Advances in Upper Extremity Prosthetics

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KEYWORDS

• Prosthetic • Prosthesis • Upper extremity • Electrocorticography • Myoelectric

KEY POINTS

- Individually powered, myoelectrically controlled digits have opened the door to multifunctional, more lifelike prosthetic hands and partial hands.
- The future of prosthetic limb control may come from direct central nervous system control or from peripheral nervous system control via targeted reinnervation or neurointegration.
- The full potential of prosthetic limbs, no mater how powerful and nimble they become, will not be realized until the limbs can confer sensibility to their user.

INTRODUCTION

Lower extremity prosthetics have evolved to the point at which a bilateral below-the-knee amputee may be competitive with the best runners in the world.[1] The same success has not yet graced the upper extremity amputee. It was not long ago that the best we could offer a patient was a clumsy body-powered hook that provided one function: either active opening or closing (**Fig. 1**). Multiple task-specific terminal devices were required to accomplish simple daily tasks, requiring the patient to change these devices as needed.

Myoelectric devices offered more functionality and control because of active opening and closing, but the devices were heavy, limited to individuals with more proximal amputations (at least proximal to mid forearm), and short on battery life. The strength and speed of the limb is difficult to control and is limited by the properties of the sensors, motors, and bearings.

Another difficulty has been that neither myoelectric nor body-powered prostheses replicate the appearance of a normal hand. Passive or aesthetic prostheses may be worn for special occasions, but confer no function other than as an insensate extension of the residuum.

Innovations in prosthetics over the last several years have succeeded in improving several critical parameters: control, attachment, functionality, speed, size, weight, and power. Advances in motors, bearings, batteries, and materials have allowed for the development of devices that are easier to don, retain their charge longer, offer more control, are more versatile, and are more durable.

Better mechanics and materials have also advanced passive prostheses, which may now be made to have lockable, passively mobile joints. A posable hand is advantageous as a helper hand for performing simple tasks, and may be sufficient for a high-functioning unilateral amputee. Aesthetically, these limbs can be made to mirror the patient's intact arm, down to the hair and subcutaneous veins.

Patients will only use their prosthesis if they perceive an improvement from wearing it. Beyond improvements in function, patients also cite improved social integration, self-image, and perception by others. As prosthetics improve, not only functionally but also aesthetically, the threshold for acceptance will therefore be lowered. Patients who previously shunned prosthetic

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Fig. 1. "Artificial limb" worn by a gunlayer on the destroyer HMS Doon during World War I. Note the great attention to detail and the craftsmanship involved. However, the utility of the limb would have been limited by the simple hook terminal device and the weight of the materials (steel and leather). (*Courtesy of* Dan A. Zlotolow, MD.)

use are inquiring about cutting-edge prosthetics they have read about online or have seen on television.

These advances have not been inexpensive and likely would not have been possible so quickly without a commitment from the US Government. Improved front-line medical care combined with effective body armor in the Iraq and Afghanistan conflicts resulted in many soldiers returning home alive but with missing or severely compromised limbs. In 2006, the Defense Advanced Research Projects Agency (DARPA) responded with the Revolutionizing Prosthetics program. The Contineo Multi-Grasp Hand from Orthocare Innovations (Oklahoma City, OK) will be the first available commercial product resulting from this program.

MECHANICAL IMPROVEMENTS

The most advanced prosthetic upper limbs on, or soon to be on, the market are the i-Limb Ultra hand (Touch Bionics, Hillard, OH), the BeBionic V2 hand (RSL Steeper, Leeds, UK), the Contineo Multi-Grasp hand, and the Michelangelo hand (Otto Bock, Duderstadt, Germany). All offer much greater functionality than any previous single device. All also rely on myoelectric control with 1 or 2 sensors. Different grip, pinch, and other functional patterns may be interchanged by a combination of myoelectric firing patterns (such as a short series of 2 or 3 contractions) or by manually adjusting the thumb position. The Contineo Multi-Grasp hand also features powered thumb abduction and adduction. Some offer a fully rotating forearm and wrist flexion/extension, whereas other terminal devices require manual wrist positioning.

The great advance that has allowed for the development of these hands has been the development of individually powered digits. Because the fingers are individually powered, a great variety of pinch and grasp patterns is possible. The user may now perform a 3-jaw chuck, power grip, tip pinch, key pinch, and many other patterns without the need to switch terminal devices. Also, individual finger torque control assures that the hand wraps around objects while providing equal pressure at each digit (**Fig. 2**). Variable pressure application allows the user to pick up an egg and a briefcase with the same terminal device, letting the user hold any object, regardless of contour, with the full grip of all the digits. It also assures a more natural-looking grasp pattern.

Aesthetically, the uncovered hands look like science fiction robot/cyborg hands (**Fig. 3**). Some users prefer to leave the components as exposed as possible, with only a grip-enhancing translucent silicone covering to showcase the cyborg look. For those who prefer discretion, silicone skin-colored coverings are also available in up to 10 different skin tones. Custom hand-painted "skins" are also available at a higher cost. Because the hands are all designed to simulate the positions of an intact hand, the hands look remarkably lifelike with a well-matched skin

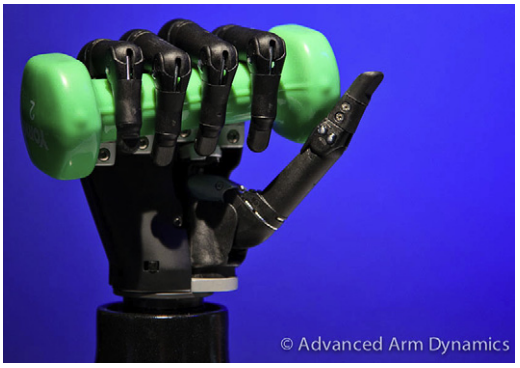

Fig. 2. Myoelectric prosthesis (i-Limb Ultra; Touch Bionics) showing the capability of each of the fingers to close around an object independently while applying the same amount of pressure. (*Courtesy of* Advanced Arm Dynamics, Redondo Beach, CA; with permission.)