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The Development and Future of Prosthetics Controlled by Myoelectrical Impulses

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Abstract

Objective: To document the developmental history of prostheses to better understand the circumstances that led to enabling amputees to experience touch through sensory reinnervation surgery in conjunction with an innovative bionic arm; and to prove that sensory reinnervation is the key to further progress. Methods: The topic was researched extensively using scholarly databases and read relevant accounts of experimental studies and outcomes. Results: By examining the progress made in the field of prostheses, it has been determined that a sensory reinnervation technique is at the forefront of bionic limb technology and predict that it will continue to be utilized and perfected in the future.

List of Acronyms:
TMR- Targeted Muscle Reinnervation
MPL- Modular Prosthetic Limb

A prosthesis is a device that replaces a biological component of one's body. A.B. Kinnier wrote, "the objective is to make the prosthesis as nearly possible an extension of the wearer's will rather than am external power tool" (Parry, 1968). Scientists have been striving to create a prosthetic that can replace the function of the invalid component indistinguishably. This is the highest level of prosthetic aspiration (Craver, 2010). Through harnessing the brain's bioelectrical impulses with electrodes, scientists began tinkering with the idea of a mind-controlled prosthetic. Through many experiments, engineers worked to refine this method and used peripheral nerves attached to healthy muscles to collect directional input, resulting in myoelectrical control of bionic attachments without the need for electrode implantation. Recently, researchers have found a way to use a prosthetic as a relay device between outside stimuli and the brain. Engineers have entered a phase of devices that, from a functional perspective, can almost compete with a biological limb. The use of myoelectrical impulses and sensory reinnervation methods to control bionic limbs is redefining the field by yielding prosthetics that can receive input in addition to formulating output.

Methods

Various peer reviewed sources were gathered predominantly through JSTOR along with a plethora of electronic sources, such as research websites and lab produced videos, to collect data for this paper. I read papers recounting the results of relevant experimentation that were published throughout the decade to gain a sufficient comprehension of the topic and to produce a timeline of development.

Results

In examining the implications of a prosthetic which utilizes revolutionary technology, its developmental history must be examined. An early form of artificial limbs, known as body power prosthetics, works by harnessing the power of a joint to produce a small range of motion below the designated attachment site. While they were developed during the civil war, many people use them today as a cheaper alternative to the cutting-edge prosthetics. However, scientists and engineers have been working to find alternate methods of input to generate a more precise range of motion. As John T. Scales, Department of Biomechanics and Surgical Materials at the University of London, writes, the concept of an arm controlled by myoelectrical currents originated in Britain during the mid-1950's (Scales, 1965). A Science News article published in 1966 discusses research done at Litton Systems in Toronto regarding capturing lost motor impulses in otherwise idle muscles. While the concept of myoelectrical control is more than half a century old, it took decades to make real strides in harnessing the brain's neural signals, and eventually, adapting to those produced by the muscles (Society for Science & the Public, 1966).

In the past ten years, the development of prosthetics that respond to bioelectrical input has evolved through trial and error. In order to match neural firings to specific motor commands, scientists first had to discover which brain areas encode for each motion. Markus Hauschild, Grant H. Mulliken, Igor Fineman, Gerald E. Loeb, and Richard A. Andersen, a group of researchers involved in biology, neuroscience, and engineering, used two rhesus monkeys to map the brain's motor control areas. They did this in attempt to refine the motor control of those fitted with electrodes on their brains. The researchers discovered that while the motor cortex controls individual and immediate movement, the posterior parietal cortex gives rise to signals related to the goal and trajectory of a motion. After this breakthrough, researchers understood which areas of the brain could be targeted for the reading of neural impulses related to movement. Once scientists had made this discovery, the developmental stage of neural prosthetics began. These prosthetics are intended to record the brain's electrical signals from the sensorimotor pathway and project them to an external device (Hauschild, et al. 2012).

At the University of Pittsburgh, neurobiologist Andrew Schwartz developed a small electrode that is to be implanted into the brain in order to read its electrical impulses.

He detected patterns in neural firings and matched them with specific commands of motion. Schwartz succeeded in having patients move a robotic arm, though with a very limited range of motion (Gaidos, 2011).

J. Andrew Pruszynski and Jorn Diedrichsen predicted in 2015 that the future of prosthetics would revolve around improving the durability of electrode implants, developing stimulation protocols on the prosthetic to simulate touch, and working on isolating single nerve cells. They assumed that recording neural impulses directly from the brain would be the focus of researchers and engineers for years to come. Pruszynski and Diedrichsen expected patients to receive recording chips that would be implanted in the posterior parietal cortex and the motor cortex, allowing for precise movements and the ability to create an overarching goal for the movement (Pruszynski, Diedrichsen, 2015).

S. Musallam, B. D. Corneil, B. Greger, H. Scherberger, and R.A. Anderson conducted various experiments in the area of neural encoding for prosthetic use. They attempted to decode intended goals of trajectory and use their discovery to prove the viability of a prosthetic device which not only responds to a neural firing but anticipates subsequent ones. Using monkeys as tests subjects, the researchers placed electrodes on the simians' brains and mapped the various neurons which fire when an intended goal, such as reaching for an object, is actualized. They believe that this technology will make it easier for patients to acclimate to bionic limbs by expediting certain series of motion (Musallam, et al. 2004). Yet the drawback of having to permanently imbed electrodes into the brain has made their discovery worthwhile on concept though not in practical application.

However, this method of directly implanting electrodes and various other devices in the brain proved to be undesirable, since it requires the patient to undergo a complex surgery on multiple contact points of brain tissue. It would require hundreds of microscopic wires to identify input from microscopic individual nerves. Another issue present in this technique is that it renders the possibility of sending sensory feedback to the brain unreasonable, since it would be nearly impossible to convey an electrical signal of a specified magnitude to a particular neuron through an electrode. Due to the inconvenience inherent in this process, scientists began looking at alternate possibilities to harness the brain's signals.

While attaching electrodes to the brain may elicit satisfactory motor control, the process of doing so is incredibly complex and intricate. In response to this challenge, scientists began exploring other venues of collecting nerve impulses farther away from their site of generation. The concept is as follows: The body starts a command in the brain, then it travels down the spinal cord to nerves in the periphery, while sensation takes the same pathway but in the opposite direction. When a limb is lost, the neural signals are generated by the brain and travel down to the point where the prosthetic attachment site would be. Since muscles amplify nerve signals by about 1000 times, fewer sensors would be necessary to interpret signals and relay commands if electrodes would be attached to muscle nerves. This would be much safer and more practical than placing them directly onto the brain (Kuiken, 2011).

In response to this issue, scientists spent years perfecting a method of removing a nerve from the site of amputation and reinnervating it to a stronger muscle. Todd Kuiken and Gregory A. Dumanian, MD, of Northwestern Memorial Hospital, pioneered the development of a surgical procedure that would accomplish this feat (Barlow, Burt, 2021). Reinnervation works by taking a nerve that is at the site of amputation and relocating it. Therefore, a nerve that was part of a severed arm may be reattached to the chest, where a command to open a hand will cause a relaxation in the chest muscles (Kuiken, 2011). The contraction produces much larger signals and the electrical activity is then recognized by electrodes which translates the information into movement of the prosthetic (Bate, 2013). This provided a major step forward regarding the level of control awarded to amputees through their prosthetic. Targeted muscle reinnervation allows for more intuitive control of a prosthetic through creating additional control sites.

In further utilization of the muscle reinnervation technique, engineers began working on the next level of prostheses advancement: receiving outside sensory information. Since they were able to create a prosthetic capable of receiving information from the brain, they began to wonder if the reverse is possible as well.

The concept of prosthesis receiving stimuli and bypassing damaged organs to deliver an impetus to the brain has been achieved in various areas previously, which inspired scientists to achieve the same with mechanical limb prosthetics. In Europe, engineers have discovered a way to bypass an inferior retina to project images. Wires and coils are attached to chips that are placed in the back of the eye and participants wear goggles which are fitted with a miniature video camera to captures images that are projected into the eye via laser technology within the goggles. There, the photovoltaic chips send the signals to the visual cortex of the brain where a picture is produced and can be visualized (Ehrenberg, 2012). Another form of retinal prosthetics uses a sensor to translate visual stimuli into a pattern of impulses that is akin to those produced by natural action potentials (Nirenberg, Pandarinath, 2012). Additionally, a vary common example of this phenomenon would be cochlear implants, which bypass damaged structures in the ear to directly stimulate the auditory nerve by collecting sounds and emitting impulses that mimic those typically experienced during hearing (Mayo Clinic, 2020).

Researchers Gregg A. Tabot, John F. Dammann, Joshua A. Berg, Francesco V. Tenore, Jessica L. Boback, R. Jacob Vogalstein, and Sliman J. Bensmaia, used Rhesus macaques to demonstrate how using intracortical microsimulation of the primary somatosensory cortex can give amputees a sense of touch. They did this by first locating the areas of the somatosensory cortex which respond to the various digits on each hand. After this was achieved, Tabot and his associates worked to produce sensations on the prosthetic limb that can be translated to the monkeys' brains though the electrodes. In this study they used to Modular Prosthetic Limb developed by The Johns Hopkin's Applied Physics Lab to detect these mechanical impulses (Tabot, et al. 2013).

Dr. Michael Mcloughlin, the chief engineer at the Physics lab, had been working on neural prosthetics for years when he finally succeeded in building the MPL, a machine capable of obtaining external impulses. Under the funding and auspices of the Defense Advanced Research Projects Agency, which started the Revolutionizing Prosthetics Program in 2005, Mcloughlin worked to achieve the organization's goal: to create the MPL, the world's most advanced prosthetic arm (Mcloughlin, 2016). When the Modular Prosthetic Limb interacts with an object, over 100 sensors, such as force, contact and temperature sensors, send information back to the brain, giving users the sensation of touch (The mind-controlled bionic arm with a sense of touch, 2016). With their trials, Tabot et al. were able to stimulate touch using the MLP with such accuracy that it was indistinguishable from the tactile sensation produced by the sensory nerves in the monkeys' paws. Although this was major progress in the area of sensation, engineers sought to find a method that avoided cranial electrode attachment (Tabot, et al. 2013).

Kuiken and his team conducted experiments which proved that the direct stimulation of a reinnervated nerve in the chest through pressure and temperature would produce a sensation that the patient would attribute to their phantom limb. He believed that eventually sensors would be placed on the prosthetic to accept sensory information and project it onto the reinnervated nerve (Kuiken, et al. 2007).

The assumption of Kuiken's team proved correct, for just a few years later, Dr. Ajay Smith, in conjunction with the Johns Hopkins' Applied Physics Lab, invented a surgical procedure that allows for the acceptance of sensation by the MPL through peripheral nerves. Smith invented a sensory reinnervation technique, wherein he locates the severed nerve which normally accepts tactile stimuli and implants it in an alternate area. Targeted sensory reinnervation gives them a sense of touch that isn't contingent upon electrodes being attached to the brain. Melissa Loomis, an amputee who underwent a sensory reinnervation procedure that remapped her nerves which respond to touch, became one of the first people in the world to acquire a sense of touch through her prosthetics. The sensors of the MPL then interact with those placed on the patient's reinnervated nerves that corresponded to the digits of the hand, allowing them to experience a form of touch (The mind-controlled bionic arm with a sense of touch, 2016).

Additional studies have been conducted in order to understand a patient's acclimation to highly sophisticated prostheses. Kelly L. Collins, Arvid Guterstam, Jeneva Cronin, Jared D. Olson, H. Henrik Ehrsson, and Jeffrey G. Ojemann conducted an experiment to see if "ownership" of an artificial limb can be achieved. Learning from the studies conducted on primates, these researchers already understood that a prosthetic can be supplanted with sensors to receive input directly from the primary somatosensory cortex. However, they wanted to see if the two human participants in their study would feel as though the prosthetic hand was their own by bypassing the peripheral nervous system. They found that the participants' brains fell for the illusion of ownership regarding their artificial limb (Collins, et al. 2017). This was a step forward in understanding how seamlessly amputees would be able to acclimate living with a bionic body part and how electrical stimulation of the somatosensory cortex can play a role in the illusion. However, regardless of how sophisticated the world of prosthetics will get, there will always be a need for adaption, which will vary by patient (Marks, Michael, 2001).

Discussion

As with any study attempting to showcase the forefront of technological development, those explored above run the risk of eventual obsoletion. The same way that attaching electrodes to read neural impulses was at some point a cutting-edge technique, sensory reinnervation may one day prove to be an inferior mode of prostheses control. The next step may be to increase the level of tactile sensor reception and one day have prosthetics distinguish between materials, which may require an alternate method of sensory perception. However, as seen through the studies by Collins and associates19, patients already find a prosthetic indistinguishable from its biological counterpart, rendering future advancements open-ended. Since scientists have achieved their functional goals, they must now find a way to mass produce these prosthetics and increase their availability to all those in need.

Conclusion

By exploring the long chain of progress attached to the field of prosthetics, one can better understand and appreciate the dedication necessary to produce a bionic arm that is controlled through myoelectrical impulses. Additionally, we can predict that the future of development will probably revolve around integrating Smith's sensory reinnervation method on a larger scale and attempting to refine bionic limbs by equipping them with additional sensors above those for pressure and temperature. However, we must understand that science and engineering are ever-evolving disciplines. Just as cerebral electrode placement had been improved upon and later overshadowed, sensory reinnervation may one day be replaced by systems currently not within our realms of imagination.

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