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TRANSHUMERAL LEVEL FITTING AND OUTCOMES FOLLOWING TARGETED HYPER-REINNERVATION NERVE TRANSFER SURGERY

Lipschutz, R.D., [1,2] Miller, L.A, [1,2] Stubblefield, K.A., [1] Dumanian, G.,[3]
Phillips, M.E., [1] and Kuiken, T.A. [1,2]

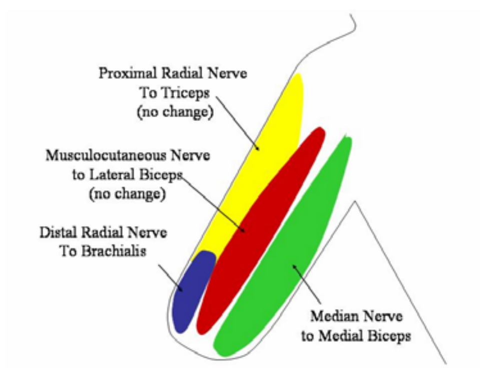
[1] Neural Engineering Center for Artificial Limbs, Rehabilitation Institute of Chicago
[2] Dept. of PM&R, Feinberg School of Medicine, Northwestern University
[3] Dept. of Surgery, Division of Plastic Surgery, Feinberg School of Medicine, Northwestern University, Chicago, Illinois, USA

INTRODUCTION

In a typical transhumeral myoelectric system, biceps and triceps control both elbow and hand. Mode selection (frequently co-contraction) is used to switch between these two functions. In addition to requiring that these movements be performed sequentially, use of the biceps and triceps is not physiological for control of the hand. A novel approach for simultaneous control of multiple myoelectric functions was developed. This was made possible by 'Targeted Reinnervation'; a surgical intervention, which involves the transfer of the peripheral nerves that used to provide signals to the forearm for hand function, to remaining muscles on the transhumeral limb.

SURGERY

Surgery was performed on a 43 year old individual who sustained a transhumeral amputation secondary to a motor vehicle accident in August of 2002. The goal of the surgery was to create 2 new myoelectric signals that were more physiologically associated with hand open and hand close. During surgery first the biceps muscle was separated into its two heads, medial and lateral. Then the brachialis muscle and medial head of the biceps were denervated from the musculocutaneous nerve and the nerve ligated. The amputated distal radial nerve and the median nerve were then cut back to remove the neuroma and sutured onto the denervated brachialis and medial biceps muscles, respectively, so that the transfer nerve abutted the distal nerve segments of the denervated muscle. Subcutaneous fat was then removed in order to increase the transmission of the myoelectric signals to the surface of the skin. With these procedures being performed, it was anticipated that the distal radial nerve signal to the brachialis muscle would elicit a muscular contraction that is consistent with hand open while the medial nerve signal to the medial biceps would elicit a muscular contraction consistent with hand close.



Transhumeral Limb Following Muscular Reinnervation

RECOVERY

Initially, following the surgery, the individual was unable to use his prosthesis secondary to post-surgical swelling. Shortly after this period, it was noted that the transhumeral socket was not longer fitting appropriately due to the significant reduction in size of the limb secondary to the removal of subcutaneous fat; therefore, he was fit with a new socket using the original two myoelectric sites. Approximately six months after the surgery, the individual was able to independently contract his triceps, brachialis, medial and lateral heads of his biceps muscles.

PROSTHETIC FITTING

Pre-surgical fitting of a conventional prosthesis

The initial prosthesis for this individual consisted of a transhumeral myoelectric prosthesis with chest strap, flexible suction socket within a laminated frame, two site myoelectric control, linear transducer, Liberating Technologies, Inc. Boston Digital Arm, Otto Bock wrist rotator and Otto Bock hand. The individual chose a powered hand over a powered hook for aesthetic reasons. For a short period of time, the control scheme was designed to use the two myoelectric sites (over biceps and triceps) to control both the elbow and hand. This was performed with a "time out" from elbow to switch to hand and a co-contraction of lateral biceps and triceps as a means of mode selection back to elbow. The linear transducer was activated with scapular or biscapular protraction and was used to control wrist rotation only. Although the individual could operate the prosthesis with this control scheme, the clinic team felt that use of his biceps and triceps, for hand close and open respectively, would prove confusing following the surgery. This is due to the fact that the individual would get use to using these muscles for hand operations and may later interfere with his attempt to have isolated, simultaneous control of hand and elbow.

It was then decided to use the existing components in a different control scheme. The two-site myoelectric control was then used exclusively for control of elbow flexion and extension. Hand and wrist were controlled via the linear transducer in a "slow vs. fast" pull scheme. For instance, a slow pull initiation of the linear transducer would begin to close the hand while a fast pull initiation of the linear transducer would open the hand. Once the type of pull selected the direction, the motion could then be controlled proportionally by the amount of pull on the linear transducer. As expected, the ability to pull on the linear transducer slowly proved challenging. Because of this; we incorporated a length of elastic webbing parallel to the line of pull of the transducer in order to provide a reminder to the user that he was initiating the hand or wrist motion. Wrist control was performed in a similar fashion. Mode selection between hand and wrist was now accomplished via a bump switch that was mounted on the medial aspect of the humeral section.

Post-surgical fitting of the experimental prosthesis

Approximately 4 months after surgery there were noticeable contractions of the brachialis and medial biceps muscles. The individual underwent extensive myoelectric testing in order to isolate signals to his four different myo-sites. This isolation proved difficult due to the proximity of the medial biceps and triceps sites. Although the triceps muscle covers a fairly broad area on the posterior arm, the best location for a consistent myoelectric signal was on the superior, medial aspect of his arm just distal to the axilla. The brachialis muscle had a detectible contraction through palpation although it was weaker than the other three sites. Additionally, the synergistic control of muscle groups, i.e. elbow flexion/hand close and elbow extension/hand open proved challenging. When strong contractions of the lateral biceps were initiated for rapid elbow flexion, the hand would often close as well. Similar results were seen for triceps and hand open. Six months after the surgery, the individual was fit with his first 4-site myoelectric prosthesis for simultaneous, bi-directional control of the hand and elbow. The components being used were identical to the pre-surgical set-up with the exception of two additional electrodes. Also, the programming scheme within the microprocessor had to be altered to recognize these two additional electrodes and their respective functions. Wrist rotation continued to be controlled via the linear transducer in a "slow vs. fast" scheme as previously described. A chest strap and suction socket continued to be used for

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the experimental design with particular attention paid to the location of the electrodes. The site for the brachialis muscle was located distally in the postero-lateral quadrant. This proved challenging as any slipping of the socket would create and inadvertent "hand opening" signal. The chest strap was modified with an additional, adjustable strap that originated from the posterior part of the chest strap and ran across the shoulder through the delto-pectoral groove. This strap provided increased suspension of the prosthesis necessary to reduce any socket pistoning.

OUTCOMES MEASURES

A series of tests showed significant improvement in function for this individual using his experimental prosthesis vs. the conventional myoelectric fitting. Subjectively, this individual preferred the operation of the experimental prosthesis, as the movements appeared smoother and more natural. The patient had voluntary, simultaneous control of the hand and elbow while controlling his wrist rotator with biscapular protraction. Objectively, the individual was able to increase the speed of his movements 3-fold in a Box and blocks test. This is a validated test where individuals are required to move blocks from one side of a box, over a divider, to the other side. (Table 1) The Box and blocks test primarily required the use of only the powered elbow and hand. A Clothespins test was also performed that required the subject to use the powered wrist as well. This was a timed test with requirements relocating three clothespins. There was a marked increased speed of 54% (Table 2). The difference in speed was greater for tests where bimanual manipulation was of greater need as might be expected. On the AMPs testing his motor score increased from 0.51 with the conventional myoelectric prosthesis to 1.05 on the experimental prosthesis and process scores increased from 0.35 to 1.10. The AMPs test is a validated experiment assessing an individual's performance with Activities of Daily Living (ADL's).

Table 1: Comparison of Box and blocks test between conventional and experimental prosthesis (number of blocks moved in 2 minutes)

	Conventional	Experimental
Trial 1	9	20
Trial 2	5	22
Trial 3	8	26
Average	7.3	22.7
% difference		+322%

Table 2: Comparison of clothespin test between conventional and experimental prosthesis (time in seconds to move 3 clothespins)

	Conventional	Experimental
Trial 1	52	45
Trial 2	75	27
Trial 3	61	30
Average	62.7	34.0
% difference		-54.2%

DISCUSSION

This was the first attempt to perform targeted muscle reinnervation on an individual with a transhumeral amputation. The surgery proved successful with reinnervation of both the brachialis and medial head of the biceps muscles. Although the technical fitting of the prosthesis was somewhat challenging, independent myoelectric sites were obtained for use of simultaneous control of an electronic elbow and hand. Physiological control was achieved by transferring the peripheral nerves that use to control the hand to denervated muscles in the transhumeral limb. These targeted muscles were then used as biological amplifiers to send the signal to surface electrodes within the transhumeral socket and amplified to control a myoelectric hand in a more natural manner than conventional myoelectric, transhumeral fittings. This "natural physiological control" proved effective in the individual's ability to control the prosthesis. Evidence of this is seen in the measured outcomes of various tests.

Several challenges were encountered during the fitting and adjustment of the prosthesis. Accuracy in donning the socket so that the electrode placement was optimal over the intended myo-sites was the primary challenge. The movement of the soft tissue around a singular bone made it possible for the myo-sites to shift depending upon the technique in which the socket was applied. A donning aid was utilized with this suction socket in order to approximate a "hydrostatic" fit. Electrode gain and threshold adjustments were frequently performed during the fitting and training processes. Fortunately, the visual display of these parameters, provided in the software by Liberating Technologies, Inc., proved invaluable in the understanding of which muscles were contracting, at what strength they were contracting and with which other muscles were they co-contracting. Lastly, as is the case in many externally powered fittings, the individual complained that both the pre- and post-surgical prostheses were "heavy".

There was no sensory reinnervation of the skin, which had been seen in a previous surgery involving an individual with bilateral shoulder disarticulation amputations. This is likely due to two things. First, the nerve anastomosis was underneath a thicker muscle so that the sensory fiber had more difficulty regenerating to the skin. Second, the skin was not denervated so that it was not receptive to reinnervation. In the future, we hope to provide targeted sensory reinnervation to transhumeral amputees by identifying discreet skin nerve segments and mobilizing the cut nerve down to the nerve transfer anastomosis so that the sensory nerve fibers can reinnervate skin on the residual limb and provide a pathway to give the amputee the 'feel' of the objects he is touching.

CONCLUSION

It is apparent from both the subjective and objective data that this targeted muscle reinnervation proved effective for this individual's ability to control his transhumeral prosthesis. Although any muscle could have been used to provide input for the hand and potentially provide simultaneous, myoelectric motor movements, the physiological basis for using the peripheral nerves that are consistent with hand open and close allowed the user to control the device in a natural manner without having to re-train his mind and body to substitute an artificial movement in order to control the myoelectric hand. Additional subjects have subsequently undergone similar surgical procedures with anticipated results similar to this first subject.