Controlling myoelectric prosthetics through the use of nerves and muscles

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ABSTRACT

People who are fitted with prosthetics due to the loss of a limb may have difficulty performing simple daily tasks that may be taken for granted, such as tying shoe laces or opening a jar. The prosthetics used today are often rigid, inflexible, bulky molds that are standardized and have minimal degrees of freedom. The development of myoelectric-controlled prosthetics has greatly facilitated the performance of daily tasks by the user, although the best method for controlling these prosthetics is still to be determined. This paper compares and discusses three major advancements in prosthetic control – electrode arrays, osseointegration, and targeted muscle reinnervation – by examining stability, accuracy, and movability of the user controlling the prosthetic. It is determined that the most beneficial solution for the user would be the implementation of osseointegration and targeted muscle reinnervation combined. This combination would allow the creation of a prosthetic that would increase the accuracy and stability of the artificial limb, and that would provide a more permanent and long-term solution. In addition, the creation of a myoelectric-controlled prosthetic that incorporates these two methods would allow for further research and would increase the stability, accuracy, and movability of the user.

INTRODUCTION

The performance of simple daily tasks is often a challenge for those who are impaired by a physical disability. This physical impairment may be due to the loss of a limb, particularly an upper limb, which may be caused by illness, accident, injury, or war, among other reasons. The loss of an arm often decreases the individual's ability to perform daily tasks, such as tying shoe laces, holding various objects, or typing efficiently. Transporting, manipulating, and feeling objects are the primary functions of the hand and without these abilities someone's life may be drastically changed [1]. Many prosthetics do not allow a sufficient range of motion or usability by the user because they do not permit the artificial hand to grab objects or to be controlled easily. Growth in the biomedical field has allowed the creation of myoelectric prosthetics that facilitates the control of the prosthetic by the user's own muscles and nerves. These advancements permit a larger range of motion and an increased degrees of freedom.

This paper will study three main advancements in myoelectric prosthetic control: electrode arrays, osseointegration, and targeted muscle reinnervations. By comparing and contrasting the stability of the prosthetic, the accuracy of control, and the movability of the user, the most crucial advancement in myoelectric-controlled prosthetics can be determined. The comparison of these three methods will determine that the combination of osseointegration and targeted muscle reinnervation would allow greater advancements and development in myoelectric prosthetics, rather than the use of electrode arrays, osseointegration, or target muscle reinnervation independently.

BACKGROUND

Although the creation of various artificial limbs has improved over time, many prosthetics are still rigid, inflexible, and difficult to use. Characteristics such as dexterity, strength, and size of the hand need to be considered during the designing of artificial limbs in order to match those of a human hand [1]. The hand has 24 degrees of freedom, which allows for the completion of specific and complex tasks, whereas many prosthetics have 1 to 6 degrees of freedom [1]. With the knowledge of the constraints that should be applied to design a functional prosthetic resembling a human hand, the creation of myoelectric-controlled prosthetics has improved the versatility of artificial limbs through increased range of motion and usability. However, there are still many variables to consider in order to create a prosthetic that can satisfy the functional requirements of an upper limb. Three of the most crucial advancements in this field – electrode arrays, osseointegration, and targeted muscle reinnervation – will be compared using the following variables: prosthetic stability, control accuracy, and user movability.

I. ELECTRODE ARRAYS

Electrode arrays are one of the most recent advancements in myoelectric prosthetics. The array consists of multiple electrodes that allow the transmission of information from neural interfaces to electrical circuits. This information will then be transmitted to the prosthetic to control the artificial arm using neural signals from the user’s muscles. The array will be implanted into the residual nerve of the

Figure 1: Coil electrode array [2]

user, allowing the nerve cells to grow through the frame (see Figure 1) in order to transmit information and increase the stability of the electrode array in the nerve tissue [3]. The multitude of electrodes in the array will allow an augmented amount of information to be gathered from the multiple inputs [3]. Since there will be a large amount of information to be gathered, mapping the data being transmitted by the low intensity array will allow the data to be organized and recorded efficiently [3]. Further advancements in this method would allow the array to electrically stimulate the somatosensory cortex of the user, which is the central sensory area responsible for the sense of touch, and may eventually allow the user to regain their sense of touch [4]. However, this method is a fairly new advancement and is still under development to create a fully functional electrode array that would be able to accurately control a prosthetic.

II. Osseointegration

This method, initially termed osseointegration in the 1950s by Dr. Rickard Brånemark, Professor at UCSF School of Medicine, is another rapidly advancing method of using myoelectric-controlled prosthetics [5]. It is the process of transplanting a prosthetic directly on to the bone. This would limit the movement between the implant and the bone, and allow the bone to fuse with the implant over time. Electromyography (EMG) is commonly used to control the prosthetic limb. EMG is the process of recording electrical activity using electrodes implanted in the muscles and peripheral nerves of the user (see Figure 2B) [6]. This method may produce long-term solutions due to the stable implant of the prosthetic and electrodes, allowing increased stability and reliability when communicating signals from the nerves to the prosthetic [6]. However, a study done by Zeiquat et al. on 16 patients with implanted prosthetics determined that implant failure is most commonly affected by the loosening of the implant [7]. Correctional surgery may be required to reverse this loosening. Some restrictions of fitting a patient with an osseointegrated prosthetic include available bone surface area, scar tissue, and soft tissue present on the limb, which may affect controllability [6].

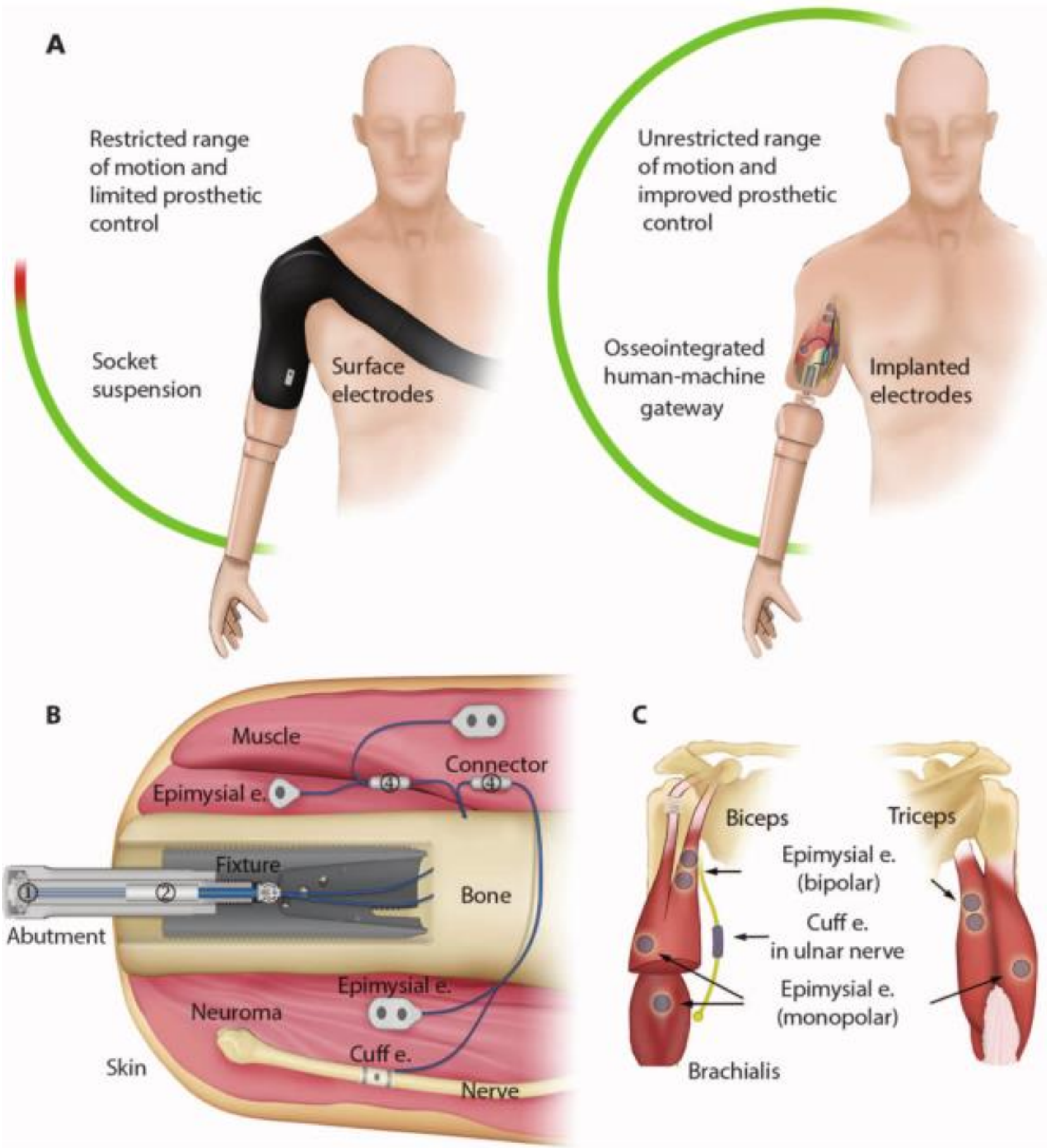

Figure 2: Depiction of osseointegration process. (A) The arm socket for the surface electrodes often restricts movement of the user, whereas implanted electrodes allow a larger range of motion of the user and increased degrees of freedom. (B) The attachment of the electrodes in the muscle, and the implant of the artificial limb in the bone. (C) The placement of electrodes in an upper arm amputee [6].

III. Targeted Muscle Reinnervation

Targeted muscle reinnervation (TMR) is another method of controlling artificial limbs using nerves. It is a surgical technique that takes the nerves initially used to control the limb and transfers them to remaining muscles that are now biologically useless [8]. For example, nerves that once controlled the hand may be surgically transferred to the chest of a patient, since certain chest muscles are no longer used because of the missing limb. The signals from these muscles are commonly analyzed using surface electromyography (sEMG) to convey information from the nerves to the myoelectric prosthetic [9]. This method uses electrodes placed on the skin of the user to gather information from muscle movement and contractions. A negative aspect of this method is that the placement of the electrodes on the skin may be unstable since the electrodes may become disconnected due to user movements, poor connections, or interferences [10]. Additionally, the surface electrodes may restrict movability of the user (see Figure 2A). Finally, it may be difficult for the user to learn unnatural movements and contractions of the muscle where the nerves have been transplanted, although these movements may become more natural as the nerves have time to fully grow in [11].

IV. Combination of Osseointegration and Targeted Muscle Reinnervation

Huang et al. propose that a combination of osseointegration using EMG and TMR would allow for the creation of a multifunctional myoelectric-controlled prosthetic [8]. In order to increase the accuracy while identifying the movement of the user, EMG should be specially localized to accurately read the maximal amount of signals transmitted from the muscles [8]. Osseeintegration would also provide stability of the artificial limb.

DISCUSSION

Although each of the methods of improving myoelectric control above is a possible solution to increase movability and usability of the myoelectric prosthetic by the user, they each have their respective advantages and disadvantages. The solution proposed for the most accurate and reliable artificial limb should be able to mimic tasks performed by a human hand.

I. ELECTRODE ARRAYS

Electrode arrays promise an advanced accuracy of movements and a more definitive feedback transmitted from the neural interfaces to the electrical circuits connected to the prosthetic. However, this method requires increased stability of the array as it is being used. If the array is not stable, the necessary feedback for the myoelectric control will not be accurate, and the prosthetic movements will not correlate with the neural signals the user is trying to send. In order to produce accurate feedback and work efficiently, the sensations from the nerves must remain stable over time and the recordings must be steady from the motor structures of the electrodes [4]. In addition, this method is still under development and currently does not allow complete control of the prosthetics. The need to increase array stability may also restrict movement of the user in order to avoid detachment of the electrode array.

II. OSSEOINTEGRATION

Of the three solutions analyzed, osseointegration is the primary method that increases stability and provides a more long-term solution. Since the prosthetic will be directly implanted on the bone, allowing the bone to grow around it over time, the prosthetic will be stable as it will act as a direct extension of the arm. A study by Brånemark and his colleagues examined eight different hand motions performed by a single patient who had been fitted with an osseointegrated prosthetic [6]. The movements were recorded by EMG from the muscles surrounding the prosthetic resulting in a 94.3% accuracy of movements [6]. However, by using EMG with this method, the electrodes are often inserted in the muscles adjacent to the prosthetic (see Figure 2B). This method provides less accurate control compared to the alternative methods discussed, since the muscles around the implanted limb may not necessarily be the ones directly used to control the missing limb. Nevertheless, this method does provide a large range of movement for the user since the electrodes will be inserted in the muscles and the prosthetic will be directly attached to the bone.

III. TARGETED MUSCLES REINNERVATION

Targeted muscle reinnervation may also allow further advancements when implementing a technique of controlling myoelectric prosthetics. It is difficult to analyze the stability of the prosthetic since the method of attachment of TMR depends on the location of the transplanted nerves. TMR maximizes accuracy because the nerves that would have been used to control the missing limb are transplanted into muscles that are no longer biologically functional. This allows more precise control of the prosthetics because the transplanted nerves would be used to control the myoelectric limb. A study approved by the Northwestern University Institutional Review Board was performed on three patients who had undergone TMR surgery and suggests that a 96% accuracy for classifying intended movements from the elbow, wrist, thumb, and fingers using sEMG can be attained [8]. The use of sEMG was also tested by Castellini and van der Smagt who studied results from an individual controlling a prosthetic and fitted with 10 sEMG electrodes [9]. The recordings demonstrated that the average accuracy for various grasps performed by the robotic limb was $89.67 \pm 1.53\%$ when compared to the types of grasps the patient was attempting to perform by contracting his muscles [9]. However, TMR is often composed of electrodes that restrict the movement and motions of the user. The electrodes may become detached because of the user's movements or the poor connections between the electrode and the skin. This detachment will prohibit the user from being able to control the prosthetic.

IV. Combination of Osseointegration and Targeted Muscle Reinnervation

The combination of osseointegration and targeted muscle reinnervation will be the most beneficial method of designing and creating a prosthetic limb that will increase the usability and degrees of freedom of the user. The integration of the two methods would allow the most efficient method of myoelectric control. Osseointegration would allow a long-term stability of the artificial limb and accuracy when the user is moving the artificial limb in a given direction. It will also increase the movability of the user due to the secure implant. Furthermore, TMR will allow maximized accuracy of prosthetic control due to the transplanted nerves in biologically non-functional muscles. There are possibilities of wireless implants that would improve the control of the prosthetic by consisting of EMG, rather than sEMG, and would allow a more long-term solution for TMR [12]. Therefore, the combination of these two methods would greatly improve usability by allowing more accurate control of the prosthetic, which will increase the efficiency in their performance of daily tasks. Table 3 below summarizes the advantages and the disadvantages of the three methods of myoelectric control analyzed by comparing the stability of the prosthetic, the accuracy of control, and the movability of the user. This table confirms that combining osseointegration and TMR would provide the more beneficial method of myoelectric control.

Table 1: Summary of the three methods analyzed

Method / *Variables*	Electrode Array	Osseointegration	Targeted Muscle Reinnervation
Stability of the prosthetic	- Requires increased stability of array	+ Increased stability from implantation of prosthetic directly on the bone	○ Difficult to determine
Accuracy of control	- Still under development - Does not allow complete control + Promises efficient data collection	- Less accurate control from electrodes implemented in muscles adjacent to the prosthetic	+ Increased precision due to transplanted nerves
Movability of the user	- Increased required stability may restrict user movements	+ Increased range of motion due to stability	- Electrodes on skin surface reduce movability

CONCLUSION

Today, an efficient, functional prosthetic can greatly improve the life of an amputee. The creation of myoelectric prosthetics has allowed major advancements in the biomedical field. Electrode arrays, osseointegration, and targeted muscles reinnervation are three influential advancements that have allowed an increase in range of motion, degrees of freedom, and usability for patients fitted with artificial limbs. Following a comparison of these three important and rapidly advancing techniques, it was determined that the most efficient technique for the design and implementation of an accurate robotic limb is the combination of osseointegration and targeted muscle reinnervation. This combination would allow stable, long-term implanted prosthetics using osseointegration, and reliable connections between the EMG electrodes and the prosthetics. It would also allow increased accuracy using TMR by transplanting the nerves used to control the limb to biologically non-function muscles. Finally, movability will also be increased from using EMG electrodes that will not prevent the movements of the user, and from implementing a permanently implanted prosthetic.

RECOMMENDATIONS

The most effective method for the increase in efficiency and accuracy of myoelectric-controlled prosthetics is the combination of osseointegration and targeted muscle reinnervation. Further research could be performed to determine the best method of implanting the prosthetic using osseointegration. Additionally, the most efficient electrodes could be determined following this research to establish the electrodes that would most accurately transfer information from the nerves to the prosthetic and to increase control. Weight, size, and material were not considered in this analogy and should be a further topic of research to determine the feasibility of these methods using the available material. Furthermore, the combination of these two methods would allow the creation of a more accurate prosthetic and should be tested to determine the effects that combining osseointegration and TMR would produce.

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