

## **SHOULDER DISARTICULATION FITTING WITH 6 INDEPENDENTLY CONTROLLED MOTORS AFTER TARGETED HYPER-REINNERVATION NERVE TRANSFER SURGERY**

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### **INTRODUCTION**

In 2002, targeted hyper-reinnervation nerve transfer surgery was performed unilaterally on a bilateral shoulder disarticulation amputee. The goal of this surgery was to create additional sites using the remaining unused brachial plexus nerves to allow simultaneous control of multiple movements using more natural control schemes [1,2,3].

As a result of the nerve transfer procedure, 4 new myoelectric control sites were created on the left pectoralis muscle. Subsequent prosthetic fitting found that the user was able to operate the elbow and hand in a coordinated fashion using three electrodes. Various outcome measurements showed an improvement in prosthetic function.

However, with the increase in the number of input signals, a goal was set to build a prosthesis with the maximum number of controlled motors available. Six motorized components were identified: three were commercially available in the USA, one was commercially available in other countries and two were a research prototype.

### **COMPONENTS**

An experimental prosthesis was built for control by a person with shoulder disarticulation amputation with the maximum number of motorized joints currently available. The six powered functions, integrated by LTI, included a prototype shoulder, an experimental humeral rotator, a Boston Digital arm, a wrist rotator, and a hand with powered wrist flexion/extension.

A Scottish company, TouchEMAS, was the supplier of the powered shoulder joint. In a traditional mounting, this shoulder has flexion and extension movement only in the sagittal plane. However, in addition to the powered joint, an LTI manual locking shoulder was mounted horizontally to allow rotation of the powered shoulder in various planes. That is, the powered shoulder could be positioned to flex and extend in the sagittal plane or rotated laterally to move in the coronal plane (abduction-adduction).

The next component distally was the humeral rotator. This mechanism was developed by Weir and Grahn and is based on a Boston 2 elbow drive unit [4]. Because of the mounting technique used to connect the humeral rotator to the Boston Digital arm, access to the electrode and other input connections (located at the top of the elbow turntable) was difficult. A jumper for all of the input connectors was fabricated to facilitate the change of various input cables. This jumper board was then mounted to the humeral shaft connecting the shoulder to the humeral rotator. To prevent over-extension of the cables as they crossed over the humeral rotator, a mechanical stop was fabricated into the rotator mounting plate.

The elbow unit/controller was the Boston Digital Arm. This system allows for nine analog (myoelectric or other proportional) inputs, five digital inputs and direct control of five motors. By passing input signals through the elbow to an additional LTI VariGrip controller

located in the forearm, we were able to increase the number of motor control signals to the required six.

An Otto Bock electric wrist rotator was mounted distal to the elbow. The input cables were modified to allow the coaxial plug to contain the two control signals necessary for hand control. The Shanghai Keshen Hand (Model M21) was used. This hand has powered open and close and powered wrist flexion and extension. It was modified to fit the Otto Bock quick disconnect wrist. The wrist rotation and the wrist flexion and extension were controlled by signals from the extra VariGrip controller. The remaining four motors were controlled directly by motor signals from the Boston Digital Arm.

In addition to the motors, other components required modification. During previous myotesting, the subject had difficulties with co-contraction of radial nerve functions (elbow/wrist/hand extension) and it was not possible to separate the elbow extension signal (radial nerve transfer) from the cardiac signal (ECG). Because the subject had practiced this movement (arm extension) over the past year, he had increased the EMG signal in magnitude but it was still not great enough to isolate for two-site elbow control.

Models were developed of the cardiac interference and algorithms created to remove this interference in the input [5]. However, implementation of these algorithms proved difficult due to the processor setup. Therefore, additional models were created to investigate the use of simpler filtering techniques. Eventually, the LTI DC electrode amplifiers were modified to add a 60Hz low-pass filter and the LTI AC electrode amplifiers were modified to a narrow band pass centered at 120 Hz. This proved to be effective in reducing a majority of the ECG interference and allowed the use of the fourth control site. Improved function was achieved as this modification was done to all of the electrode amplifiers located on the chest wall.

## **CONTROL**

The subject controlled hand opening and closing, elbow flexion and extension and humeral internal and external rotation using myoelectric signals. Unexpectedly, two independent myoelectric signals, for hand open and hand close, could be reliably recorded over the median nerve-muscle unit. Though the median nerve innervates mainly hand-close muscles, the subject imagined thumb abduction to "open" the hand. This is also a median nerve function. These two areas were used for hand open and close. The musculocutaneous nerve transfer was used for elbow flexion and the radial nerve transfer was used for elbow extension.

The subject had some remaining deltoid musculature that could be used for a myoelectric site. This signal was used to control internal humeral rotation while a latissimus dorsi site was used to control external humeral rotation. This is counter-intuitive since the latissimus dorsi muscle is an internal rotator of the humerus, however, this felt easier and more comfortable to the subject and thus was implemented.

Switches could not be placed in the harness for operation of the other functions because the harness was already in use to anchor the straps for the right body-powered system. We also preferred to avoid chin switches. To maximize the number of controls mounted in the socket, a rocker switch was positioned superiorly within the socket to control the shoulder. This rocker was modified by adding two FSR's to make the output signals proportional to the force applied to the rocker. Forward movement of the rocker flexed the shoulder joint (or lifted the arm) and backward movement of the rocker brought the arm down. A force-sensitive resistor (FSR) touch pad was mounted anterior within the shoulder cap to control wrist flexion and a second was mounted posterior to control wrist rotation. Each of these two FSRs controlled movement via a

single-site control where a soft/slow touch moved the motor in one direction and a hard/fast touch moved the motor in the opposite direction.

## RESULTS

Although the subject only wore the prosthesis for about 15 hours in his first two week session, he was able to control multiple joints simultaneously, and he could perform tasks that he could not do before. Clearly, his functional workspace was greatly enhanced by the shoulder (allowing active reach up) and the humeral rotator (allowing him to bring the arm into and past mid-line. He was more efficient in doing specific tasks, such as donning a hat and shaking hands. He was also better at pre-positioning the terminal device in space; for example, by reaching forward and moving his hand directly in front of himself in a smooth coordinated movement, by reaching above his head, and also by positioning the terminal device near the mid-line of the body. The subject was able to demonstrate simultaneous control of at least 3 degrees-of-freedom by reaching up (shoulder flexion), out (elbow extension) and opening or closing the hand.

The subject found the nerve transfer EMG controlled functions to be the easiest to use. Operation of the humeral rotator with EMG control was also relatively easy. Control functions with shoulder motion were clearly more difficult, although progress was made even in the short time he had to work with the arm. Shoulder flexion/extension improved quickly. Operation of the wrist rotator and the wrist flexion/extension motors with just single site FSR touch pads using soft/slow for one direction and hard/fast for the other continues to be the most challenging, least reliable and the heaviest cognitive burden.

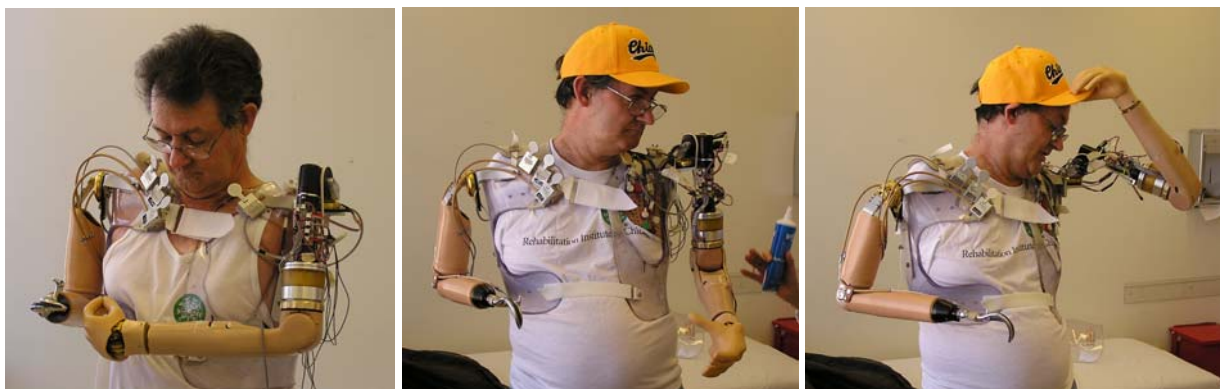


Figure 1: Photographs showing subject using six-motor prosthesis.

## DISCUSSION AND FUTURE WORK

There was a marked increase in functional range of motion for our subject using the six-motor prosthesis. With little training, he showed an ability to control a prosthesis using the four additional control signals added through the targeted reinnervation of the pectoralis musculature. The targeted hyper-reinnervation technique makes possible the creation of new control signals for even more complex prosthetic systems.

A number of different control schemes need to be considered and tested. For example, the subject prefers to use myo switch control of his terminal device and wrist rotator with proportional control on his home set of prostheses, even though the option is available to use FSR touch pads to allow simultaneous control of the wrist with the hand. During future visits,

we plan to implement and test a control scheme where the hand and wrist are sequentially controlled with his hand open and close nerve transfers.

Although the current procedure only used the four major brachial plexus nerves, it opens the possibility to divide the nerves into multiple fascicles reinnervating smaller areas of muscle, and creating even more signals.

In the future, to record the small, tightly-spaced signals created by divided hyper-reinnervation, myoelectric signals will need to be recorded by intramuscular electrodes with a transducer or through implantable myoelectric sensors [6,7].

This case demonstrates the need for more research. A larger clinical trial in high-level amputees with appropriate objective and subjective testing is warranted to see if these results can be repeated or even improved upon.

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