Medical Modeling for Precision Ulna Reconstruction Using a Microvascular Fibula Free Flap

HAND
2017, Vol. 12(5) NP104–NP108
© The Author(s) 2017
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/1558944716688531
hand.sagepub.com

Michael Alperovich¹, Jonathan M. Bekisz¹, and Vishal D. Thanik¹

Abstract

Background: Despite the growing use of medical modeling in other surgical specialties, its utilization in extremity reconstruction has remained limited. **Methods:** We present the application of medical modeling for ulna reconstruction using a microvascular fibula free flap. **Results:** Following a motor vehicle accident, the patient suffered segmental loss of the right radius and ulna with concomitant forearm soft tissue and muscle loss. Using medical modeling, imaging from the unaffected contralateral forearm and lower extremity was used to plan a reconstruction that restored the anatomic length and orientation of the ulna. Accurate ulna length was recreated from the contralateral ulna, which served as a template. **Conclusions:** Cutting guides for the osteotomies on both the fibula and ulna maximized surface contact at the native ulna and fibula junction to aid in osseous healing of the fibula flap, stabilized the fibula orientation on the ulna, and allowed for lag screw placement for additional fixation.

Keywords: extremity medical modeling reconstruction

Introduction

The microvascular fibula free flap has remained the reconstructive method of choice for critical length defects in the radius and ulna.^{2,6} Offering a robust and reliable blood supply with minimal donor site morbidity, excellent outcomes can be achieved. Furthermore, the septocutaneous perforators of the fibula provide a reliable skin paddle to correct soft tissue defects. Until recently, designing the fibula free flap for the upper extremity relied on a free-hand technique that could be both time-consuming and imprecise often employing more art than science.³ Medical modeling allows for more accurate upper extremity reconstruction through prefabricated cutting guides to match donor- and recipient-site osteotomies.

We present the case of a 40-year-old man who sustained open midshaft fractures of his right ulna and radius with overlying soft tissue burn injury to the skin, subcutaneous tissue, and muscle. Following several debridements and a shorter radius defect reconstruction using an iliac crest bone graft, medical modeling was used to resect a segment of devitalized ulna and restore ulna length using a microvascular fibula free flap.

Case Report

A 40-year-old right hand–dominant man with no medical history suffered a motor vehicle accident resulting in a burn

injury to his right upper extremity, open fractures and segmental bone loss to his right radius and ulna, loss of the extensor digitorum communis muscle and tendons, and loss of the extensor pollicis longus tendon. Notably, his radial, median, and ulnar nerves remained intact. Treated first at an outside facility, he was transferred to our institution 4 weeks after his accident following spanning radius and ulna plate placement. Following his transfer to our institution, the patient underwent several additional debridements to remove sequestrum and local tissue rearrangement for improved soft tissue coverage. Six weeks later, the right radius was reconstructed using a right iliac crest corticocancellous bone graft to fill the segmental defect. The patient was casted for 12 weeks with bony union confirmed radiographically (Figure 1).

Next, attention was directed toward ulna reconstruction to restore fully the patient's right forearm bony anatomy. Given the increased bone gap in the ulna and compromised soft tissue envelope, a microvascular free fibula was planned for ulna reconstruction 6 months after his radius

¹New York University Langone Medical Center, New York City, USA

Corresponding Author:

Michael Alperovich, Hansjorg Wyss Department of Plastic Surgery, New York University Langone Medical Center, 307 East 33rd Street, New York, NY 10016, USA.

Email: alperovich@gmail.com

Figure 1. Preoperative plain film demonstrating the ulnar defect and a spanning plate as well as the radius with a healed interpositional corticocancellous bone graft.

reconstruction. The right upper extremity had a preserved distal radioulnar joint (DRUJ) with 60° of pronation/supination. Consequently, a 2-bone forearm was favored over other surgical alternatives such as a 1-bone forearm or a Sauvé-Kapandji procedure.

Using computed tomographic (CT) imaging of the unaffected contralateral upper extremity as a template, correct ulna length could be restored to the right upper extremity. Along with the left lower extremity and right upper extremity CT data, medical modeling was used to plan oblique osteotomy cutting guides for the right ulna and left fibula. Cutting guides provided precise fibula length for ulnar length recreation as well as predictive screw holes for plate fixation (Figure 2). The preoperative CT angiogram can be used to identify the nutrient artery during medical modeling and placement of osteotomies. However, it was not directly utilized for this purpose during the reconstruction.

On the day of surgery, the left fibula microvascular free flap was dissected in the usual fashion with a large skin paddle over the single bone segment. Native fibula bone was preserved 5 cm from the proximal head and 6 cm from the distal end. The prefabricated cutting guides were affixed to the fibula and used to make the proximal and distal osteotomies according to the planned angles. Angled cuts provided increased bone-to-bone contact at the ulna-fibula junction, placement of a lag screw for further stabilization, and prevention of fibula rotation around the ulna.

Following the fibula harvest, the right ulna was debrided, ulna hardware placed at the outside hospital removed, and the prefabricated cutting guide affixed to the ulna for removal of nonviable ulna bone (Figure 3). In total, 13 cm of devitalized or damaged ulna was excised. The ulnar artery and basilic vein were dissected and prepared for arterial and venous anastomosis to the peroneal artery and vein.

The left fibula microvascular free flap was divided at its proximal pedicle attachment and brought to the right ulna. The distal segment of ulna was affixed using a 7-hole ulnar plate and 3.5-mm screws with a single lag screw from the ulna to fibula through the oblique osteotomy. A second 7-hole ulnar plate and 3.5-mm screws were placed from the proximal ulna to the fibula. Two plates were used rather than a single plate largely due to personal preference and to limit stress shielding. The medical modeling and predictive screw holes could be utilized with either method.

The peroneal artery was anastomosed to a branch of the ulnar artery using a hand-sewn anastomosis and the peroneal vein was anastomosed to a branch of the basilic vein using a 3.5-mm venous coupler. After inset and closure of the skin paddle and soft tissue, the right upper extremity was splinted in elbow flexion, wrist extension, and metacarpophalangeal flexion. The patient was casted after the acute postoperative period for a planned prolonged period of bone immobilization.

One month postoperatively, the cast was inadvertently removed while the patient was convalescing at an outside facility, and he developed proximal plate loosening necessitating placement of a new proximal 12-hole compression plate. By 14 months postoperatively, CT imaging revealed excellent bone healing between the native ulna and donor fibula. This viable bony platform will serve for future tendon reconstruction to restore function (Figure 4).

Discussion

In the past decade, medical modeling has grown in popularity for complex surgical reconstructions. It allows the surgeon to simulate the operation prior to surgery, anticipate reconstructive challenges, and provide for a more streamlined live operation. In the upper extremity, the unaffected contralateral side can be used as a template to match reconstructive ideals.

Although use of this technology has increased in other surgical fields, to date medical modeling has had very limited and preliminary applications in the upper extremity.^{5,7-9} Our case applies this technology toward segmental forearm reconstruction to restore both ulna bone length and orientation as well as overlying soft tissue.

Our case required the restoration of appropriate ulna length following traumatic shortening. When planning the length of fibula to harvest, CT imaging from the contralateral, unaffected ulna was used to plan the fibula osteotomies. This is an illustrative example of creating a mirror

Figure 2. Virtual Surgical Planning images. Top left: Planned I-piece ulna cutting guide secured with 0.045 K-wires. Top right: Planned fibula cutting guide. Bottom: Series showing preoperative anatomy, planned resection, and simulated postoperative outcome with fibula flap inset.

Figure 3. Intraoperative photograph following removal of the spanning ulna plate and placement of the ulna cutting guide secured with K-wires.

image template of the unaffected contralateral side to plan bone length, osteotomies, best fit of the graft, and hardware placement.¹⁰

Through medical modeling, the patient's intraoperative course is more streamlined as the cutting jigs, osteotomy angles, and drill holes are preplanned. A free-hand technique based on intraoperative judgment is replaced with execution of a surgery preplanned virtually.³

By designing angled osteotomies on the fibula and ulna, contact between the 2 bone surfaces is optimized to provide an exact fit. This maximization of bony contact between the flap and native bone increases surface contact for healing.^{1,4} The oblique cut provided enough overlap for lag screw fixation at one end. Finally, it also prevented the ulna from rotating around the fibula flap.

From a patient safety and resources perspective, medical modeling has been shown to decrease total operative time

Figure 4. Postoperative imaging. Left: Immediate postoperative plain film with fibula flap inset to the ulna. Right: 14-month postoperative computed tomographic scan with bony union between the fibula flap and native ulna.

and provide for more accurate osteotomies than cases that are not modeled.¹ By reducing time spent in the operating room, the patient receives decreased total anesthetic, and there is less utilization of costly intraoperative resources. Despite the added up-front cost of medical modeling, the total savings may offset or at least balance the extra costs from employing this technology.

Medical modeling will continue to increase in popularity. With a low barrier to entry as well as a number of demonstrated benefits for both patient and surgeon, medical modeling possesses considerable value as a resource for improving operative outcomes and efficiency. Although its use in surgery of the hand and upper extremity has to this point been limited, our case demonstrates its potential within this field and suggests that others may likewise find it beneficial to begin utilizing similar strategies in approaching difficult and complex cases.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures 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 the individual who underwent surgery in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Chang EI, Jenkins MP, Patel SA, et al. Long-term operative outcomes of preoperative computed tomography—guided virtual surgical planning for osteocutaneous free flap mandible reconstruction. *Plast Reconstr Surg*. 2016;137:619-623.
2. Gan AW, Puhaindran ME, Pho RW. The reconstruction of large bone defects in the upper limb. *Injury*. 2013;44:313-317.
3. Levine JP, Bae JS, Soares M, et al. Jaw in a day: total maxillofacial reconstruction using digital technology. *Plast Reconstr Surg*. 2013;131:1386-1391.
4. Marsell R, Einhorn TA. The biology of fracture healing. *Injury*. 2011;42:551-555.
5. Murase T, Oka K, Moritomo H, et al. Three-dimensional corrective osteotomy of malunited fractures of the upper extremity with use of a computer simulation system. *J Bone Joint Surg Am*. 2008;90:2375-2389.
6. Noaman HH. Management of upper limb bone defects using free vascularized osteoseptocutaneous fibular bone graft. *Ann Plast Surg*. 2013;71:503-509.
7. Oka K, Moritomo H, Goto A, et al. Corrective osteotomy for malunited intra-articular fracture of the distal radius using a custom-made surgical guide based on three-dimensional computer simulation: case report. *J Hand Surg Am*. 2008;33:835-840.
8. Schweizer A, Furnstahl P, Harders M, et al. Complex radius shaft malunion: osteotomy with computer-assisted planning. *Hand*. 2010;5:171-178.
9. Schweizer A, Furnstahl P, Nagy L. Three-dimensional correction of distal radius intra-articular malunions using patient-specific drill guides. *J Hand Surg Am*. 2013;38:2339-2347.
10. Zheng G, Li S. Pre-operative planning and surgical technique. In: *Computational Radiology for Orthopaedic Interventions*. Springer International; 2016:126-136. Springer International Publishing, Switzerland 2016.