muscles in the residual limb.8 The nerves grow over a period of months into the portions of muscle they were implanted and generate signals that can be captured on the surface of the residual limb and used to control a prosthesis. Harnessing the output of otherwise unused nerves opens the possibilities for better prosthetic control. Conversely, it presents new challenges because these signals need to be interpreted appropriately and translated into functional movement of the prosthesis. Research on signal recognition and algorithms for translating those signals into functional motion of the prosthesis is important because it will likely result in improved prosthetic control and improved functional gains.

**Device Suspension**

Arguably, the last hurdle to overcome in achieving a fully functional prosthesis is its attachment to the user. Current systems are attached externally with a socket that fits over the residual limb. Advances in socket and suspension systems continue to allow prosthesis users to have longer wearing times. For others, the suspension systems are uncomfortable and limit wear time.

Osteointegration has been trialed to provide prosthetic suspension for people with amputations.9 The use of the implantable portion of the prosthesis has largely been limited by the risk of infection at the biologic-mechanical interface. Contrary to joint replacement prostheses (eg, hip or knee replacements), implanted devices to provide prosthetic suspension are partly in the body and partly exposed to the elements. The main challenge for a more permanent attachment of the prosthesis is the lack of compatibility between biologic and nonorganic materials.

**Other Challenges**

The availability of an advanced upper limb prosthesis has the potential to revolutionize the rehabilitation of people with upper limb amputations over the next few decades; however, it also presents some challenges that are not addressed by technology. It is important to mention that functional gains are not dependent only on the capabilities of the device used or the ability of the user to control it and wear it comfortably; in addition the devices and training for using them also needs to be accessible. Currently, some of the most advanced devices appear best suited for a select group of highly functioning patients; perhaps others would benefit from simpler systems. Studying the performance of advanced devices in multiple populations, including nontraumatic amputees, can provide some key insights as to the optimal devices to use based on the underlying patient characteristics. The training necessary to effectively use advanced prosthetic devices is not trivial. The complexity of amputee rehabilitation is being addressed by the development of consortia with multiple research interests (see the Major Extremity Trauma Research Consortium website10 as an example). Multidisciplinary rehabilitation teams will continue to be necessary to facilitate the process. The basic tenets of what we do will remain: providing the best-suited device and training to maximize the function and quality of life of our patients.

**Keywords**

Amputation; Amputees; Arm prosthesis; Rehabilitation; Technology; Upper extremity

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