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PROSTHESES CONTROL BASED ON TMR
a case study

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Introduction

The surgical treatment by targeted muscle reinnervation has been applied to more than 25 patients after traumatic loss of upper extremities in North America.

In November 2006 this procedure was applied for the first time to a patient in Europe. The 18- year-old male patient suffered from bilateral limb loss after a high voltage accident, which happened in October 2006. The patient ended up with a medium long transhumeral residual limb on the right side and a shoulder disarticulation on the left side.

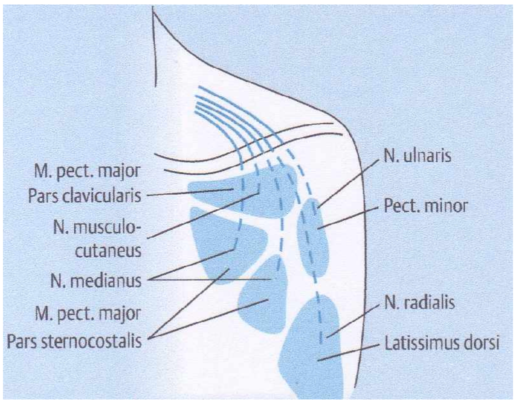
He did undergo a primary rehabilitation at the rehabilitation center "Weisser Hof" and left rehabilitation after three months. The right side was fitted with a DynamicArm®, a wrist rotator and a SensorHand Speed. The system was controlled by the EMG signals of the biceps and the triceps. The switching between levels was achieved by co-contraction. The left side was fitted by a cosmetically arm with minimal functionality since trial fittings with functional arms failed.

Assessment Phase

The initial rehabilitation outcome was not in accordance with the specific needs of the patient: he did not reach a sufficient level of independence for everyday activities and it was not possible for him to return to work. For an improved functional outcome the surgical procedure of targeted muscle reinnervation was considered. For an investigation about the local situation of the arm - plexus a screening by ultrahigh resolution ultrasound was done. This showed intact branches of the fascicular structure. Electrical diagnostic methods indicated intact proximal branches of the nerves. An interdisciplinary team, consisting of neurosurgeon, a Doctor for physical medicine, an occupational therapist, a CPO and some expert engineers for artificial limbs was formed. This team developed a rehabilitation plan. For the surgery a nerve transfer matrix was developed, which should secure proper functionality for the upcoming prosthetic fitting [Figure1].

Source (nerve)	Target (neuromuscular unit)	Target phantom function
N. musculo-cutaneous	N. pectoralis clav.	Elbow flexion
N. medianus	N. pectoralis stern.	Fingerflexion Pronation
N. medianus	N. Pectoralis abd.	Wrist flexion
N. ulnaris	N. Pectoralis minor	Intrinsic Function
N. radialis	N. thoracodorsalis	Fingerextension

Table 1: nerve transfer matrix



Surgical intervention

The goal of the intervention was to unhinge the greater branches of the arm plexus and to connect them to existing neuromuscular units. This rerouting was done according to figure1.

The nerve transfers were done by end to end nerve-cooptation. For better signal separation the musculus pectoralis minor and the M pectoralis major pars clavicularis were moved.

In addition the trunctus medius C7 was connected to the nervus supraclavicularis, which was cut at the punctum nervosum. By that means a sensible skin area should be generated, which can represent the sensory areas of the hand. The whole region was defatted for better signal quality.

Postoperative phase

Six weeks after the intervention the patient did undergo a training plan. He was supervised by an occupational therapist. The primary goal was to enhance the overall fitness and endurance and to correct the body posture and symmetry. As soon as measurable EMGs were detectable a specific training program was started. The patient visited the clinics every six weeks for follow-up. After three months voluntary muscle contractions at the M. pectoralis minor et major could be identified. Sensibility at the Trigonum colli laterale recovered. There the patient could clearly differentiate different regions of his hand. (Figure 2).

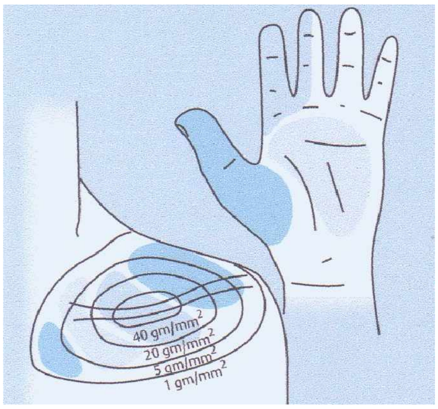


Figure 2: isobaric lines of sensation and hand regions

After six months there were sufficient signals at the segments of the M pectoralis, which allowed starting the fitting process (Table 2)

Source (nerve)	**Target (neuromuscular unit)**	**Result**	**Target phantom function**
N. musculo-cutaneous	N. pectoralis clav.	excellent	Elbow Flexion
N. medianus	N. pectoralis med.	excellent	Close fist
N. medianus	N. Pectoralis inf.	good	Wrist Flexion
N. ulnaris	N. Pectoralis minor	??	Intrinsic Function
N. radialis	N. thoracodorsalis	??	Finger Extension

Table 2 nerve transfer matrix postoperative after six months

After 17 months the nerve growth process seemed to be completed. All targets provide excellent signals. On the target units a further differentiation of phantom arm movements was possible (Table 3)

Source (nerve)	**Target (neuromuscular unit)**	**Result**	**Target phantom function**
N. musculo-cutaneous	N. pectoralis clav.	excellent	Ellbow Flexion
N. medianus	N. pectoralis med.	excellent	Close fist
N. medianus	N. Pectoralis inf.	excellent	Wrist Flexion, Pronation
N. ulnaris	N. Pectoralis minor	excellent	Intrinsic Function
N. radialis	N. thoracodorsalis	excellent	Finger Extension, Supination

Table 3 nerve transfer matrix postoperative after 17 months

Prosthetic fitting

The patient was fitted with two different arm systems, the "Take Home Arm" and the "6 Degrees of Freedom Arm".

The "Take Home Arm"

This system has a passive shoulder joint with free swing and a preflected position, a modified DynamicArm®, a wrist rotation unit and a Sensorhand Speed. For direct control of the 3 Degrees Of Motion a sixth EMG signal was needed. Therefore the musculus deltoideus was integrated into the control scheme. Standard EMG electrodes were used, however because of the skin movement a modified suspension of the electrodes was necessary (Figure 3).

Figure 3: modified suspension of electrodes

This system is used by the patient daily as his standard rehabilitation device.

The “7 Degrees of Motion Arm”

This arm is an outcome of the DARPA “Revolutionizing Prosthetics” program. It provides 7 degrees of motion and is controlled by pattern recognition techniques (Figure 4).

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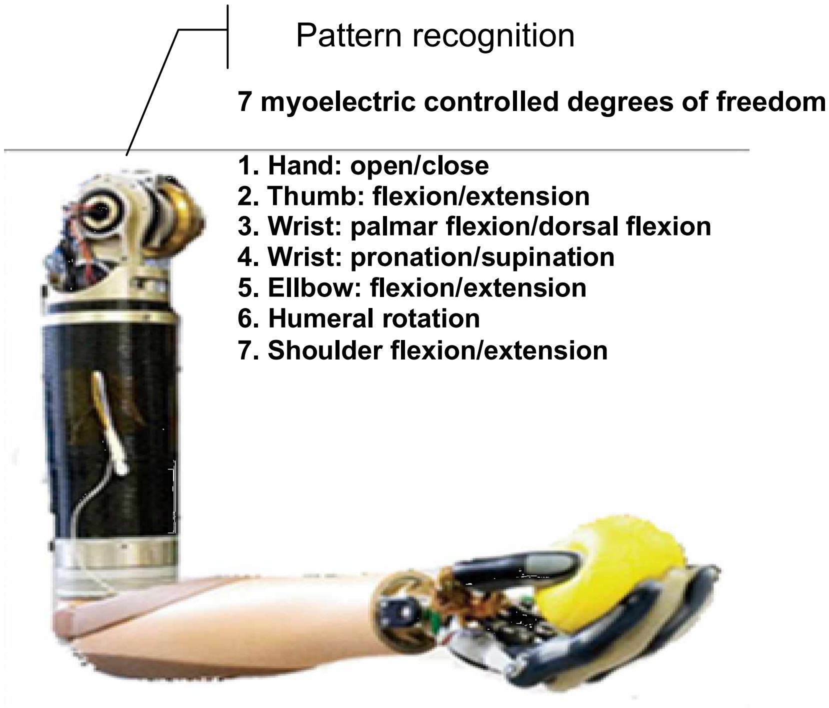

Figure 4: 7 Degrees of Freedom Arm

Up to 24 adhesive electrodes were used for control. This system was used in the laboratory only

Patient outcome:

The patient is using the “Take Home Arm” daily as his standard rehabilitation device. He achieved a sufficient degree of independence and was able to return to work in the logistics and warehouse of a car dealer. The “7 Degrees of Motion Arm” was tested on a regular basis in a laboratory environment. The patient was able to intuitively control all degrees of motion. No additional input devices were necessary.

Outlook

The functionality and the degrees of motion of the “Take Home Arm” will be extended step by step by using the findings of the laboratory tests.

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