Targeted muscle reinnervation in the initial management of traumatic upper extremity amputation injury

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Abstract Targeted muscle reinnervation (TMR) was initially designed to provide cortical control of upper limb prostheses through a series of novel nerve transfers. Early experience has suggested that TMR may also inhibit symptomatic neuroma formation. We present the first report of TMR performed at the time of a traumatic shoulder disarticulation. The procedure was done to prevent painful neuroma pain and allow for myoelectric prosthetic use in the future. Eight months post-operatively, the patient demonstrates multiple successful nerve transfers and exhibits no evidence of neuroma pain on clinical exam. Using the Patient Reported Outcomes Measurement Information System (PROMIS), the patient demonstrates minimal pain interference or pain behavior. Targeted muscle reinnervation may be considered in the acute trauma setting to prevent neuroma pain and to prepare patients for myoelectric prostheses in the future.

Introduction

Approximately 34,000 Americans are living with major upper extremity amputations secondary to trauma [15]. Over two

thirds of these amputees are adolescents and adults younger than 45 years of age [2]. At the time of surgical revision amputation, major mixed nerves are usually treated with traction neurectomy. This technique may lead to painful neuroma formation as a result of an uncoordinated attempt of the nerve fibers to regenerate. Painful neuromas often prevent consistent prosthetic use, further limiting the functional capacity of the amputee.

Targeted muscle reinnervation (TMR) was initially developed to permit intuitive control of upper limb prostheses by performing a series of novel nerve transfers in established amputees [3–11]. For shoulder disarticulation patients, the goal is to create four independent myoelectric control sites for hand open, hand close, elbow extension, and elbow flexion [6]. Clinical experience has demonstrated TMR to be an excellent treatment for neuroma pain in the amputee. By providing a nerve target for the transected brachial plexus nerve endings, TMR serves to restore continuity of the nervous system despite the absence of native distal nerve segments. As suggested by clinical and preclinical data, reconstitution of nerve integrity through nerve transfer or repair successfully inhibits neuroma formation [5, 7]. These nerve transfers simultaneously provide the potential for appropriate patients to be fit with cortically controlled myoelectric prostheses [4]. TMR performed at the time of initial trauma presentation or during the initial hospitalization has not been reported.

Case report

A 54-year-old woman suffered a traumatic left upper extremity amputation at the level of the proximal humerus due to a roll-over motor vehicle accident. On examination in the operating room 6 h after the initial trauma, the

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Fig. 1 Amputated limb with significant crush injury, extensive contamination, and avulsion of all neurovascular structures

amputated limb was found to have significant crush injury and contamination, with avulsion of all neurovascular structures and extensive skin degloving (Fig. 1). The limb was deemed unsalvageable and replantation contraindicated [14]. After ligation of the axillary vessels,

Fig. 2 Acute traumatic left upper extremity amputation with necrotic skin flaps requiring debridement 72 h after initial traumatic amputation

Fig. 3 X-Ray of the dislocated residual humerus displaced into the chest wall with complete ligamentous disruption

excisional debridement of devitalized tissue was performed and skin flaps overlying the pectoralis muscles were allowed to demarcate. Seventy-two hours after the initial trauma, the patient was taken back for additional excisional debridement of devitalized skin (Fig. 2) and a shoulder disarticulation revision amputation due to complete ligamentous disruption (Fig. 3).

One week after initial traumatic amputation, the patient returned to the operating room for definitive coverage and TMR. The brachial plexus nerves were

Fig. 4 Preparation for targeted muscle reinnervation: The identified nerves are labeled in this image of the left chest at the time of the third surgery. The nerves identified with the red vessel loops are the motor branches to the pectoralis major and minor. At the top of the picture, there are three separate nerves identified that correspond to the two sternal branches (*left*) and a single clavicular branch (*right*) to the pectoralis major. The damaged nerves of the brachial plexus along the bottom half of the picture are marked as medial cord, lateral cord, and posterior cord from left to right

Fig. 5 This diagram depicts the nerve transfers performed with the labeled brachial plexus nerves in yellow with their muscle segment targets in red. Note that the pectoralis major has three segments and the pectoralis minor has been mobilized and anchored lateral to its native position to prevent overlapping electromyographic signals

identified, and significant avulsion injury was observed. When followed proximally to the cord level, the nerves appeared grossly intact. To confirm that there was no root level disruption of the brachial plexus, the medial (C7, C8, T1) and lateral (C5, C6) pectoral nerves were identified and stimulated using a hand-held nerve stimulator. Given that this procedure was performed more

Fig. 6 The brachial plexus cord to motor nerve coaptations were performed using epineurial sutures and sealed with fibrin glue, as shown

Fig. 7 Eight months post-operatively, the split-thickness skin graft is well healed over the pectoralis muscles

than 72 h after initial injury, positive nerve stimulation was presumed to indicate an intact nerve pathway [12].

The individual motor nerves to the clavicular head of the pectoralis major, the sternal head of the pectoralis major (two separate nerves), and the pectoralis minor were identified (Fig. 4). The pectoralis minor was disinserted, repositioned, and anchored lateral to the pectoralis major to prevent overlapping of potential EMG signals. The medial, lateral, and posterior cords were identified and sequentially debrided until they revealed healthy nerve fascicles. The individual cords were mobilized and coapted to the recipient motor nerve targets close to their entry point into the newly denervated muscle segments (Fig. 5). The lateral cord was split along a natural cleavage plane to attempt capture of separate median and musculocutaneous nerve functions. The four nerve coaptations were performed with 6–0 polypropylene suture and reinforced with fibrin glue (Fig. 6). A split-thickness skin graft was then applied for muscle coverage where needed (Fig. 7).

Eight months following the procedure, the patient demonstrates no neuroma pain on clinical exam, and displays minimal pain-related behavior or pain interference as determined by the Patient Reported Outcomes Measurement Information System or PROMIS (Fig. 8) [1, 13]. The cord level nerve transfers have successfully reinnervated the pectoralis muscles, triggering contraction under cortical control. The patient does report phantom sensations (but not phantom pain), functional limitations, and mood depression consistent with her

Fig. 8 This figure demonstrates the patient's PROMIS score results for pain behavior and pain interference. The diamond is the estimated score. A score of 50 is average for the US general population, and most people will fall between 40 and 60. The Standard Error (SE) is demonstrated by the lines on either side of the diamond and demonstrates the likely range

of the actual score. The estimated pain behavior score indicates that the patient's pain behavior is very low, within the 10th percentile for the general population. The pain interference score reveals that she falls in the lowest 1 % of the general population

injury pattern. For financial reasons, she has deferred prosthetic fitting.

Discussion

This case demonstrates the feasibility of TMR for pain control in the acute traumatic amputation setting. Despite the traumatic and proximal nature of her amputation, the patient demonstrates no evidence of neuroma pain, as demonstrated by her postoperative clinical exam and PROMIS scores [1, 13]. Additionally, she has four distinct myoelectric control sites, should she decide to proceed with prosthetic fitting in the future.

Not all trauma patients are candidates for this technique. Those with significant comorbid injuries or an unclear level of nerve injury should be managed via traditional methods. However, in appropriately selected patients, there are several advantages to performing TMR in the acute setting. Technically, the donor nerves are clearly visible and not yet distorted by scar. Likewise, the nerves are minimally contracted, making transfer to recipient muscle segments more feasible. Most importantly, coaptation of the transected nerves to nearby motor nerve targets produces a neurophysiologic microenvironment that facilitates near-normal regeneration, thus inhibiting the chaotic growth that underlies neuroma formation [7]. The prevention of symptomatic neuromas can improve post-traumatic rehabilitation.

TMR was considered during the initial hospitalization for this patient to prevent neuroma formation and pain and to allow for a potential myoelectric prosthetic

under cortical control in the future. The muscle targets reinnervated by TMR in the shoulder disarticulation patient do not compromise any existing limb or upper body functions. In addition, the introduction of pattern recognition technology for control of myoelectric prosthetics makes the specific pattern of nerve transfers performed less critical to achieving successful motor control outcomes. In both acute and delayed settings, soft tissue manipulation is often necessary to create strong, spatially distinct EMG signals. Use of split-thickness skin grafting of target muscles, as was done in this case, allows for ideal electrode sensibility.

Conclusion

Targeted muscle reinnervation may be considered in the acute trauma setting to prevent neuroma pain and to prepare patients for future myoelectric prostheses.

Conflict of Interest Jennifer E. Cheesborough declares that she has no conflict of interest.

Jason M. Souza declares that he has no conflict of interest.

Gregory A. Dumanian declares that he has no conflict of interest.

Reuben A. Bueno declares that he has no conflict of interest.

Statement of Human Rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent Informed consent was obtained from this patient included in this manuscript.

References

1. Cella D, Riley W, Stone A, et al. The Patient-Reported Outcomes Measurement Information System (PROMIS) developed and tested its first wave of adult self-reported health outcome item banks: 2005–2008. *J Clin Epidemiol*. 2010;63(11):1179–94.
2. Dillingham TR, Pezzin LE, MacKenzie EJ. Limb amputation and limb deficiency: epidemiology and recent trends in the United States. *South Med J*. 2002;95(8):875–83.
3. Dumanian GA, Ko JH, O'Shaughnessy KD, et al. Targeted reinnervation for transhumeral amputees: current surgical technique and update on results. *Plast Reconstr Surg*. 2009;124:863–9.
4. Dumanian GA, Souza JM. Surgical techniques for targeted muscle reinnervation (TMR). In: Kuiken TA, Barlow AK, Schultz AE, editors. *Targeted muscle reinnervation: a neural interface for artificial limbs*. Boca Raton, FL: CRC Press; 2013.
5. Guse DM, Moran SL. Outcomes of the surgical treatment of peripheral neuromas of the hand and forearm: A 25-year comparative outcome study. *Ann Plast Surg*. 2012 Aug 3; Epub ahead of print.
6. Hijjawi JB, Kuiken TA, Lipschutz RD, et al. Improved myoelectric prosthesis control accomplished using multiple nerve transfers. *Plast Reconstr Surg*. 2006;118:1573–8.
7. Kim PS, Ko JH, O'Shaughnessy KK, et al. The effects of targeted muscle reinnervation on neuromas in a rabbit rectus abdominis flap model. *J Hand Surg Am*. 2012;37(8):1609–16.
8. Kuiken TA, Dumanian GA, Lipschutz RD, et al. The use of targeted muscle reinnervation for improved myoelectric prosthesis control in a bilateral shoulder disarticulation amputee. *Prosthet Orthot Int*. 2004;28:245–53.
9. Kuiken TA, Miller LA, Lipschutz RD, et al. Targeted reinnervation for enhanced prosthetic arm function in a woman with a proximal amputation: a case study. *Lancet*. 2007;369:371–80.
10. Kuiken TA, Li G, Lock BA, et al. Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms. *JAMA*. 2009;301:619–28.
11. O'Shaughnessy KD, Dumanian GA, Lipschutz RD, et al. Targeted reinnervation to improve prosthesis control in transhumeral amputees. A report of three cases *J Bone Joint Surg Am*. 2008;90:393–400.
12. Myckatyn TM, Mackinnon SE. The surgical management of facial nerve injury. *Clin Plast Surg*. 2003;30(2):307–18.
13. 13. PROMIS. Available at: <http://nihpromis.org/measures/instrumentoverview>. Accessed April 24, 2013.
14. Tintle SM, Baechler MF, Nanos GP, et al. Traumatic and trauma-related amputations, Part II: upper extremity and future directions. *J Bone Joint Surg Am*. 2010;92(18):2934–45.
15. Ziegler-Graham K, MacKenzie EJ, Ephraim PL, et al. Estimating the prevalence of limb loss in the United States - 2005 to 2050. *Arch of Phys Med and Rehab*. 2008;89:422–9.