UPDATES IN TARGETED SENSORY REINNERVATION FOR UPPER LIMB AMPUTATION

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OBJECTIVE

Advanced robotic devices capable of simulating the dexterous ability of the upper limb have raised the enticing prospect of replacing the lost intricate functions of the arm following upper limb amputation. However, a large gap still exists in the application of this technology. In particular, the ability to provide physiologically relevant sensory feedback—to have the amputee feel the prosthetic hand as their own—has not yet been achieved.

Targeted sensory reinnervation, a refinement of the original targeted muscle reinnervation procedure pioneered by Kuiken et al.[1], is a recent and promising development in the effort to create a functional human-machine interface with a closed loop sensory feedback system. Targeted reinnervation (TR) aims to re-establish hand sensation on the skin of the amputated stump so that it can be readily accessed non-invasively during functional tasks.

We will review the surgical approaches that have been used for sensory reinnervation in the upper arm.

REFERENCES

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METHODS & RESULTS

There has been an evolution of three main surgical techniques associated with targeted sensory reinnervation:

1. Traditional Targeted Reinnervation

During the first TR case, the skin overlying the anticipated motor points was thinned of subcutaneous tissue to reduce electrode interference.[1] This resulted in local denervation of the skin, which then allowed for competitive reinnervation of afferent nerve fibers. Rather than correlating to the precise somatotopic map of each transferred nerve, the referred sensations are typically variable and intermixed, including native anatomic skin sensation.[2] The variability of the somatotopy potentially limits the predictability and reliability of using this approach for harnessing a sensory feedback access point.

2. Cutaneous Nerve End-to-Side Targeted Sensory Reinnervation

A modification of the TR procedure involved adding two end-to-side sensory nerve transfers in a proximal transhumeral amputee.[3] The supraclavicular cutaneous nerve was cut and the distal segment was coapted to the side of the ulnar nerve. The intercostobrachial cutaneous nerve was coapted to the median nerve. By 6 months, the anterior chest skin was reinnervated by both median and ulnar afferents. In most areas, however, a mixture of digit and native chest sensations were elicited.[2,3] There was improvement in control of the sensory reinnervation territory, but not in exclusivity for the recipient nerve as evidenced by the ability of the competing median nerve afferents to find their way to the desired site of ulnar nerve reinnervation.

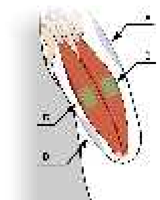


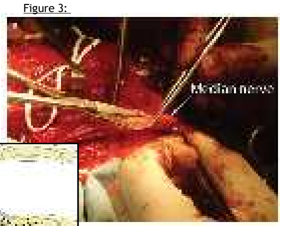
Figure 1
Schematic of target sensory cutaneous sites
A. cutaneous branch of axillary nerve coapted to ulnar nerve
D. intercostobrachial nerve coapted to median nerve
in relation to anticipated motor control sites
B. coapted ulnar nerve trunk to brachalis
C. coapted median nerve trunk to medial head of biceps

3. Sensory Fascicle End-to-End Targeted Sensory Reinnervation

To more reliably restore the hand map on cutaneous target areas of the residual limb, a further modification was made. Somatosensory evoked potentials (SSEP) were used to assess more precisely the sensory content of specific fascicles of the main reinnervating nerves and to identify target cutaneous nerves.[4] The sensory fascicle end-to-end TR technique developed by the authors uses intra-operative SSEPs by recording over the somatosensory cortex to allow inter-operative identification of fascicles with high sensory content from the median and ulnar nerves by individually stimulating separated fascicles after intrafascicular dissection. Once a predominantly sensory fascicle is identified and coapted to a cutaneous sensory target nerve, the remainder of the main nerve is directed to the motor branch of the target muscle. This technique resulted in discrete exclusive sensory patches of the ulnar and median nerve hand maps in the designated territories, with no overlap.

Figure 2:

Figure 3:



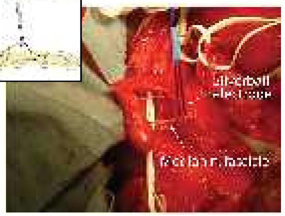


Figure 4:

Figure 5:

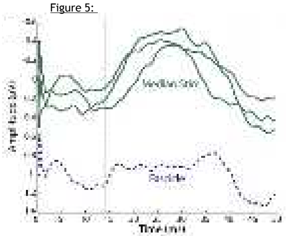
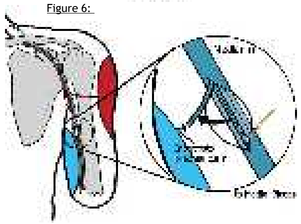


Figure 6:



Figures 2-4:
Schematic and photographs of intrafascicular dissection of the median nerve after the epineurial sheath has been opened longitudinally and individual fascicle stimulation with silverball hook electrode

Figure 5:
Inter-operative SSEP recordings from the entire median nerve trunk (top three traces) and from stimulation of an individual fascicle. The fascicle that produced the largest SSEP was used.

Figure 6:
Schematic showing a fascicle of the median nerve (blue) coapted to the intercostobrachial nerve while a fascicle of the ulnar nerve (red) was connected to the cutaneous branch of the axillary nerve

CONCLUSIONS

With the traditional TR procedure and the end-to-side coaptations, there appears to be little control over which afferent fibers regenerate from the transferred nerves. In contrast, with the fascicular end-to-end technique, two spatially separated wide spread areas with discrete sensation for individual digits in the two nerve territories are created. We were able to demonstrate potential functional relevance by having the subject utilize this sensory feedback to execute tasks while operating a myoelectric training tool, without having to rely on visual guidance or auditory cues.[4]

Figure 7:
Transfer sensation mapped on transhumeral residual limb. Territory of the median nerve digits corresponded to the intercostobrachial cutaneous nerve. Territory of the ulnar nerve hand map corresponded to the axillary nerve cutaneous distribution.

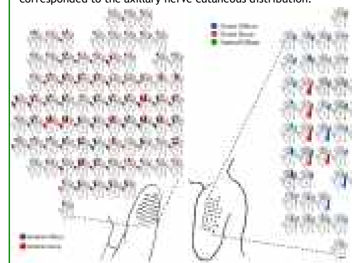


Figure 8:
Experimental setup of the myoelectric training tool.

We have no conflicts of interests to declare