Brain controlled robotic arms

Advancements in prosthetic technology

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ABSTRACT

A prosthesis is a medical device used to replace a missing body part. These devices are designed to restore both functionality and form to the patient. The field of prosthetics has a rich history that extends back centuries. Recent advancements have led to the development of more sophisticated and innovative prosthetic technology, such as brain controlled myoelectric prosthetic limbs. While current prosthesis options such as passive prostheses and body-powered prostheses have their respective limitations, myoelectric prosthetic limbs offer an unheralded level of functionality for patients. This article will discuss current and ongoing advancements in the field of prosthetics, with specific regards to artificial limbs. There will be discussion of the history of prosthetics and current prosthesis options for patients. In addition, there will be an assessment of their respective benefits and limitations.

INTRODUCTION

A prosthesis is a device that replaces a missing body part lost to a disease process, congenital abnormality, or trauma. Prostheses are typically used to correct deficits in functionality resulting from limb loss. The cosmetic appearance of a prosthesis has proven equally important, concealing injuries and mimicking real limbs. The field of prosthetics has grown to include neuroprosthetics such as cochlear implants and bladder control implants. While the history of prosthetics extends back 950 to 710 BCE, in recent times we have witnessed great advances in the utility and functionality of prosthetic limbs.¹ This is due mostly to advancements in our understanding of neuroscience and robotics. The development of brain-controlled arm and hand robotic prostheses has been a major breakthrough in the field. While the costly and novel nature of these newly developed prostheses has made the technology inaccessible to most of the population, it is hoped that the devices will return a new level of functionality and independence to patients. This article will discuss advancements in artificial limbs, particularly in the realm of brain-controlled myoelectric prosthetic hands. We will also discuss current limitations and barriers in available limb prosthetics.

A BRIEF HISTORY OF LIMB PROSTHETICS

Prosthetic limbs have had a long and innovative history. The earliest discovered example of a prosthesis was a big toe belonging to an Egyptian noblewoman dated 950 to 710 BCE. It is asserted that the toe was created due to the importance of traditional Egyptian

sandals with specific regards to identity and religion. While the absence of the big toe was unlikely to impair the woman's physical functioning, the importance of wearing thonged sandals was enough to warrant its construction and application. Here, we see that the first use of a prosthesis was to complete a sense of "wholeness" and identity, a sentiment that remains pertinent to contemporary prosthetics. As time and understanding of materials progressed, we began to see the use of a prosthesis in its contemporary sense to restore both form and functionality. Pliny the Elder famously described ancient Roman general Marcus Sergius (218 to 210 BCE) who, upon losing his right arm in battle, fashioned an iron hand with which he could grasp his shield and remain in battle.²

Since these early forays into the field, prostheses have taken all shapes and forms, ranging from peglegs to gold hands based on available materials and socioeconomic status. Prosthetic technology has advanced in tandem with the development of amputation techniques. For example, in 1831 Sir James Syme developed the ankle-joint amputation technique that was capable of sparing the heel pad in a foot amputation.³ This not only allowed natural leg muscle to bear most of the weight but also for the easy design and fitting of a prosthetic foot to enhance balance. Advancements in prosthetic technology have built upon each other and on discoveries in robotics, culminating in the modern-day development of brain-controlled robotic prosthetic arms.

CURRENT OPTIONS IN LIMB PROSTHETICS

There are several options for prosthetic limbs currently available. Deciding which prosthetic limb is the right fit for a patient is often a collaborative effort between prosthetists, surgeons, physical therapists, nurses, and other physicians. The decision is highly variable depending on many different factors. For example, patients must consider their lifestyle and personal preference for limb rehabilitation, while physicians must consider prospective risks, prospective fit, and potential requirement for further surgery, among other considerations.⁴ Broadly speaking, however, patients may choose between a passive prosthesis, conventional or body-powered prosthesis, electrically powered prosthesis, and the novel myoelectric prosthesis.⁵

Passive prostheses are typically used for cosmetic purposes and often mimic the look of a natural limb. While lightweight and flexible, they offer very little functionality with respect to actions such as grip, manipulation, and balance.⁶ They are typically recommended when comfort and appearance are the primary concern for the patient. Conversely, body-powered prosthetic limbs offer greater functionality and consist of a more complex interface but are not as cosmetically pleasing in comparison to their passive

counterparts. Body-powered prostheses function through a system of cables such that orienting the body in certain positions allows for control of the prosthetic terminal device, typically a hook or hand.⁵ Based on the results of patient questionnaires, Biddis et al determined how the design priorities of prostheses meet patient needs.⁷ Both passive and body-powered prosthetic limbs appear to meet their respective designs goals, yet have flaws with regards to function and appearance respectively. As many as 36% of prosthesis users suffer from sores, abrasions, and bruises as a result of poor fit, limiting the amount of time that the prosthesis can be worn.⁸

MYOELECTRIC PROSTHETIC LIMB

The myoelectric prosthetic limb has been one of the greatest innovations in prosthetic technology in the history of the field. They provide the highest degree of functionality of all currently available prosthetic limbs, while also mimicking the form of the human body. Unlike body-powered or electrically powered prostheses, they are capable of executing complex movements in an intuitive manner similar to the operation of a natural limb. They harness electromyographic (EMG) signals generated through neural impulses in skeletal muscles that reflect the intention for movement of the user.⁹ Electrode sensors located at the interface between the prosthesis and the human body record EMG signals. These electrodes can be on the skin surface, or surgically implanted intramuscularly in order to collect signals.¹⁰ There are different benefits that the different electrode placements confer. Surface electrodes can record activity from relatively large portions of muscle tissue, are easier to manage, and have lower cost. Conversely, intramuscular electrodes provide focal recordings from deep muscles relatively free of crosstalk, allowing for more precise activation.¹¹

Following detection, the amplitude and frequency of EMG signals is processed through a myoelectric control scheme before initiating limb movement. A wide variety of control schemes have been developed, each with their own complexities. There are 3 common control schemes: on-off myoelectric control, proportional myoelectric control, and finite state machine control. The simplest control scheme is on-off myoelectric control. This control scheme initiates movement once the EMG signal reaches a predetermined threshold.¹² Upon actuation, the hand is operated at a constant speed, independent of the level of EMG signal or contraction. In the proportional myoelectric control scheme, the voltage applied to the motor powering the hand is proportional to the intensity of EMG signal received at the electrode.¹³ This allows for fast versus slow movements and more precise control of applied grip and contraction force. Finally, the finite state machine control involves the defining of pre-set hand postures and relates them to predefined EMG inputs.⁹ While this form of pattern recognition allows for smooth integration of prosthetic movement, it restricts the multifunctionality of the prosthetic hand to only the pre-programmed movement sets defined by software. While advancements are certainly apparent with regards to control schemes, many improvements are required to increase the multifunctionality of these devices. Outside of the 3 discussed here,

there are numerous additional control schemes, some with higher level processing such as pattern recognition control.

While the development of myoelectric prosthetics has been a boon to patients suffering from limb loss, there are a number of drawbacks that have limited their widespread utility. The primary limitation is undoubtedly cost. A body-powered prosthetic arm may cost approximately Can\$5500, but its myoelectric counterpart may cost Can\$30 000 to Can\$80 000.¹⁴ Furthermore, repair of these hands typically requires proprietary components and trained professionals, which can further drive up costs. Another current limitation of myoelectric prosthetic arms is the lack of sensory feedback to the user. Human control of grasping and manipulation relies mostly on proprioception and tactile feedback. As a result, most users of prosthetic arms rely on sight to drive control of limb movement and force, as the limbs themselves do not provide sensation.¹⁵ There has been a variety of attempts to provide forms of sensory feedback in prosthetic systems, yet none have proven effective.

Table 1. Prosthetic limbs: summary of function, advantages, and disadvantages

Type of Prosthesis	Control and Movement	Advantages ^a	Disadvantages
Passive	<ul style="list-style-type: none"> Prosthesis is kept static, no movement 	<ul style="list-style-type: none"> Cosmetic in nature Aids in balance and simple movements (carrying, etc.) Very little maintenance required Psychological advantages – enhanced sense of wholeness, self-confidence 	<ul style="list-style-type: none"> Poor utility for complex movements (grasping, gripping, etc.)
Body-powered	<ul style="list-style-type: none"> Movement powered by cables connecting to different body parts Movement of prosthesis attachment point, for example a healthy shoulder, will move the prosthesis 	<ul style="list-style-type: none"> Relatively light Lower initial costs Easy maintenance that can be provided by user rather than professional 	<ul style="list-style-type: none"> Unnatural appearance such as hook attachments can have negative social and psychological impacts Dependent on muscle strength for optimal use Some body movements impact cable tension, prohibiting certain motions Can feel bulky and unnatural leading to limb discomfort
Electrically powered	<ul style="list-style-type: none"> Movement powered by motors Motors controlled through various schemes, most common of which being the toggling of switches or buttons using healthy limbs 	<ul style="list-style-type: none"> Can be made to appear as a natural arm Larger functional range of movements based on predetermined movement sets (ex. gripping, grasping) Not dependent on muscle strength for operation 	<ul style="list-style-type: none"> Higher cost Heavier, leading to fatigue Poor amputation architecture can prohibit use Battery dependent Repair can be expensive and require professional assistance Movements can require complex sequence of switches and buttons – steep learning curve
Myoelectric	<ul style="list-style-type: none"> Movement powered by motors Sensors pick up electrical signals generated by residual muscle at attachment point Electrical signals processed through various control schemes to activate motors 	<ul style="list-style-type: none"> Can be made to appear as a natural arm Larger functional range of movements based on naturally generated electrical signalling – similar to natural limb movement Intuitive use due to similarity to natural limb 	<ul style="list-style-type: none"> May be prohibitively expensive Heavier, leading to fatigue Poor amputation architecture can prohibit use Battery dependent Repair can be expensive and require professional assistance

^aNote that the optimal prosthetic limb for an individual can also depend on other factors, including the extent of damage to residual limb, level of independence, profession, and level of activity.

CONCLUSION

The field of prosthetics has had a long and inventive history. The purpose of prosthetic limbs has evolved from completing a sense of wholeness and form, to restoring function from a lost limb, to a combination of both in contemporary medicine. While there are several readily available options for prosthetic limbs such as passive prostheses and body-powered prostheses, the myoelectric prosthetic limb has been one of the biggest developments in contemporary prosthetic technology. Myoelectric prostheses allow for higher degrees of functional independence with a more precise control over the prosthesis with regards to manipulation, grip, and balance. While there are some limitations to myoelectric prosthetic limbs, such as the high price and lack of sensory feedback, current research seeks to facilitate the improvement and widespread implementation of this technology.

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