Attachment of a Myoelectric Prosthesis After Transulnar Osseointegration Implantation

A 2-Patient Case Study

Kayla M. Jaime, MS, Taylor J. Reif, MD, Haris Kafedzic, MPO, CPO, Glenn Garrison, LPO, CPO, Jennifer Dhawan, MSOP, MScRS, and S. Robert Rozbruch, MD

Investigation performed at Hospital for Special Surgery, New York, New York

Abstract

Case: This report discusses 2 successful cases of traumatic transulnar amputees who underwent osseointegration implantation. After surgery, a myoelectric prosthetic equipped with Coapt (Chicago, IL) recognition software was attached directly to the implant. Patients underwent training with pattern recognition software to learn to control the myoelectric prosthetic with the multiarticulating hand and wrist. Both implants osseointegrated without signs of loosening at the most recent follow-up of 18 months and 2 years, respectively. Prosthetic control gradually improved to allow activities of daily living.

Conclusion: These cases demonstrate what can be achieved with interdisciplinary coordination between surgeons, prosthetists, and emerging technologies.

Upper extremity amputation significantly alters one's ability to interact with the environment and perform activities of daily living. In 2005, it was estimated that there were 1.6 million people living with amputations in the United States, 8% of whom experienced major loss of an upper extremity[1]. The increase in diabetes and other chronic conditions may double these numbers by 2050[1]. To address these needs, advancements have been made over several decades to improve both surgical procedures and prosthesis development.

One such surgical advancement is the bone-anchored transcutaneous osseointegration implant. During osseointegration surgery, a porous metal rod (usually titanium) is implanted directly into the bone with a polished transcutaneous collar that exits the skin through a surgically created stoma[2]. With time, the bone interdigitates around the implant, creating a secure and direct anchorage point for the external prosthesis. This eliminates the socket and its associated problems such as instability, sweating, pinching, and skin irritation. Furthermore, the direct skeletal connection of the prosthesis allows improved energy transfer from the residual limb to the prosthetic limb.

In the prosthetics realm, myoelectric prostheses, which do not rely on the residual strength of the patient, have allowed patients to convert electromyographic (EMG) signals into complex hand and wrist motions. Coupled with pattern recognition software, the myoelectric signals allow the operator to choose between multiple hand gestures in a more natural manner[3].

The 2 patients presented in this report sustained traumatic transulnar amputation with short resultant limbs. The small residual bone stock coupled with soft-tissue scarring rendered them unable to use a traditional socket prosthesis. Osseointegration prostheses, which require only a few centimeters of bone-implant interface to provide stable anchorage, offered these patients an option for prosthesis fitting. These patients demonstrated what can be achieved with interdisciplinary coordination between surgeons, prosthetists, and emerging technologies.

The patients were informed that data concerning their cases would be submitted for publication, and they provided consent

Case Report

Case 1. A 53-year-old man presented 2 years after a work-related accident resulted in proximal transulnar amputation

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSCC/B759).

Keywords osseointegration; traumatic amputation; myoelectric prosthesis; Coapt pattern recognition software; elbow; transulnar amputation; revision amputation

of his right arm. On examination, the distal extent of the ulna could be palpated directly beneath the skin; he exhibited 5/5 strength in flexion and extension of the elbow with range of motion 0° to 120°. The residual ulna measured 58 mm and the radius 20 mm on elbow radiographs. A computerized tomography (CT) scan was obtained to plan a custom osseointegrated implant for the residual bone obtained through a humanitarian device exemption.

Surgically, a wire was inserted percutaneously into the ulnar medullary canal to the proximal extent of the olecranon. An annular skin incision was made to create the stoma and access the ulnar canal (there was no intervening fat or muscle to manage); then serial cannulated reamers were used to expand the canal to the width of the implant. The custom titanium implant, measuring 14 × 48 mm, with porous coating to encourage bone ingrowth and provide initial press fit stability was then inserted retrograde into the ulna (Figs. 1-A and 1-B). A screw was placed through a transverse interlocking hole for initial rotational stability because of the short (<5 cm) segment. There were no complications.

Postoperatively, the patient was instructed to avoid loading the implant for 3 months to allow bone ingrowth and to clean the stoma with sterile saline on gauze for 2 weeks, followed by regular water with baby shampoo in the shower. He then underwent electromyography of the residual arm, which proved the patient was able to generate sufficient transcutaneous microvolts over the muscle belly of both the biceps and triceps to control a myoelectric prosthesis. With this, he began rehabilitation training using the Coapt pattern recognition system using a virtual arm. A cuff with 8 sets of electrodes was placed over his distal humerus, covering the biceps and triceps (Fig. 2). These electrodes captured EMG signals generated

Fig. 1-A

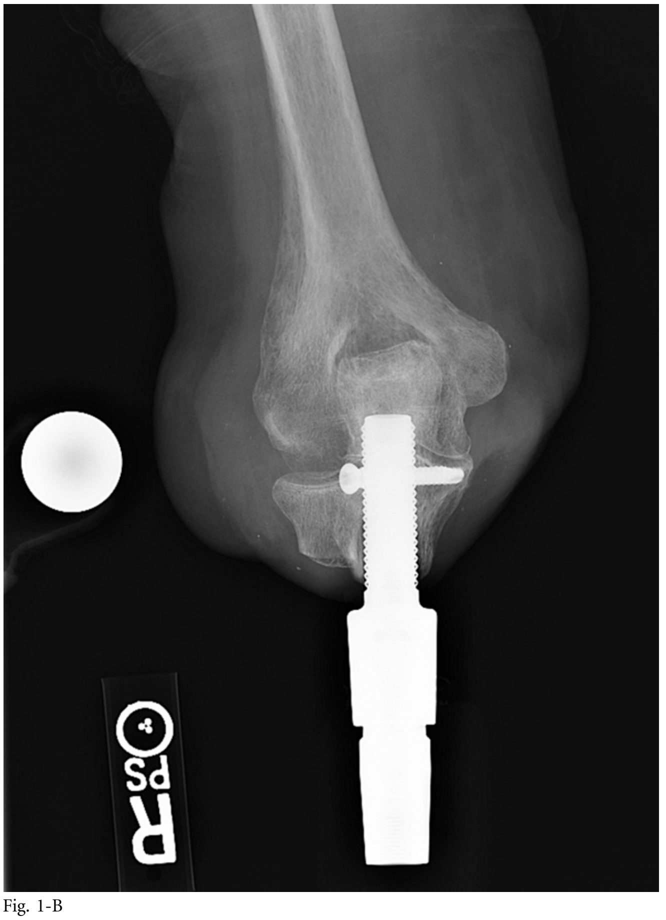

Fig. 1-B

Figs. 1-A and 1-B AP and lateral views of the elbow demonstrating osseointegration implant with transverse interlocking hole for initial rotational stability with a short (4 cm) implant.

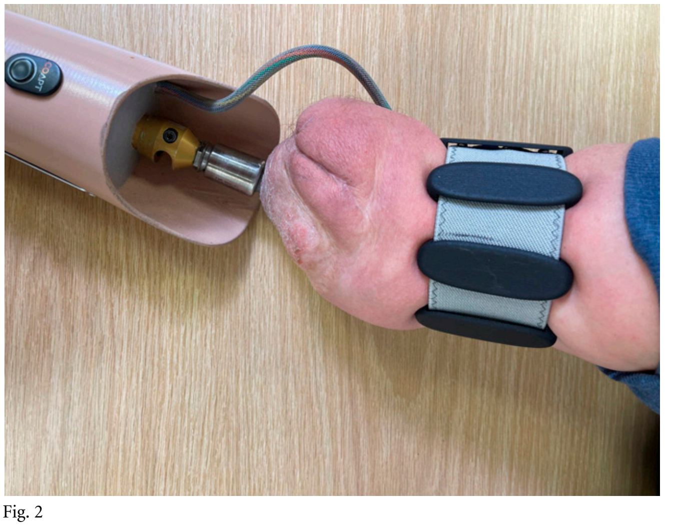

Fig. 2

Photograph of the 8 electrodes encircling the biceps and triceps, which deliver electromyographic signals to the external prosthesis equipped with Coapt software.

JBJS Case Connector
Volume 11 · Number 4 · December 15, 2021

Fig. 3-A

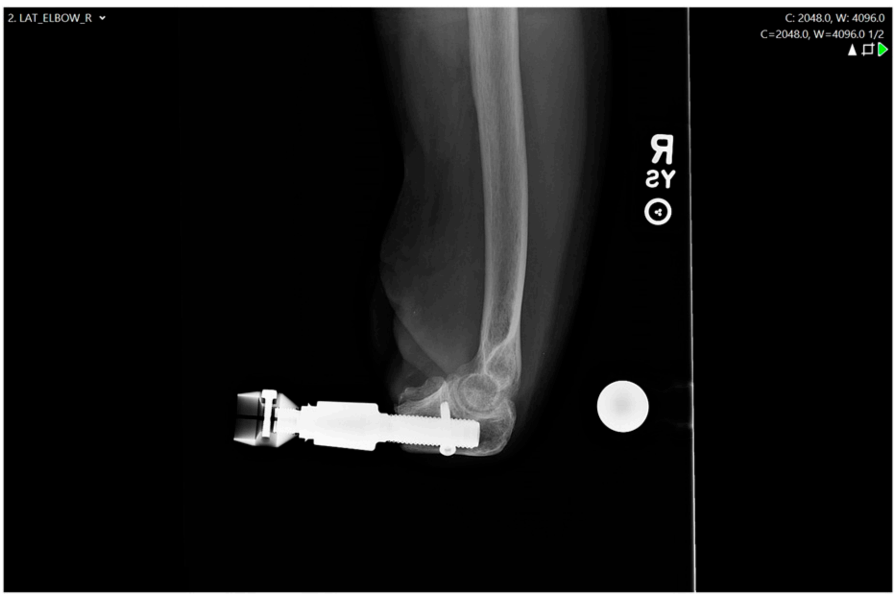

Fig. 3-B

Figs. 3-A and 3-B AP and lateral views of the elbow 2 years after osseointegration implantation. The custom dual cone and abutment are visible distally.

through his muscle contractions and were then converted into movement of the virtual arm. The pattern recognition software analyzed the signals that he could generate for certain motions while the patient visualized how those patterns controlled the hand and wrist. The training built muscle memory in a weightless environment that is easier to control and set expectations for the prosthesis itself.

The external prosthesis was attached to the osseointegration implant abutment, leading into a custom carbon fiber forearm (sized using contralateral tracings), which housed the necessary hardware for the Coapt system (https://coaptengineering.com/Chicago, IL), electronic wrist, and TASKA hand. The patient then began real-world training with the hand and wrist. The hand is a robust, waterproof, multiarticulating myoelectric hand with high-speed digits to ensure high dexterity and precision required for everyday tasks. The electronic wrist further emulates normal anatomy by allowing full pronation and supination (Video 1).

On the 2-year follow-up examination, the patient exhibited 5/5 strength in flexion and extension of the elbow with an improved range of motion of 0° to 125°. Radiographs showed a well-fixed implant with no evidence of loosening

Fig. 4-A

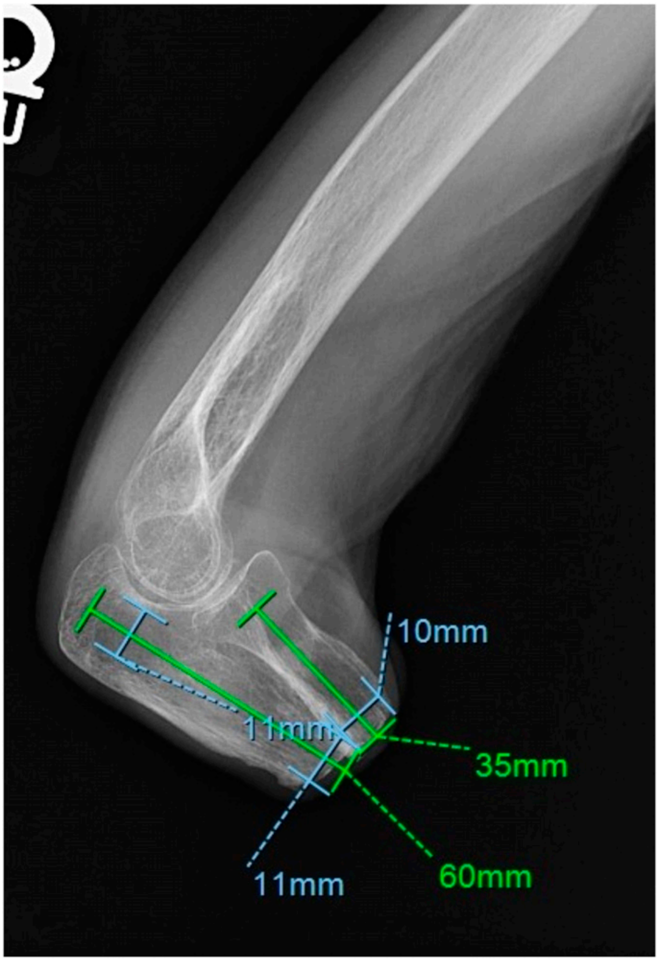

Fig. 4-B

Fig. 4-C

Fig. 4-A Photograph of the short residual limb incompatible with a socket prosthesis **Fig. 4-B** Preoperative radiograph of the elbow with measurements to plan custom implant design **Fig. 4-C** Titanium osseointegration implant with the macroporous-coated stem.

(Figs. 3-A and 3-B). With continued training, he has regained the ability to perform activities of daily living (Video 2).

Case 2. A 54-year-old woman with a history of systemic lupus erythematous experienced a thrombotic event resulting in distal ischemia and ultimately transulnar amputation of her left arm 1 year before presentation. Her short residual limb did not tolerate a socket prosthesis (Fig. 4-A). On examination, she exhibited a flexion contracture of 75° with further flexion to 130° but 5/5 strength of the bicep and tricep musculature and 2+ sensation in all dermatomes. The residual ulna measured 60 mm and the radius 35 mm on radiographic imaging (Fig. 4-B). A CT scan was obtained to plan a custom implant for the residual bone. An 11 mm x 60-mm implant was inserted into the residual ulna

Fig. 5
One-year postoperative radiograph of the elbow demonstrating implantation with press fit stability.

in a similar fashion as described above, but during final impaction, resistance was encountered so the implant was not fully seated to the collar. Owing to the longer segment available for integration, a crosslock screw was not used when designing the implant (Fig. 4-C). The patient then underwent the same pattern recognition training regimen, and a similar prosthesis was attached. Since surgery, she has had 2 soft-tissue infections of the stoma, which resolved quickly with oral antibiotics. At her 18-month follow-up, her flexion contracture had improved from 75° to 45° with further flexion to 130°. Radiographic images showed no evidence of septic loosening (Fig. 5).

Discussion

Short residual limbs, especially those compromised by scarring, soft-tissue flaps, skin grafts, or redundant tissue, are a challenge for the patient and prosthetist. With a paucity of soft tissue, there is less surface area for force distribution and fit, so the patient has difficulty maintaining the residual limb in the socket without crossing more proximal joints, which then creates proximal trimlines that inhibit the function of the joint rather than preserve its use. With stable bone anchorage, an osseointegration implant preserves full range of motion and allows the user to operate the external prosthesis with natural body mechanics. In these patients, the natural range of motion of the shoulder and elbow was preserved, and with continued prosthetic training, they both demonstrated the ability to perform activities of daily living (Video 3).

Cumbersome body-powered prostheses fitted to the patient using sockets, cables, or harnesses can lead to ulcers, pain, poor fit, intolerable perspiration, limited dexterity, decreased range of motion, and increased energy expenditure[4]. This often results in passive use of the device or complete rejection along with overuse of the contralateral limb[5]. Alternatively, electric-powered prostheses are not dependent on a patient's muscle strength and use surface myoelectric signals to control externally powered devices. Although this once was limited to direct control, which records EMG amplitude of isolated muscle contractions to enable single degrees of prosthetic movement, computer software has expanded its capability to control multiarticulating hand and wrist prostheses (Video 4).

The Coapt pattern recognition system uses computer algorithms to recognize complex EMG signal patterns through several electrode locations. Pattern recognition provides a substantial advantage by using distinct patterns of several muscle activation sites to offer more degrees of movement. Specifically, pattern recognition systems decipher the patient's intent by classifying distinct sets of muscle activation into motion classes, thus offering more intuitive control of the prosthetic hand and wrist by relying on the body's natural coordination of several muscle contractions. With increased use, the activation of specific learned muscle groups should continue to improve the control of the prosthesis, which can be recalibrated repeatedly, potentially allowing simultaneous control of elbow and prosthesis, which is otherwise limited by crossed signals.

The surgical portions of the procedure are similar to the implantation of an intramedullary nail or total hip arthroplasty. As such, this may facilitate adoption of the technique once implants are more widely available. The stability of the titanium bone interface, which forms without an intervening fibrous layer, allows for anchoring a prosthesis without a socket. Although infection risk would seem to preclude a transcutaneous intramedullary implant, studies from across the world report a low risk of septic loosening or explantation[6-8], demonstrated by a 9% 10-year cumulative risk of explantation of transfemoral implants because of osteomyelitis in 1 study[7] and a 3% risk with a 6.3-year follow-up in another[9]. Previous infection does not preclude reimplantation[10]. However, most infections are superficial, confined to the stoma, and managed with a short course of oral antibiotics, and even some deep infections can be managed with intravenous antibiotics and preservation of the stem[7].

The osseointegration implants are purchased by hospitals and covered by insurance under codes for intramedullary rod insertion, but the cost of the prosthetic devices (elaborate mechanized components can exceed **$100,000**) has limited commonplace usage. The above patients obtained funding for their myoelectric prostheses through insurance and personal donations, respectively. Thus, there are sparse data supporting the long-term outcomes and durability of these devices, but the experience of early adopters will be critical to promote future accessibility and affordability.

Conclusion

Osseointegration implants combined with myoelectric pattern recognition allow advanced prosthetic control without the need for a cumbersome socket. ■

Kayla M. Jaime, MS
Taylor J. Reif, MD
Haris Kafedzic, MPO, CPO
Glenn Garrison, LPO, CPO
Jennifer Dhawan, MSOP, MScRS
S. Robert Rozbruch, MD

Department of Limb Lengthening and Complex Reconstruction, Hospital for Special Surgery, New York, NY

E-mail address for K.M. Jaime: kayla.jaime@tu.edu

References

1. Ziegler-Graham K, MacKenzie EJ, Ephraim PL, Travison TG, Brookmeyer R. Estimating the prevalence of limb loss in the United States: 2005 to 2050. Arch Phys Med Rehabil. 2008;89(3):422-9.

2. Hoellwarth JS, Tetsworth K, Rozbruch SR, Handal MB, Coughlan A, Al Muderis M. Osseointegration for amputees: current implants, techniques, and future directions. JBJS Rev. 2020;8(3):e0043.

3. Leone F, Gentile C, Ciancio AL, Gruppioni E, Davalli A, Sacchetti R, Guglielmelli E, Zollo L. Simultaneous sEMG classification of hand/wrist gestures and forces. Front Neurorobot. 2019;13:42.

4. Pezzin LE, Dillingham TR, Mackenzie EJ, Ephraim P, Rossbach P. Use and satisfaction with prosthetic limb devices and related services. Arch Phys Med Rehabil. 2004-05;85(5):723-9.

5. Pierrie SN, Gaston RG, Loeffler BJ. Current concepts in upper-extremity amputation. J Hand Surg Am. 2018;43(7):657-67.

6. Hagberg K, Ghassemi Jahani S, Kulbacka-Ortiz K, Thomsen P, Malchau H, Reinholdt C. A 15-year follow-up of transfemoral amputees with bone-anchored transcutaneous prostheses: mechanical complications and patient-reported outcomes. Bone Joint J. 2020;102-B(1):55-63.

7. Tillander J, Hagberg K, Berlin Ö, Hagberg L, Brånemark R. Osteomyelitis risk in patients with transfemoral amputations treated with osseointegration prostheses. Clin Orthop Relat Res. 2017-12;475(12):3100-8.

8. Al Muderis M, Lu W, Li JJ. Osseointegrated Prosthetic Limb for the treatment of lower limb amputations. Unfallchirurg. 2017;120(4):306-11.

9. Ranker A, Örgel M, Beck JP, Krettek C, Aschoff HH. [Transcutaneous osseointegrated prosthetic systems (TOPS) for transfemoral amputees - a six-year retrospective analysis of the latest prosthetic design in Germany]. Rehabilitation (Stuttg). 2020-12;59(6):357-65.

10. Brånemark R, Berlin Ö, Hagberg K, Bergh P, Gunterberg B, Rydevik B. A novel osseointegrated percutaneous prosthetic system for the treatment of patients with transfemoral amputation. Bone Jt J. 2014;96-B(1):106-13.