OPEN

PRS GLOBAL OPEN

CASE REPORT
Peripheral Nerve

TMR Using a Free Rectus Flap after Transhumeral Amputation

Logan G. Galbraith, BA*
Daniel Najafali, BS†
James R. Gatherwright, MD‡

Summary: Targeted muscle reinnervation offers an approach to regain use of the affected extremity through electronic prosthesis while limiting phantom pain and neuroma limb production or pain. In this case report, we present the first reported case of leveraging the rectus flap for targeted muscle reinnervation. The case herein is of a 28-year-old woman who sustained a severe right upper extremity crush injury while being involved in a vehicular roll-over collision requiring right transhumeral amputation. Plastic surgery, orthopedic surgery, and vascular surgery were consulted to manage the right upper extremity injury. *(Plast Reconstr Surg Glob Open 2024; 12:e5574; doi: 10.1097/GOX.0000000000005574; Published online 12 February 2024.)*

Targeted muscle reinnervation (TMR) aims to combine proximal nerve endings with distal motor component nerve targets for appropriate axonal regeneration and has been demonstrated to provide superior benefits compared with conventional neurectomy.[1] It offers benefits such as improved phantom limb pain and minimizes neuroma formation by providing regenerated fascicles a destination and purpose compared with conventional techniques. In the setting of amputation, the residual nerves are transferred to appropriate muscle targets that are denervated, which serve as a conduit for reinnervation by those residual nerves. TMR is leveraged to allow for optimal integration with an electronic prosthesis to improve upper limb function, control, and ease of use.[2–4]

Quality of life can be diminished as loss of limb function combined with possible neuroma formation or phantom limb pain leads to disability. Precise control over prostheses becomes challenging with upper extremity amputations at the elbow or higher.[2,3,5,6] Since its first report in 2004 by Kuiken and colleagues for a gentleman with bilateral shoulder disarticulation, TMR has been increasingly used in the setting of traumatic amputations.[7,8] The rectus abdominis flap leveraged in the following case has been postulated by Kim et al in an animal model (New Zealand white rabbits) to provide signals from three independent nerves.[9] Combining the unique nerve signals from the rectus flap for intuitive control of a prosthesis to improve quality of life was the goal for this patient. TMR has its roots in innovation and engineering and by pairing novel muscle grafts with the landscape of evolving bionic limbs and sensors, patients undergoing these procedures will see a marked improvement in quality of life and functionality of the affected limb.[10,11]

CASE

We present a 28-year-old woman with a history of tobacco use and obesity who sustained a right arm crush injury while involved in a vehicular roll-over collision requiring right transhumeral amputation (Fig. 1). She was evaluated in the emergency department, and when EMS arrived, the patient's right upper extremity was trapped underneath a semitruck. As part of her workup, she underwent computed tomography imaging of her brain, cervical spine, chest, abdomen, and pelvis. Plastic surgery, orthopedic surgery, and vascular surgery were consulted. It was determined after arrival that the right upper extremity would not be salvageable. The patient's initial local flap became compromised, and a free tissue transfer with TMR was planned. There were areas of necrosis at the amputation site requiring debridement before proceeding. First, the radial, median, and ulnar nerve neuromas were resected creating appropriate nerve material (Fig. 2). An end-to-end, 9-0 nylon, conduit-assisted, tisseel nerve coaptation was performed. Then a pedicled nerve transfer was used to graft each of the aforementioned upper extremity

*From the *Northeast Ohio Medical University College of Medicine, Rootstown, Ohio.; †Carle Illinois College of Medicine, University of Illinois Urbana-Champaign, Urbana, Ill.; and ‡Department of Plastic and Reconstructive Surgery, Cleveland Clinic, Cleveland, Ohio.*

Received for publication September 10, 2023; accepted December 11, 2023.

DOI: 10.1097/GOX.0000000000005574

Disclosure statements are at the end of this article, following the correspondence information.

Related Digital Media are available in the full-text version of the article on www.PRSGlobalOpen.com.

Fig. 1. Affected upper extremity status post motor vehicle collision.

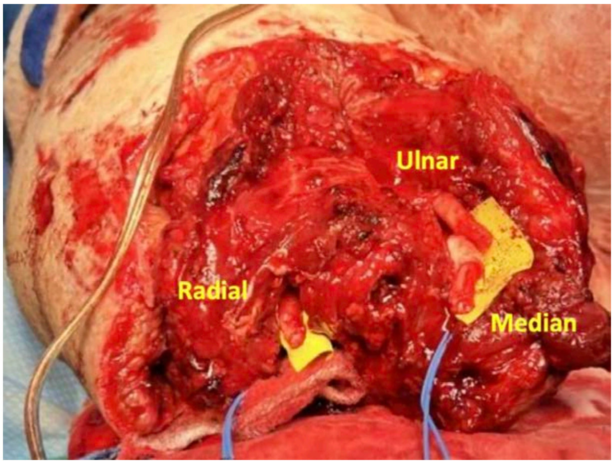

Fig. 2. View of the nerve components that were appropriately isolated.

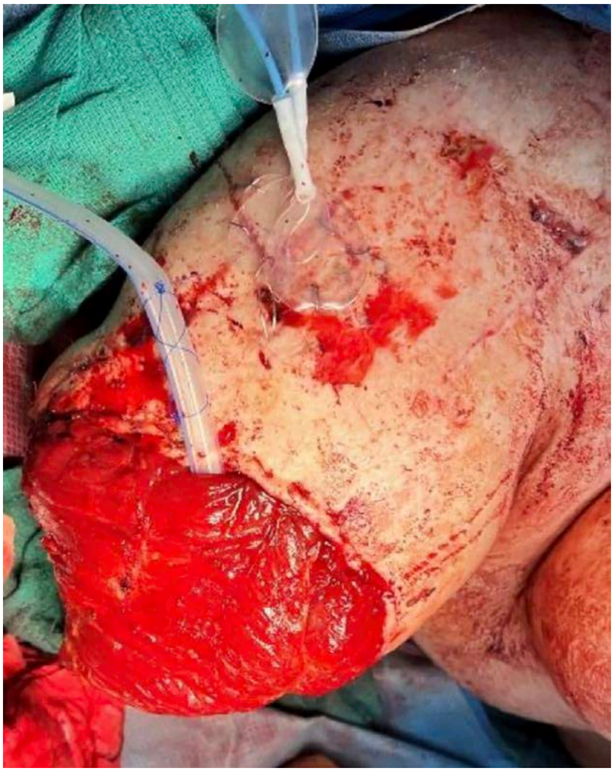

Fig. 3. Free tissue transfer with Integra used to envelope and protect the amputation stump.

nerves (eg, radial, median, ulnar) into selected intercostal nerves in each of the three regions of the free right rectus flap. All the nerves were dissected to provide 2–3 cm of length. The three nerves that were coaptated were selected on location/proximity to damaged nerves to provide a tension free repair. Free tissue transfer with Integra was used to envelope and protect the amputation stump (Fig. 3). After the procedure, this patient experienced no complications other than anemia due to acute blood loss. She was given appropriate fluid resuscitation and a blood transfusion postoperatively with uneventful transfer to the PACU in stable condition. In the following months, the patient reported no phantom pain or uncomfortable sensations. In addition, the patient gained the ability to control the firing of three distinct regions of the rectus flap. Currently, the patient has healed following grafting with an EMG pending. She has a nonfunctional prosthesis at this time due to insurance coverage issues. At follow-up,

Fig. 4. Postoperative image of patient status post TMR using a free rectus flap.

the patient reports 0 of 10 pain with phantom pain that lasts minutes one to two times a week. A postoperative image is provided in Figure 4. The simulation of moving the affected extremity is demonstrated in Videos 1 and 2. [**See Video 1 (online),** which shows the patient postoperatively.] [**See Video 2 (online),** which shows the patient postoperatively.]

DISCUSSION

The use of the rectus flap for TMR is not a completely novel concept. In fact, Kim et al demonstrated the success of using a rectus flap in rabbits after forearm amputation.[9] They found that the rectus flap maintained its segmental innervation from the transected ulnar, radial, and median nerves. After prolonged nerve stimulation, the muscle flap showed decreased glycogen in the region innervated by that nerve. In this way, the Kim and colleagues were able to demonstrate the segmental nature of the rectus flap and its implications for TMR. Still, there have been no reports on the use of a rectus flap for this purpose in humans.

Although there are other donor sites for free tissue transfer for performing TMR with the ulnar, radial and median nerves, many advantages exist when using a rectus flap. In particular, this approach requires only one muscle donor graft. With only one graft needed to carry out TMR for three nerves, donor site morbidity is minimized, preserving surrounding healthy tissue architecture. In this way, possible donor site complications such as pain, seroma or hematoma formation, compartment syndrome, and muscle necrosis are further reduced.[12]

TMR, having the ability to reduce neuroma formation, provides a benefit for pursuing the procedure; however, there is much more to be gained from this intervention. The ability to use TMR in combination with an electronic prosthesis allows for restoration of lost functionality secondary to amputation. This is achieved as TMR muscle grafts transform neuronal signals into conventional electric current.[2,10]

Transhumeral amputation leaves patients with three major nerve dissections. With the loss of these nerves comes the loss of abduction, adduction, extension and rotation of a previously functioning limb. The psychological and emotional impact of this loss should not be overlooked.[13] The surgeon's goal in this case was to restore these mechanics, through powered prosthesis. The rectus flap having three innervation regions offered the unique opportunity to perform TMR with three separate nerves grafted into a single flap. This technique produced three unique "contact points" for controlled nerve triggering of a fitted prosthesis. The patient continues to work toward the implementation of a fitted prosthesis. This case accentuates the plastic surgeon's call to innovation and the expanding frontier of plastic surgery.

CONCLUSIONS

This case demonstrated that TMR leveraging the rectus flap for traumatic upper extremity amputation offers favorable functional control of myoelectric prostheses, aesthetic outcomes, and treatment of symptomatic neuromas. Plastic surgeons should continue to innovate and partner with colleagues in engineering to extend the realm of possibilities for TMR in the setting of traumatic amputation.

Logan G. Galbraith, BA
Northeast Ohio Medical University College of Medicine
4209 St
Rootstown, OH 44272
E-mail: lgalbraith@neomed.edu

DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

1. Dumanian GA, Potter BK, Mioton LM, et al. Targeted muscle reinnervation treats neuroma and phantom pain in major limb amputees: a randomized clinical trial. *Ann Surg.* 2019;270:238–246.
2. Cheesborough JE, Smith LH, Kuiken TA, et al. Targeted muscle reinnervation and advanced prosthetic arms. *Semin Plast Surg.* 2015;29:62–72.
3. 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;369:371–380.
4. Tham J-L, Sood A, Saffari TM, et al. The effect of targeted muscle reinnervation on post-amputation pain and functional

outcomes: a systematic review and meta-analysis. *Euro J Plast Surg*. 2023;46:475–497.
5. Kuiken TA, Li G, Lock BA, et al. Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms. *JAMA*. 2009;301:619–628.
6. 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;124:863–869.
7. 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;28:245–253.
8. Souza JM, Cheesborough JE, Ko JH, et al. Targeted muscle reinnervation: a novel approach to postamputation neuroma pain. *Clin Orthop Relat Res*. 2014;472:2984–2990.
9. 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;37:1609–1616.
10. Farina D, Vujaklija I, Branemark R, et al. Toward higher-performance bionic limbs for wider clinical use. *Nat Biomed Eng*. 2023;7:473–485.
11. Pasquina PF, Kuiken T, Hargrove L, et al. A pilot trial to assess implantable myoelectric sensors (IMES) to improve prosthetic function for transhumeral amputees with targeted muscle reinnervation. 2022. Available at https://apps.dtic.mil/sti/citations/trecms/AD1179158. Accessed January 24, 2024.
12. Collins J, Ayeni O, Thoma A. A systematic review of anterolateral thigh flap donor site morbidity. *Can J Plast Surg*. 2012;20:17–23.
13. Rosca AC, Baciu CC, Burtaverde V, et al. Psychological consequences in patients with amputation of a limb an interpretative-phenomenological analysis. *Front Psychol*. 2021;12:537493.