SURGICAL TECHNIQUE

Triangular Vascularized Free Fibula Flap for Massive Carpal Reconstruction

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Massive carpal loss following trauma, tumor, or infection poses a difficult reconstructive challenge. There are limited reconstructive options for such cases, particularly when the metacarpal bases are also lost. We describe a method of carpal reconstruction using closing wedge osteotomies in a triangular vascularized free fibular flap, and a proposed algorithm for the management of metacarpal instability in this setting. *(J Hand Surg Am. 2021;■(■):■−■. Copyright © 2021 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Carpal reconstruction, free fibular, triangular.

Massive carpal reconstruction following trauma, tumor, or infection is a challenging clinical scenario. Operative options are governed by the etiology, size of the defect, and articulations involved. Patient-specific megaprostheses have been previously used with good results but are contraindicated in the presence of an infection.[1] A vascularized free fibula flap provides sufficient length, allows the delivery of higher concentrations of systemic antibiotics, and presents a geometric profile similar to the native radius.[2] Jones et al[3] described a technique of "double barreling" the graft, allowing increased loading capacity. Several reports have documented successful reconstitution of large defects due to prior sepsis, including transcarpal reconstruction. However, complete involvement of the distal carpal row and bases of the metacarpals, with disruption of the intermetacarpal ligaments, necessitates a more complex mode of reconstruction.

Here, we describe a triangular vascularized free fibula flap, created by performing closing wedge osteotomies, to provide bony reconstitution in the setting of massive carpal loss involving the base of the metacarpals (Fig. 1), and propose a strategy for the management of metacarpal instability in this setting.

INDICATIONS AND CONTRAINDICATIONS

A triangular vascularized free fibular flap (TVFFF) can be used in any situation necessitating reconstruction of large skeletal defects with multiple points of proximal or distal fixation. Although we have employed it in the setting of massive carpal reconstruction, it may also conceivably be used in midfoot reconstruction.

Contraindications to its use include active infection, a history of peripheral vascular disease involving the lower extremities, preoperative Doppler studies or angiography indicative of notable atherosclerotic disease, or anomalous lower extremity vasculature. As the free fibular flap provides vascularity, it can be used in infected beds (such as cases with prior carpal osteomyelitis) and provides considerable length for reconstruction. Although damage to recipient vessels (such as the radial or ulnar arteries) from previous truama is not a contraindication, it can increase the technical difficulty.

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FIGURE 1: Triangular vascularized free fibular flap to maintain length and stabilize metacarpals in the setting of a prior infection.

Alternative sources of vascularized osseous flaps include the iliac crests, scapulae, ribs, and medial femoral condyles. These, however, do not allow spanning of large defects, as permitted by TVFFF.

SURGICAL ANATOMY

The fibula is long, straight (up to 40 cm in length) and tricortical in profile, allowing it to easily match forearm defects or be fitted into the intramedullary canal of larger long bones. It may be harvested as a composite fasciocutaneous or fasciomusculocutaneous flap, enabling soft tissue reconstruction and direct monitoring of the vascular anastomosis. There is limited donor-site morbidity given the slight load the fibula bears across the ankle, particularly if efforts are made to preserve the distal 6−8 cm of the fibula during harvest to avoid ankle instability or deformity.[4]

The fibula has both endosteal and periosteal blood supplies, arising predominantly from the peroneal artery. The peroneal artery branches from the posterior tibial artery approximately 2−3 cm distal to the popliteus muscle and descends along the medial border of the fibula, passing between the flexor hallucis longus and tibialis posterior. Endosteal vascularity arises from a nutrient vessel that enters the bone in the posteromedial aspect of the middle third of the fibula, at a mean of 17 cm (range, 14−19 cm) below the styloid process, and is considered the major blood supply. The resulting blood flow is centrifugal, from the medulla to the cortex. The periosteal circulation is profuse and net-like, supplying the outer one-third of the cortex, and arises from the peroneal vessels. This rich periosteal blood supply permits multiple osteotomies, as has been shown in head and neck reconstruction.[5] It is considered the minor blood supply. The peroneal pedicle has a length of 6−8 cm, an arterial diameter of 1.5−3 mm, and venae comitantes that lie on either side of the artery.

Generally, recipient vessels should be located outside the zone of injury and provide antegrade flow to the flap. Although both the radial and ulnar arteries can be used as recipients at the wrist level, the radial artery is preferred because of easier accessibility, its nondominance in the vascular supply to the hand in the majority of patients, and the diminished risk of damage to surrounding neurologic structures. In general, end-to-side anastomoses are preferred, even with a reassuring Allen test. The radial artery has 2 accompanying venae comitantes (one slightly larger than the other), which can be incorporated in an end-to-end anastomosis to provide adequate venous drainage.[6] The radial artery has two accompanying venae comitantes (one slightly larger than the other) which can be incorporated in an end-to-end anastomosis to provide adequate venous drainage.[7] The cephalic vein provides the major venous outflow to the radial side of the forearm; although an alternative venous recipient, it is often damaged in cases of trauma, and may also present a caliber mismatch.

SURGICAL TECHNIQUE

Careful preoperative evaluation of both the donor and recipient sites is important. A history of intermittent claudication, deep vein thrombosis, lower limb trauma, and varicose veins should be elicited. The quality of both dorsalis pedis and posterior tibial pulses is assessed, as is the integrity of the lower limb skin. Abnormal pedal pulses or major lower limb trauma necessitates preoperative donor leg computed tomography angiography, which will help exclude the presence of arteria peronea magna. The residual donor site soft tissue envelope should be assessed, and a composite flap should be harvested if required. Assessment of recipient vessels should be performed

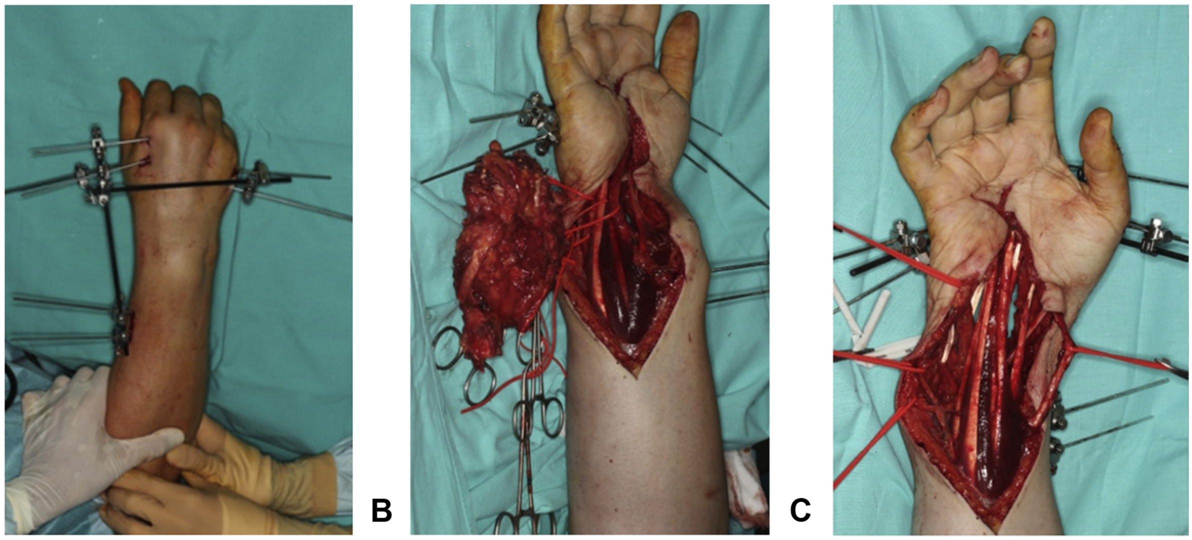
A 

FIGURE 2: Case 2. **A** Frame installation prior to tumor resection. **B** Bars and nuts were removed for easier resection of the mass. Note collapse of the hand without distraction. The resected tumor is shown lying next to the wrist. **C** Replacing the frame restores anatomic parameters.

clinically and by Doppler ultrasound, with computed tomography angiogram if there is a concern.

The length and location of the defect (taking into account further resection of the diseased tissue) will determine the length and configuration required for the flap. In the case of tumor resection, an external fixator is fitted prior to any resection to later accurately restore the skeletal length and width. For ease of intraoperative access, the frame can then be removed with the pins left in situ; reinstalling the fixator following resection will allow the restoration of anatomic parameters (Fig. 2).

The intraoperative technique is divided into 3 separate phases: graft harvest, recipient site preparation, and defect reconstruction.[8] The fibula is harvested in the standard manner. Once the pedicle is exposed, the lower limb tourniquet is deflated with the graft in situ until the recipient site is prepared, to diminish ischemia time.

The incision over the recipient site is planned to avoid areas of compromised skin and facilitate bone exposure and dissection of the recipient vessels. The pathologic lesion is adequately debrided back to viable bony margins. Metacarpal debridement is performed uniformly if possible, to allow a normal length relationship between all digits and the thumb. The recipient vessels (usually the radial artery and its venae comitantes) are assessed for the presence of a scarred soft tissue envelope, which may compromise blood flow. In this case, the anastomosis should be performed more proximally and may necessitate vein grafts in the case of inadequate pedicle length. Following the preparation of the recipient site, the fibula is detached by ligating the peroneal vessels and removing its remaining posteromedial attachment to the flexor hallucis longus.

A triangular construct is now created via 2 closing wedge osteotomies at intervals of thirds along the graft length. The closing wedge osteotomies are fashioned on the same side as the pedicle in order to avoid tension on the vascular supply at the time of osteotomy closure (Fig. 3). While performing the osteotomies, the periosteum and vessels must be carefully dissected from the fibula and protected. It is crucial to plan such that the pedicle is not tensioned following osteotomy and positioning of the fibula. The bony ends are reduced, and each apex of the triangle is fixated either with a low-profile plate with screws or an intramedullary device (Fig. 4). The construct is inserted into the bony defect. Proximal fixation to the radius is performed with the wrist in neutral to slight extension and neutral deviation, to allow normal grip strength and function. This is best performed by a sturdy, precontoured locking plate. Distal fixation to the metacarpals is performed by individual low-profile plates or intramedullary screws. Care is taken to assess the digits for rotational malalignment, as well as to ensure that the thumb is adequately opposed for function. Multiple small plates, as opposed to a large spanning plate, are preferred to theoretically minimize stress shielding. Intramedullary devices may be required in some circumstances; however, they are not optimal because of potential damage to the endosteal blood supply, and multiple small plates are preferred.

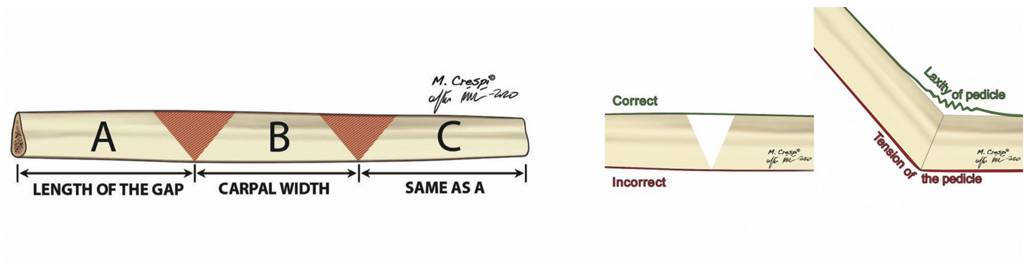


FIGURE 3: Osteotomy planning. Sufficient fibula should be harvested to restore the length of the defect. Note that each osteotomy will result in the additional loss of approximately 2 cm of fibula when the flap is triangulated, which must be accounted for when planning the fibular resection. Furthermore, the pedicle will be placed under tension if the osteotomies are performed on the contralateral side.

Cancellous bone graft is packed at junction sites to facilitate union.

The flap is revascularized in the standard manner. Dependent on the soft tissue envelope, the skin paddle can be appropriately inset or primary closure can be performed, ensuring no tension over the vascular anastomosis.

POSTOPERATIVE MANAGEMENT

The upper limb is immobilized in either a below-elbow backslab (including the thumb and digits) or with the original external fixator left *in situ*. If a fasciocutaneous flap is used, the skin paddle is left exposed to assess for flap viability. Appropriate anticoagulation and antibiotic medications are prescribed, with the duration dependent on underlying pathology.

In the setting of massive osseous reconstruction, early motion of digits is important to regain a useful functional range. The patient is reviewed at the 1-week postoperative mark, and gentle active range of motion exercises are commenced in a volar thermoplastic orthosis with detachable digit and thumb attachments. Loading and use are limited until the graft is incorporated.

The union of the graft-host sites is clinically and radiographically evaluated. Computed tomography is used if plain radiographs are equivocal.

PEARLS AND PITFALLS

To allow maintenance and restoration of adequate length and soft tissue tension, we believe it is preferential to span the wrist with an external fixator prior to debridement and tissue resection. Aggressive and extensive debridement prior to definitive stabilization is crucial to preventing recurrence of an infection or tumor, as well as to permitting adequate graft-host incorporation.

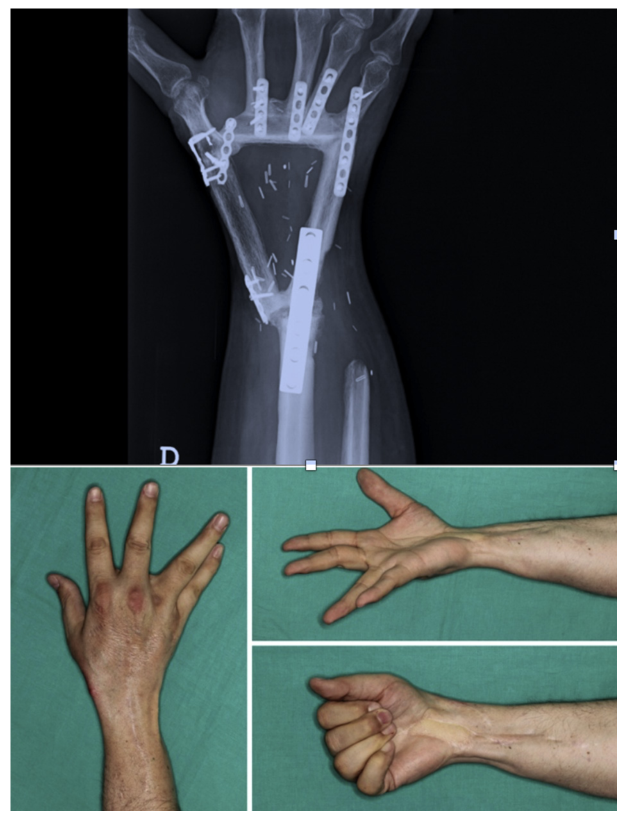


FIGURE 4: X-ray result 1 year after the procedure. Functional result at 6 years after the procedure.

Care must be taken during the creation of osteotomies and bony fixation to protect the vascular pedicle and periosteum and to avoid devascularization of the construct. As with all microvascular anastomosis, tension and pressure are to be avoided to allow patency. Bony fixation must be sufficiently stable to allow early range of motion, in order to prevent stiffness and a poor functional outcome.

COMPLICATIONS

Complications can involve either the donor or recipient site. Donor site complications have been

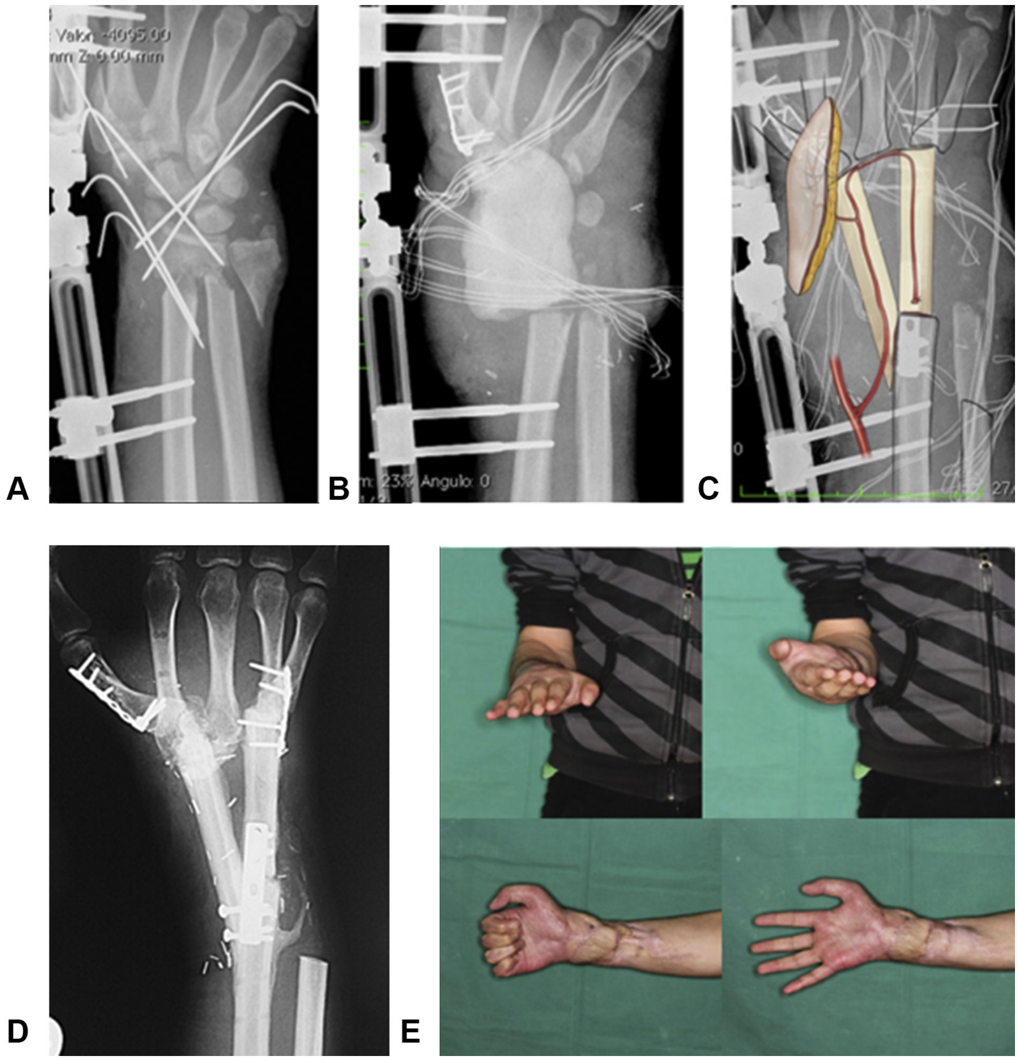


FIGURE 5: **A** Preoperative radiographs, with the infected bone exposed because of associated soft tissue loss. **B** The antibiotic spacer was left for a week, followed by insertion of TVFFF. **C** Artistic rendering of the reconstruction. **D** Radiograph 1 year after surgery. **E** Clinical photographs 1 year after surgery.

reported at a frequency of between 7% and 35%.[2,3,6,9] Donor site complications include nerve injury and painful neuromata, vascular injury, ankle pain, and ankle instability. Children are more likely to develop ankle instability than adults, although the preservation of the distal quarter of the fibula may negate this risk. Valgus deformity of the ankle may also be seen in children, occurring in 10% to 42% of patients, and may necessitate surgical management.

Recipient site complications can be either immediate or delayed. Immediate complications include damage to the superficial radial nerve, radial artery, or extensor tendons, and may be prevented by careful dissection and soft tissue handling. Damage to the graft pedicle or periosteum should be avoided by protection during osteotomy creation. Delayed complications include stress fractures around the hardware, which may necessitate revision fixation. Supplemental bone grafting is often required, with primary union rates of 61% and overall union rates of 81% after secondary procedures.[9] Recurrence of an infection or tumor may be avoided by appropriate debridement and use of antibiotics or adjunct therapy. The extensive dissection required in these cases commonly causes an excessive scar response that leads to adhesions, and may necessitate hardware removal and tenolysis to restore functional range of motion.

CASE ILLUSTRATION

We have performed this technique of complex carpal reconstruction on multiple patients for differing etiologies, as presented below. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional review board) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all patients for inclusion of their case in this report.

A 54-year-old man presented with severe radiocarpal and midcarpal septic arthritis and radial, ulnar, carpal, and metacarpal osteomyelitis following a missed infection. On examination, there was a draining abscess from the dorsal aspect of his right wrist. Following serial debridement of all infected skin, joint, and bone, he underwent a pedicled groin flap for skin coverage, with temporary skeletal stabilization via an external fixator. Following a course of appropriate antibiotics, the patient underwent a TVFFF for carpal reconstruction. The 6-month follow-up demonstrated good progress of healing, and removal of hardware and extensor tenolysis procedures have been scheduled for the patient (Fig. 1).

A 39-year-old male presented for a second opinion after having been recommended an amputation because of 3 prior recurrences of giant cell tumor of the tendon sheath (GCTTS). Magnetic resonance imaging showed multibone involvement, and prior pathologic examination revealed the benign nature of the lesion. Benign intra-articular GCTTS is a more locally aggressive variant of standard GCTTS and can result in limb amputation if clear margins are not obtained.[10] Following radical resection, a vascularized free fibular flap was used in a delta configuration to span the resulting gap, including a skin island set in the carpal canal, devised to yield fat and prevent tendon adhesion[11] (Fig. 2). At the 6-week mark, the external fixator was removed and radiotherapy commenced. All graft-host junctions united except for the proximal fibula-radial interface, which required secondary plating after radiotherapy was completed. No tenolysis was required. The function at 6 years is demonstrated in Figure 4.

A variation of this technique was used in the third patient with osteomyelitis of the distal radius, ulna, and carpus. A 26-year-old was referred 6 weeks after a crush injury with a large soft tissue defect and draining pus from a massive wrist infection (Fig. 5A). The index operation involved resection of the entire carpus and distal end of the radius. Coverage was achieved via a wrapped gracilis flap, and the bone void was filled with an antibiotic cement spacer (Fig. 5B). A week later, the defect was reconstituted with a 9-cm double-strut vascularized free fibular flap, creating a delta configuration with the bases of the metacarpals. Partial support was achieved by a sleeve of vascularized periosteum, to which a cancellous bone graft (from the tibial condyle) was packed. The gracilis was rewrapped. Primary healing occurred, and the external fixator was removed at 6 weeks (Fig. 5C). Final clinical and radiographic outcomes are shown in Figures 5D and 5E.

SUMMARY

The reconstruction of massive carpal loss following trauma, tumor, or infection poses an important challenge for the treating surgeon. In particular, when there is a loss of the metacarpal bases, traditional methods of reconstruction may not be feasible. Excellent clinical outcomes can be achieved through the use of reconstructive microsurgery and a triangular free fibular flap as described, with acceptable donor site morbidity.

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