OPEN

PRS GLOBAL OPEN

IDEAS AND INNOVATIONS

Hand/Peripheral Nerve

The Octopus Procedure Combined with Targeted Muscle Reinnervation for Elective Transhumeral Amputation

Nikhil Agrawal, MD*
Sigurast Olafsson, BS†
Brent B. Pickrell, MD†
Marilyn Heng, MD, MPH†
Ian L. Valerio, MD†
Kyle R. Eberlin, MD†

Summary: Optimizing prosthetic function and tolerance are key principles of performing an elective upper extremity amputation. It is common for upper extremity amputees to experience issues related to nonoptimal prosthetic control and pain. Targeted muscle reinnervation and regenerative peripheral nerve interfaces in elective transhumeral amputations have been introduced as techniques to address the paucity of signals that may exist for myoelectric control postamputation. These techniques require the denervation of muscle and rely on delayed muscle reinnervation to provide eventual signal amplification for prosthetic function. In addition, the fascicles cannot be separated enough to provide signals to each individual muscle. Use of native innervated forearm musculature can provide more immediate and specific signals for prosthetic use. These native muscles are often not available for use due to trauma, denervation, or dysvascularization. In elective amputations, they can be used as spare parts to provide more signals for the sensors on a myoelectric prosthetic. The concept has been used in partial hand amputations and allowed for individual digital control at the terminal prosthetic device. In this study, we describe a novel technique used for an elective transhumeral amputation utilizing native innervated, vascularized musculature to provide intuitive control of a myoelectric prosthetic. *(Plast Reconstr Surg Glob Open 2021;9:e3931; doi: 10.1097/GOX.0000000000003931; Published online 16 November 2021.)*

INTRODUCTION

Major upper extremity amputations, particularly above-elbow amputations, confer significant morbidity in terms of residual limb pain (RLP), phantom limb pain (PLP), and suboptimal prosthetic function.[1] The complex function of the hand is difficult to recapitulate, and intuitive prosthetic control is necessary. Furthermore, the major nerves are not far from the skin, and neuromas that form are likely to cause RLP and PLP.[2] Indeed, much research has been dedicated to techniques that mitigate pain and optimize myoelectric prosthetic control.[3,4]

Specifically, targeted muscle reinnervation (TMR) has been shown to minimize RLP and PLP while refining upper extremity myoelectric prosthetic use.[5,6] TMR transfers major peripheral nerves to distal motor nerves of muscles in the arm that lack function after amputation. In above-elbow amputee patients, these motor signals can then be read by sensors on the socket and result in intuitive control of the terminal device. Serendipitously, it was found that redirecting major peripheral nerves to denervated muscle, prevented end neuromas and reduced RLP and PLP.[7]

Elective amputations are rare. However, they do present the opportunity to utilize the spare parts and TMR concepts to give the prosthetic sensors more specific signals. In contrast to many traumatic amputations, elective amputations retain healthy, functioning muscles distal to the amputation site. The recently developed starfish procedure transfers retained intrinsic musculature in partial

*From the *Long Island Plastic Surgical Group, Garden City, N.Y.; and †Massachusetts General Hospital, Boston, Mass.*

Received for publication August 20, 2021; accepted September 8, 2021.

Drs. Agrawal and Olafsson contributed equally to this work.

DOI: 10.1097/GOX.0000000000003931

Disclosure: *Dr. Eberlin serves as a consultant for AxoGen, Integra, Checkpoint, and Tissium. Dr. Valerio serves as a consultant for Integra and Axogen. Dr. Heng serves as a consultant for Zimmer-Biomet, Inc. No funds were received or utilized for the research reported in this article. All the other authors have no financial interest to declare in relation to the content of this article.*

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

hand amputations to improve myoelectric signaling and permit individual prosthetic digit control.[8] We have modified this concept to be applicable to transhumeral amputations, which we call the "octopus procedure" based on the appearance of the muscles when dissected in the proximal forearm. The octopus procedure is a novel technique that combines the principles of TMR and/or regenerative peripheral nerve interfaces to increase available EMG signals for heightened prosthetic control while minimizing potential RLP/PLP in the transhumeral amputee.

THE OCTOPUS PROCEDURE COMBINED WITH TMR

The patient is a 47-year-old right-hand dominant woman who sustained an injury to her right arm that ultimately resulted in over 35 operations, including three prior total elbow arthroplasties, and more than 10 years of incapacitating pain. Prior surgical intervention failed to improve her pain and symptoms, and at the time of presentation the third elbow arthroplasty was infected and loose with penetration of the implant stem out of the humerus and the patient experiencing severe neuropathic pain (Fig. 1). After extensive discussion and multidisciplinary evaluation, the decision was made to pursue transhumeral amputation. (See **Video 1**, which displays the combined octopus procedure with TMR for elective transhumeral amputation.)

Takeaways

Question: How can the residual muscle be maximally utilized for prosthetic control after an elective transhumeral amputation?

Findings: In this article, we describe a novel technique used for an elective transhumeral amputation utilizing native innervated, vascularized musculature to provide intuitive control of a myoelectric prosthetic. The prosthetic can then recognize muscle contractions from the native muscles and perform the corresponding action. TMR is also performed to limit pain from the severed sensory nerves.

Meaning: By preserving native, healthy forearm muscles in elective amputations and combining this concept with TMR, this patient has an increased number of available EMG signals and the chance of developing symptomatic neuroma has been minimized.

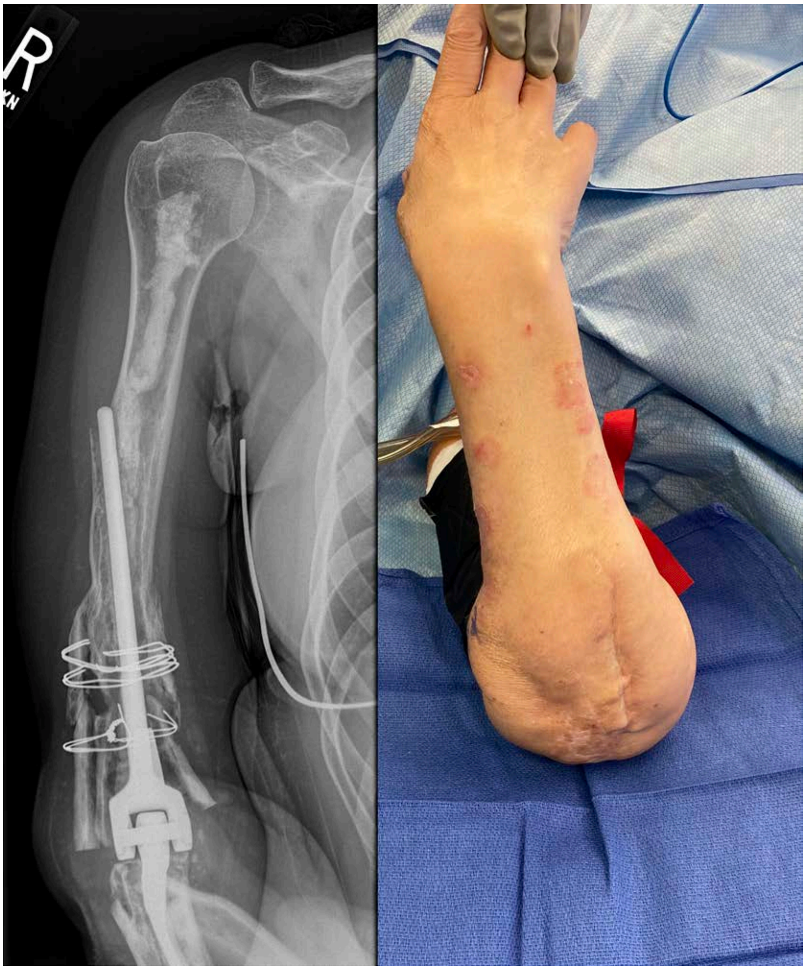

Fig. 1. Preoperative radiograph and image of the affected arm.

The forearm flexors and extensors were first isolated and pedicled to preserve the native innervation and perfusion. The osteotomy was then performed and the forearm and hand amputated, along with the prior elbow arthroplasty. The isolated pedicled, vascularized, and innervated muscle flaps were transposed proximally over the amputation stump with the flexor carpi radialis in an anterior position and proceeding medially to place each flap sequentially over the stump flexor digitorum superficialis, flexor digitorum profundus, flexor carpi ulnaris (Fig. 2). Next, the brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum communis, and extensor pollicus longus were placed lateral to posterior on the stump. Each of these innervated, pedicled flaps was secured proximally in an orientation that will allow for potential signal targets to be used by a myoelectric prosthetic with intraoperative innervation confirmed with a handheld nerve stimulator (Fig. 3). Following the securing of the innervated muscle flaps, nerve transfers were performed of the median, ulnar, and radial sensory nerves consistent with the TMR technique to minimize potential for painful neuroma formation (Fig. 4).

DISCUSSION/CONCLUSIONS

Traditional limitations imposed by upper limb amputations can have devastating consequences for patient function and quality of life, especially when the elbow must be compromised. Effective use of a prosthesis and improved pain control represent an opportunity to mitigate suboptimal outcomes. Although technology continues to improve, there are still challenges to using a prosthesis, demonstrated by evidence of up to 40% of upper extremity amputees discontinuing prostheses usage due to lack of intuitiveness, pain, and/or other causes.[9] The surgical approach we utilized builds on the starfish procedure and

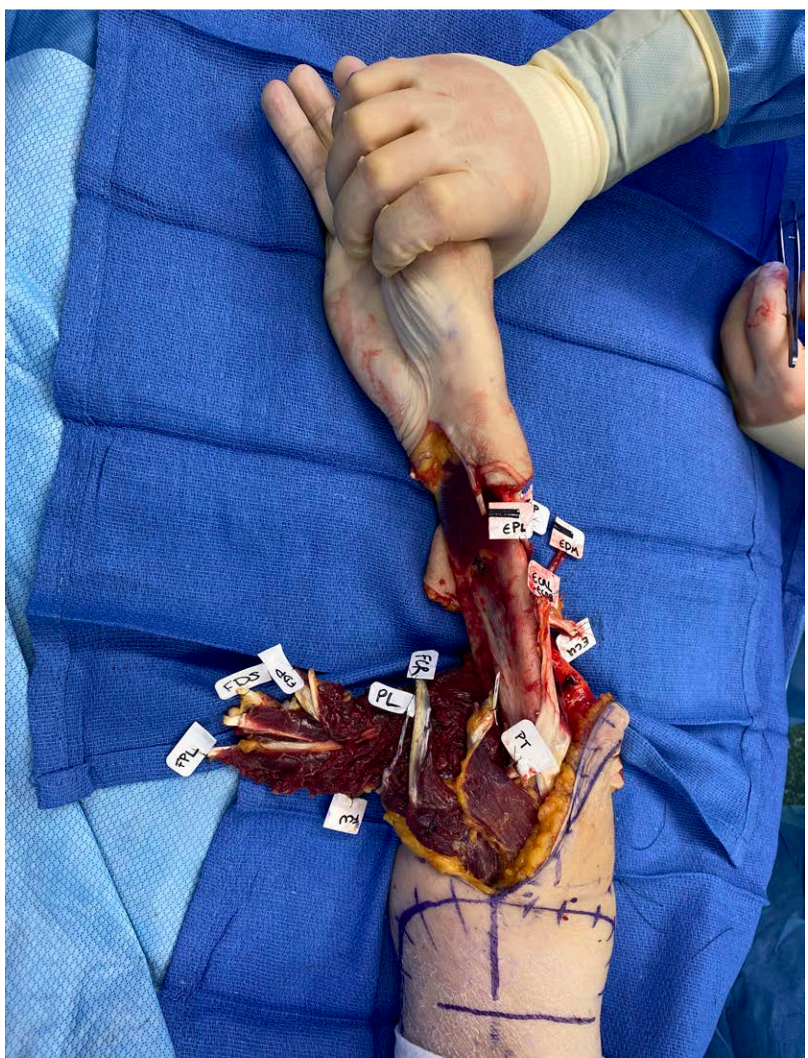

Fig. 2. The muscles of the forearm were individually dissected out and labeled. These muscles remained vascularized while providing a level of specific motor control that could easily translate to a myoprosthetic. This minimizes the amount of cortical relearning required by the patient.

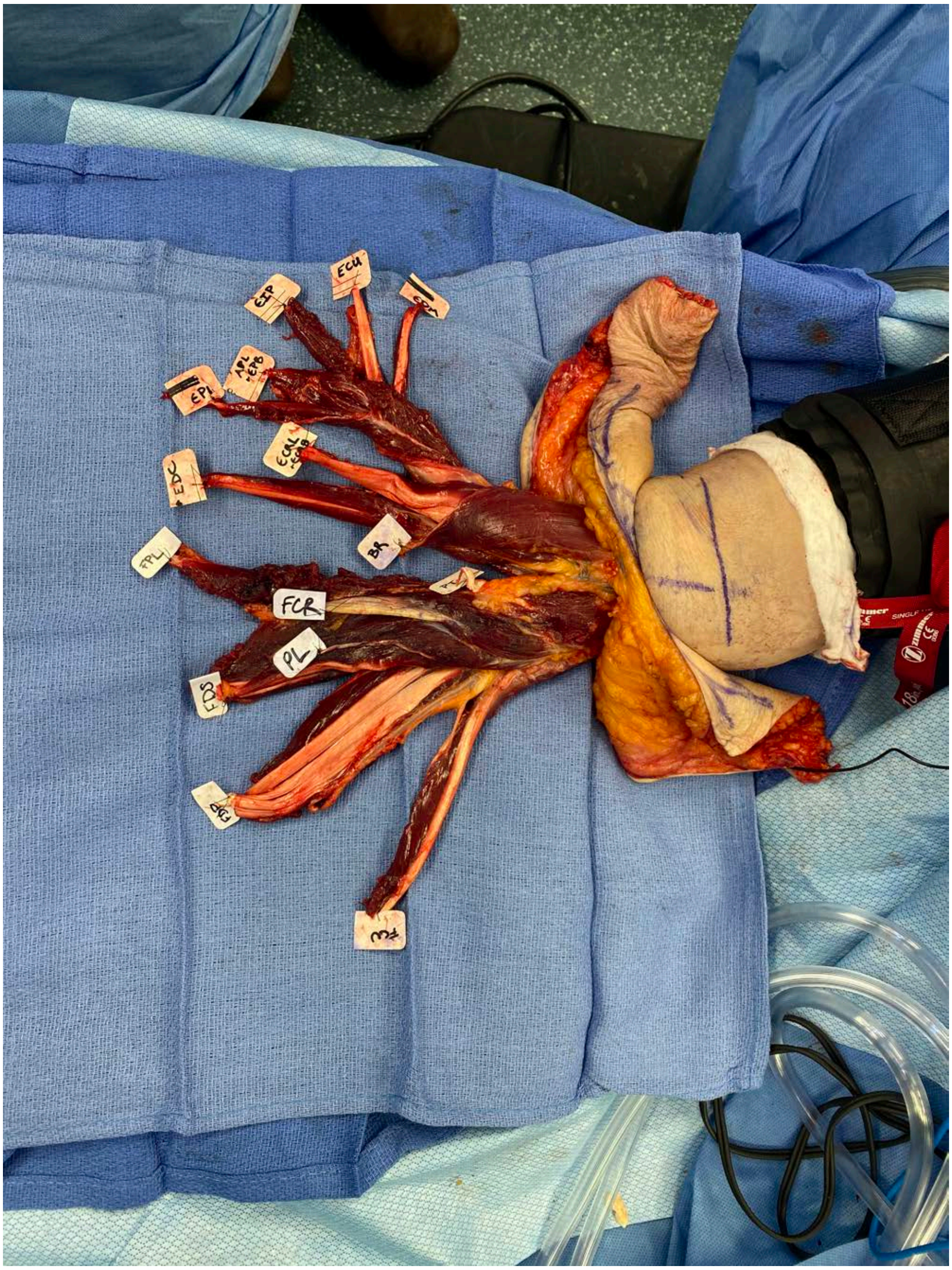

Fig. 3. The isolated muscle flaps were rotated over the amputation stump in locations that would be easily picked up by a prosthetic. TMR was also performed to minimize pain control and maximize the potential usefulness of the prosthetic.

presents a novel method to provide certain transhumeral patients with maximal targets for myoelectric signal capture. By leveraging the vascularized and innervated native muscle tissue from the forearm for the muscle transfers, potential degrees of freedom and patient intuition for myoelectric control are maintained and optimized.

Increasing the number of signals in an intuitive manner has the potential to increase function and ease of use of a prosthesis. It is hoped that this would lead to better acceptance and long-term prosthetic acceptance and long-term prosthetic use, effectively increasing the quality of life for patients. The sensors on the socket of a prosthetic can read the muscle contractions and translate them into the corresponding movement on the terminal device. With traditional TMR, the fascicles cannot be parsed out enough to separate each individual muscle. The concept of the starfish and octopus procedures is to utilize the native muscles to provide more specific signals for each movement. Performing this technique in combination with either TMR or regenerative peripheral nerve interfaces enhances the benefits for the patient by striving to prevent neuroma formation of the distal mixed motor and sensory nerves that can lead to neuropathic pain. With less pain and intuitive use, patients

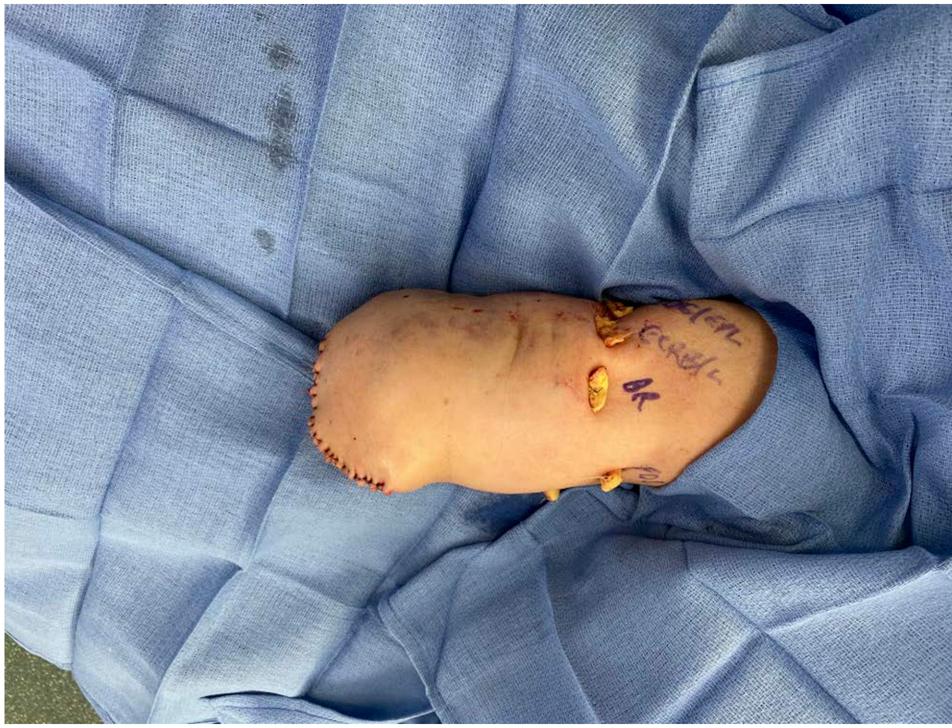

Fig. 4. The stump was closed. Tie over bolsters were used to secure the muscle tendons to the skin. These points were labeled and documented so that the prosthetic could be designed and intuitive control could be maximized.

may have incrased us of their prosthetics (**See Video 2,** which shows how the patient is now able to have intuitive control of the prosthetic. The device is calibrated to her muscle contractions and the terminal device will move in response to the corresponding signals).

In addition to transhumeral amputations, the described technique has the potential to be expanded to other variations of elective amputation. As an additional example, an elective above knee amputee may undergo a procedure in which the distal leg musculature is salvaged, transferred proximally, and preserved for use in ultimate prosthetic control. This can increase the degrees of freedom available for control in a lower extremity prosthesis severalfold.

The octopus procedure can provide individuals undergoing elective amputation the opportunity to gain greater function for myoelectric prosthetic control while also minimizing pain. The case described here is illustrative of one application of combining the octopus procedure with TMR. Greater patient numbers and long-term follow-up will be necessary to validate the potential benefits of this technique.

Kyle R. Eberlin, MD
Division of Plastic and Reconstructive Surgery
Massachusetts General Hospital
Wang Ambulatory Care Center
55 Fruit Street
Boston, MA 02114
E-mail: kyleeberlin@gmail.com

REFERENCES

1. Lans J, Hoftiezer Y, Lozano-Calderón SA, et al. Risk factors for neuropathic pain following major upper extremity amputation. *J Reconstr Microsurg.* 2021;37:413–420.
2. Maduri P, Akhondi H. Upper limb amputation. StatPearls Publishing. 2020. Available at http://www.ncbi.nlm.nih.gov/pubmed/31082006. Accessed December 2, 2020.
3. Valerio IL, Dumanian GA, Jordan SW, et al. Preemptive treatment of phantom and residual limb pain with targeted muscle reinnervation at the time of major limb amputation. *J Am Coll Surg.* 2019;228:217–226.
4. Economides JM, DeFazio MV, Attinger CE, et al. Prevention of painful neuroma and phantom limb pain after transfemoral amputations through concomitant nerve coaptation and collagen nerve wrapping. *Neurosurgery.* 2016;79:508–513.
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. Vaskov AK, Vu PP, North N, et al. Surgically implanted electrodes enable real-time finger and Grasp pattern recognition for prosthetic hands. *medRxiv.* 2020.
7. 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.
8. Gaston RG, Bracey JW, Tait MA, et al. A novel muscle transfer for independent digital control of a myoelectric prosthesis: The starfish procedure. *J Hand Surg Am.* 2019;44:163.e1–163.e5.
9. Resnik L, Ekerholm S, Borgia M, et al. A national study of veterans with major upper limb amputation: Survey methods, participants, and summary findings. *PLoS One.* 2019;14:e0213578.