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Target Muscle Reinnervation: Controlling Artificial Limbs With Thought

WHAT IS TMR?

- Targeted Muscle Reinnervation (TMR) is a surgical technique that involves the transfer of residual nerve endings to target muscles elsewhere in the body that serve as biological amplifiers of EMG signals sent from the brain.
- The goal of TMR is to produce strong, isolated EMG signals that can be easily accessed by a myoelectric prosthesis that can transmit and translate this information to perform motor functions.

HISTORY OF TMR

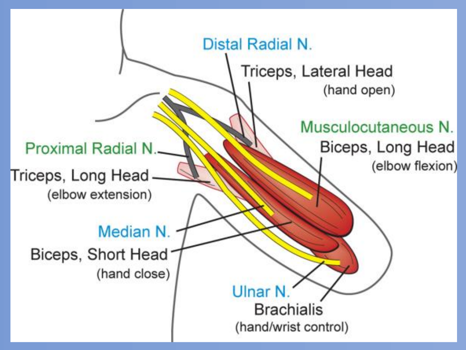
The history of targeted muscle reinnervation dates back to the early 1900's, while the history of prosthetics date back to as far as the ancient Egyptians and has been constantly improving ever since. Starting from the early prosthesis which only served appearance purposes, significant advancements throughout history have been made, such as a prosthetic that could mimic the user's natural movement and the discovery that severed nerves could be transferred to reinnervated muscles. The first TMR surgery was performed on Jesse Sullivan in 2001 and was a success, especially in combination with the myoelectric prosthetic. Since then, there has been may great advancements made within TMR and myoelectric prosthetics, allowing those who are missing a limb to function with greater ease day after day.

THE SURGICAL PROCEDURE

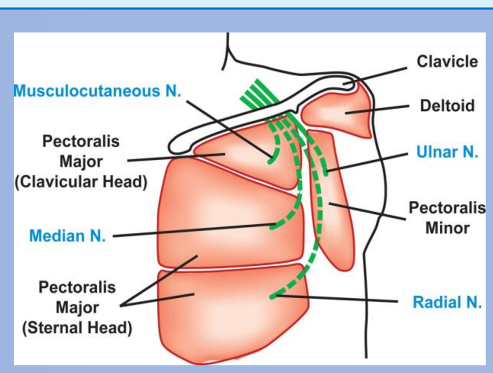
During targeted muscle reinnervation surgery, residual brachial plexus nerves (nerves that control hand and wrist function) are relocated to "target muscles" that are located near the site of the amputation. These target muscles are denervated muscles that serve as "biological amplifiers" that magnify the EMG signal sent from the brain to the nerve that it has been reinnervated with. The nerve transfers that take place are different depending on the patient and the amputation they have received because this determines how much muscle/nerve is available and how much arm length remains. For example, in a transhumeral amputation, nerves are relocated to target muscles in the arm; however, in a shoulder disarticulation, no arm remains, so nerves are relocated to target muscles in the chest, as shown in the figures below.

SUCCESSFUL TMR SURGERY REQUIRES THE FOLLOWING:

Technique	Purpose
Physically Separate Target Muscles from one another	Prevents crosstalk (mixed signals) between target muscles and allows for clear, isolated signals to be sent to prosthetic; facilitates better muscle recovery
Denervate Target Muscle	Ensures that the EMG signal from the nerve that has been relocated is the only signal that the prosthesis is receiving; makes certain that the relocated nerve is not competing for available nerve sites with a native nerve
Fat Removal on Target Muscles	Allows a stronger signal to be transmitted because it decreases the surface area through which the signal must be transmitted and decreases the barriers between the target muscle and the myoelectric prosthetic.



This figure displays the nerve transfers that occur during TMR surgery in a patient with a transhumeral amputation.



This figure displays the nerve transfers that occur during TMR surgery in a patient with a shoulder disarticulation.

BENEFITS OF TMR

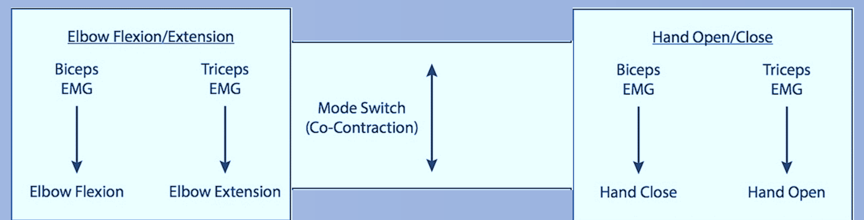
- TMR allows amputees to control their limbs more naturally. Because it allows patients to use the muscle memory that they already have, more seamless actions can be completed with ease. Patients without TMR that use myoelectric prosthetics must embark upon a very long training process to learn which muscle to flex to perform a certain action and when a mode switch needs to occur. This can be a very complicated process; however, since TMR optimizes the nerve signals that are already sent from the brain to control the prosthesis, so it requires much less training and permits intuitive action.
- TMR likewise alleviates the pain caused by neuromas, which are painful growths caused by disorganized nerve growth at an amputation site. These can cause extreme discomfort in amputees, and the pain can be so excruciating that it makes wearing prostheses extremely uncomfortable. In some cases, the pain becomes so unbearable that patients cannot wear the prosthetic.
- TMR can help mitigate this pain by creating more organized growth for the nerve. Because the nerves now have a function and are growing into the target muscles, they have a purpose and do not form these painful growths.

COMPLEX CONTROL OF MOTOR FUNCTIONS

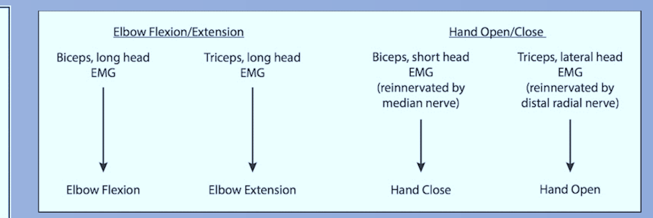
Myoelectric devices are prosthetics that receive electrical signals from flexed muscles in order to dictate a movement. The use of these without TMR is extremely difficult both mentally and physically. For a lower arm amputee, the only muscles groups that can be used reliably are the tricep and bicep. This is due to the fact that the muscles cannot flex at the same time and they must be large enough to give off clear signals. With only two sites for control, amputees can only move one part of their prosthetic at a time in a possible two directions. In order to move, they have to flex muscles that are unrelated to the resulting movement and it requires the user to switch modes for different joints. These shortcomings make use of prosthetic arms slow and unintuitive.

TMR improves arm movements significantly by increasing
- the complexity and amplitude of EMG signals
- the number of control sites
- the intuitive control of movement
- the degrees of freedom

TMR relocates nerves into muscles that flex in direct relation to movements attempted in the brain. For example, trying to twist your wrist flexes the bottom of the bicep so when it is flexed, the prosthetic hand will rotate in the desired way. Increased control sites also give users the ability to control multiple parts of the prosthetic at once like extending the elbow and rotating the wrist. With the development of more complex algorithms, myoelectric devices are able to increase the number of movements performed simultaneously. The complexity of these signals also has the potential to code minute movements that could further increase the quality of life of amputees.



This figure shows myoelectric control in patients without TMR. Because there are less control sites, an unnatural mode switch is necessary to perform certain tasks.



The figure shows myoelectric control in patients with TMR. The increased control sites removes the need for a mode switch.

SUSTAINIBILITY

Our Definition of Sustainability:
- The increased longevity and long-term improvement of the quality of life on both a mental and physical level.
- The ability to transfer this improved quality to life to future generations.
- Must be attainable by those who need it.
- Highly dependent on a balance of these three different parts of the definition

Sustainability applied to Targeted Muscle Reinnervation and Myoelectric Prosthetics:

Physically, TMR increases the quality of life of amputees by giving them the opportunity to accomplish tasks they thought they would never be able to execute. It likewise allows them to live more pain-free because of the effects of TMR on neuroma prevention and phantom limb pain.

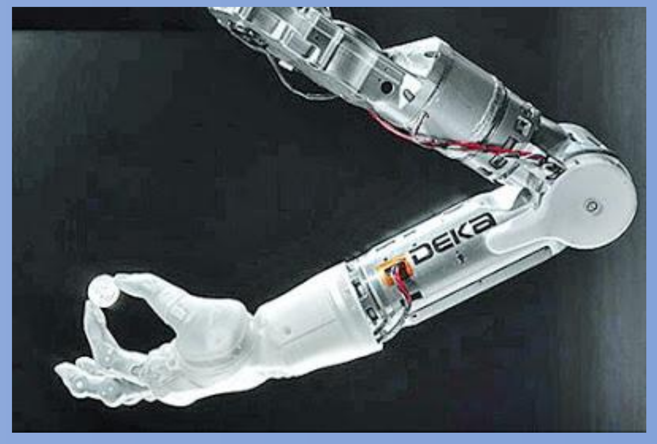
Mentally, many amputees face depression and anxiety due to the phantom limb pain and sense of purposelessness associated with amputations. However, by returning advanced limb functionality, TMR shows amputees that they do have a purpose and can significantly contribute to society. In addition, TMR alleviates most phantom limb pain, eliminating or decreasing the severity of anxiety and depression and thereby substantially increasing the quality of life.

TMR has opened up several new research areas to further the advancement of prosthetic limbs and the development of new surgical techniques to increase limb control so that the amputees of the future generation can live without phantom limb pain, facilitate great prosthesis control, and even be able to "feel" with their artificial limbs.

While TMR surgery and many advanced artificial limbs pose an economical threat for the majority of amputees, there are also several less advanced but still viable and highly functional options for those who need them. In addition, there are several research studies going on that offer compensation in addition to covering the costs of a limb and the TMR surgery.

FUTURE DIRECTIONS

Area of Research	Progress/Developments in this Area
Advanced Prosthetics	The DEKA "Luke Arm" produced by Mobius Bionics is a state-of-the-art prosthesis that offers amputees 10 degrees of freedom and can perform almost as well as a real arm. It is likewise significant because it weighs the same as a normal arm.
Sensory Perception	Targeted muscle reinnervation unleashed a whole new field of medical research that was previously unthinkable when patients who received the surgery reported "feeling" their hands and fingers in his chest, the site of the brachial plexus nerves and the target muscles. This was an unexpected but extremely significant outcome of TMR. Because the nerves still function whether they are in the arm or in the target muscle, if something touches the target muscle containing the reinnervated nerve, the patient experiences the sensation that their limb would normally feel. TMR patients have reported being able to feel certain textures, but new research is going on to generate more sensory feedback. The "E-dermis" in development at John Hopkins University is "electronic skin" designed to perceive pain and other essential sensations that were lost due to amputation.
Pattern-Recognizing Algorithm	A pattern-recognizing algorithm is being researched to pick up additional, smaller EMG signals sent from the brain and accumulate more information regarding those signals than conventional myoelectric control; consequently, further degrees of freedom are available for prosthetic control and functionality is greatly increased.



The DEKA "Luke Arm" produced by Mobius Bionics and is capable of higher motor function.

The "E-dermis" in development at Johns Hopkins that can aid amputees in perceiving more sensory feedback.