Vascularized Medial Femoral Condyle Flap Reconstruction for Osseous Defects of the Hand and Wrist

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KEYWORDS

• Medial femoral condyle flap • Metacarpal nonunion • Phalanx nonunion • Scaphoid nonunion • Vascularized bone

KEY POINTS

- The medial femoral condyle flap (MFC) has become a very valuable tool in the treatment of upper extremity nonunions.
- The MFC has applications is treating nonunions of tubular bones of the hand, carpal bones, long bones of the upper limb, and challenging arthrodesis.
- The upper extremity reconstructive surgeon should be familiar with the diverse sites where the MFC may be utilized and the surgical considerations for each.

INTRODUCTION

Free vascularized flaps utilizing the descending genicular artery system have become increasingly utilized over the past few decades.[1–13] Prior to the popularity of the medial femoral condyle flap (MFC), the most widely used source of vascularized bone was the vascularized fibula flap. Surgeons around the globe have become facile with applications of the MFC flap for many locations about the human skeleton. It is recognized to possess numerous beneficial characteristics:

- Ease of harvest: the flap is harvested in the supine position. This permits the use of a two-team surgical approach for efficiency and speed of the procedure.
- Lack of sacrifice of major peripheral artery: unlike the requirement of harvesting the peroneal artery for the fibula flap, the medial femoral condyle flap spares all of the major vessels providing perfusion to the distal extremity.
- Versatility: while the fibular flap provides a cylindrical long bone and is advantageous in lengthy osseous reconstructive cases, the MFC can provide corticocancellous segments of different widths, lengths, and shapes making useful for long bone, tubular bone, and joint reconstruction.
- Pliability: unlike the fibular flap, the MFC can be harvested as a thin corticoperiosteal flap with a pliable cortical surface. This enables the surgeon to fashion contoured onlay flap around atrophic nonunions without bone loss. Alternatively, the flap may be harvested as a corticocancellous flap for intercalary osseous defects.
- Length of pedicle: the descending genicular artery provides generous pedicle length enabling ease of anastomosis remote from the site of bony reconstruction.
- Chimeric tissue harvest: the descending genicular artery pedicle enables the harvest of corticocancellous bone, osteochondral bone, a reliable skin segment, and vascularized tendon as dictated by the reconstructive needs of the surgical defect.

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- Ease of postoperative care: unlike the fibular flap, the osteocutaneous MFC does not typically require a skin graft applied to the donor site, nor does the donor site require immobilization/splinting.

When vascularized bone flaps are employed by reconstructive surgeons at various locations around the human skeleton, the fibula remains the most common for larger defects (ie, mandibular reconstruction, long bone intercalary defects) or sites requiring structural support afforded by a cylindrical long bone flap (ie, the femur, tibia, or humerus). Because of the frequent incidence of smaller osseous defects or recalcitrant atrophic nonunion in the upper limb, the medial femoral condyle has seen widespread adaptation by reconstructive hand surgeons.

This article will address the use of the corticocancellous medial femoral condyle flap for problematic osseous defects of the tubular bones of the hand (phalanges and metacarpals), the scaphoid waist, and difficult defects of infections or failed wrist fusions. We will also briefly discuss its use in forearm defects of the radius and ulna.

FLAP ANATOMY

The medial femoral condyle is perfused most commonly by osteoarticular periosteal branches of the descending geniculate artery, which arises from the superficial femoral artery in the proximal aspect of the adductor canal. The descending geniculate artery may be absent in 6% of cases. In this instance, these osteoarticular branches covering the periosteum of the medial femoral condyle are fed by the superomedial geniculate artery arising from the popliteal artery. Familiarity with this vascular system enables the surgeon to first identify the periosteal branches, and then follow them proximally to the appropriate source vessel.[14]

The medial femoral condyle flap is often harvested with a skin component. The skin may be harvested using the saphenous artery branch of the descending geniculate artery or the distal cutaneous branches. This enables the surgeon to harvest a longitudinal ellipse of skin over the medial aspect of the thigh. This region may provide generous amounts of skin with while still readily permitting primary closure.[12,15,16]

The descending geniculate artery has a length of 9.1 to 9.9 cm from its origin to the periosteal branches and at its origin has a diameter of 2.1 mm. The average diameter of the associated veins is 1.48 to 1.63 mm. If the flap is harvested utilizing the superomedial geniculate artery, the surgeon will encounter a vessel whose average length is 4.1 cm with an average diameter of 1.7 mm. The vascular tree and details of its anatomy have been described in detail (**Fig. 1**).[14,15,17–21]

DEFECTS OF THE PHALANGES

Recalcitrant phalangeal nonunions are most often treated with vascularized bone grafting when the nonunion has previously failed conventional treatments such as autogenous bone grafting. Due to the small size of these defects, the use of the medial femoral condyle is an appealing option. The diameter of the fibula and the very small amount of bone required would make fibular transfer inappropriate for these defects.

If the resection of the nonunion results in an intercalary defect, the corticocancellous segment of the medial femoral condyle would be utilized. This is harvested using either saw or osteotome technique to elevate the cortical bone and the attached underlying cancellous bone. Alternatively, if the phalangeal defect was an atrophic nonunion without bone loss, the pliable medial femoral condyle corticoperiosteal flap may be elevated using an osteotome passed immediately beneath the cortex. This thin cortical bone can be molded (or scored on its deeper surface to enable the appropriate contour to be achieved) and applied as an onlay flap. The author usually utilizes a mid-axial approach to the digit, orients the cortical surface of the MFC on the midaxial surface of the phalanx, applies a plating construct dorsally, and the vascular pedicle is draped proximally. The proximal anastomosis can be performed into the ipsilateral digital artery or draped to the radial artery in the snuffbox if the position of the nonunion and pedicle length will permit. The venous anastomosis is typically performed on the dorsal aspect of the hand. Because of the limitations of the soft tissue envelope around the phalanges, a small skin paddle is typically taken with the MFC flap and inset into the mid-axial incision to permit ease of closure as well as a means of monitoring the microvascular anastomosis via the surface doppler (**Fig. 2**).

DEFECTS OF THE METACARPALS

Like phalangeal fractures, the use of vascularized bone is typically employed for metacarpal nonunions only after failure of previous cancellous bone grafting.[22–24] In the setting of a single metacarpal nonunion, the flap is typically inset such that the cortical surface is orthogonal to the plating construct. For the small finger, the plating would typically be dorsal and the MFC cortex applied

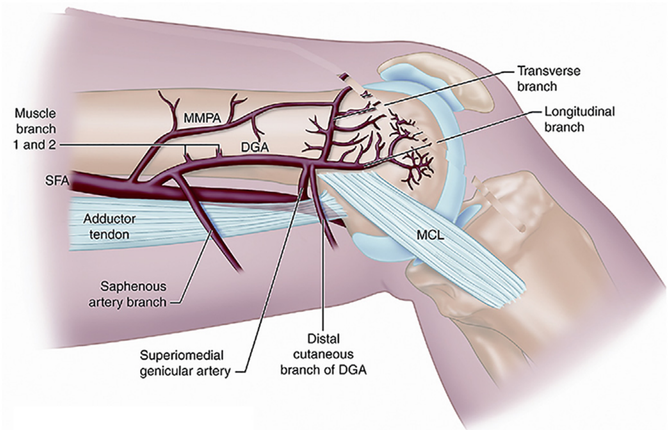

Fig. 1. The descending geniculate artery (DGA) divides into branches to the vastus medialis muscle, skin branches (including the saphenous artery and distal cutaneous artery of the DGA), and articular branches which supply the medial column of the femur.

on the ulnar surface. For the index finger and thumb metacarpals, the plating would be applied dorsally and the cortical bone would be inset radially. For the non-border digits, or for the simultaneous treatment of multiple metacarpals, the MFC flap cortical surface is applied dorsally. In an effort to achieve rigid fixation while not applying compression to the periosteal vessels on the MFC flap, the author has typically applied flexible small caliber plates that can be bent such that screw fixation can be achieved in the metacarpal defects proximal and distal to the MFC. The plates are contoured dorsally above the level of the periosteum of the intercalary MFC. In the cases of multiple adjacent metacarpals, care should be taken to score the cancellous surface of the MFC flap and bend the flap in such a manner that it recreates the arch of the hand on the coronal plane (Fig. 3).

Because of the positioning of the dorsal cortex in these cases, the vascular pedicle is draped

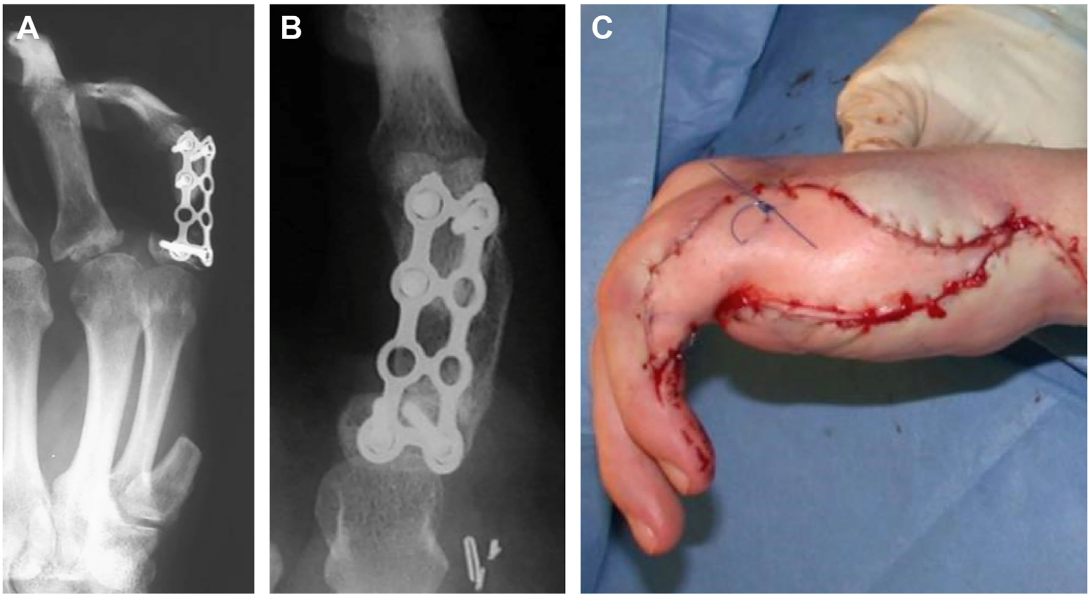

Fig. 2. Example of MFC reconstruction of a phalangeal nonunion. (*A*) Radiograph of ring finger proximal phalangeal nonunion after initial plating and subsequent failed cancellous bone grafting. (*B*) AP radiograph demonstrating healing. The corticoperiosteal MFC was used with the periosteum oriented ulnarly. (*C*) The skin segment was inset on the lateral aspect of the hand. (*From* Assi PE, Giladi AM, Higgins JP. Chapter 18: Medial Femoral Condyle Corticocancellous and Osteochondral Flaps. In: Wiesel SW, Albert T, eds. Operative Techniques in Orthopaedic Surgery. 3rd ed. Lippincott Williams & Wilkins; 2021. p. 3138-3152.; with permission. (Figure 5 in original).)

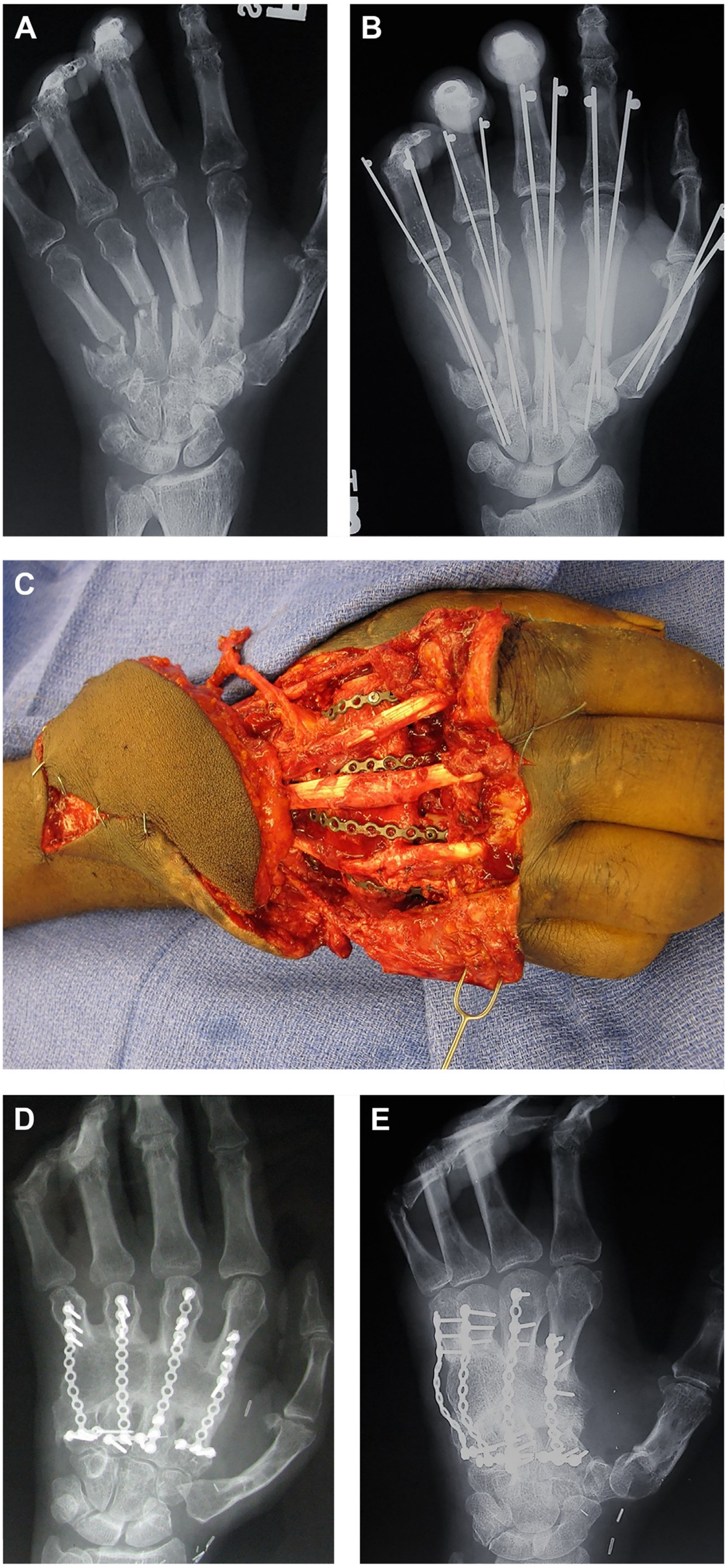

Fig. 3. Example of multiple metacarpal nonunions treated with MFC flap. (*A*) AP radiograph of fixation of five metacarpal fracture sustained from an industrial crush injury. Pin fixation was utilized because of the tenuous appearance of the soft tissue on the dorsal hand. (*B*) Radiographs 4 months after surgery demonstrating the failure of healing of metacarpals 2-5. The poor quality of the dorsal hand skin was felt to be unlikely to heal if conventional plating and cancellous bone grafting was attempted. (*C*) Corticocancellous MFC with skin paddle inset into diaphyseal nonunions of metacarpals 2 to 5. Note that the midline of the bone flap was scored longitudinally and contoured so that the flap recreated the dorsal arch of the palm. (*D*) AP radiograph of hand showing generous healing at the eight osteosynthesis sites. (*E*) Oblique radiograph demonstrating the contoured arch of the plates to avoid contact on the dorsal vascularized periosteum.

into the snuffbox for end-to-side anastomosis into the radial artery and end-to-end anastomosis into surrounding veins. A skin paddle is harvested in conjunction with the MFC flap in these cases and inset along the pathway of the access incision.

SCAPHOID NONUNIONS

The use of the medial femoral condyle corticocancellous flap has become common place in the setting of recalcitrant scaphoid nonunions.[25–28] The flap is applied via a volar approach for waist nonunions where the proximal pole is large enough to preserve. In scaphoid proximal pole nonunions with extremely small or comminuted segments that are deemed non-salvageable, the same vascular pedicle has been utilized to reconstruct the proximal half of the scaphoid using osteochondral medial femoral trochlea flaps. These have been described in detail elsewhere.[22,29–31]

The advantage of the MFC flap for scaphoid waist nonunions is in its ability to provide a corticocancellous segment that is larger than described pedicled vascularized bone flaps for this indication. The size and quality of the osseous segment are very useful in the correction of significantly collapsed scaphoid nonunions with humpback deformity. The scaphoid is approached volarly using an incision along the pathway of the FCR tendon. This approach enables access to the volar scaphoid as well as the radial artery in the distal third of the forearm. The nonunion site is opened, excavated generously and the scaphoid is restored to its appropriate carpal height. This may be done with joysticks or a temporary radiolunate pin applied dorsally (**Fig. 4**). The MFC flap may be harvested simultaneous to the scaphoid nonunion dissection by a second team to minimize operative time. The corticocancellous segment is inserted with the cortical bone facing volarward. Screw fixation is placed retrograde from the distal pole, through the MFC flap, and into the proximal pole. A flap pedicle is draped proximally and end-to-side anastomosis performed into the radial artery as well as venous anastomosis into the adjacent veinae comitante.

This procedure is typically performed without a skin paddle and the skin is loosely closed primarily. This has shown great success in the treatment of difficulty recalcitrant scaphoid nonunions. The author finds this particularly useful in patients that have a significant humpback deformity and are at high risk for surgical failure because of previous instrumentation. Patients are immobilized with 12 weeks of thumb spica casting postoperatively, followed by the confirmation of successful achievement of union with a CT scan.

WRIST DEFECTS

The corticocancellous MFC flap is also very useful in massive carpal defects. Although infrequently encountered, these defects pose a substantial reconstructive challenge in achieving successful wrist arthrodesis. Indications may include previous failed total wrist fusion, traumatic loss of carpal bones, previous osteomyelitis of the wrist joint requiring widespread carpal resection, or failed total wrist arthroplasty with substantial bone loss. These defects are often treated with more conventional cancellous bone grafting as a first-line treatment. However, if the patient has persistent nonunion, the use of the MFC can provide a versatile tool for the treatment of these odd-shaped defects. Use of the fibular flap is difficult because its narrow caliber limits the surgeon's ability to contact various distal osseous targets (ie, multiple metacarpals).

The MFC flap can be harvested as a corticocancellous or onlay corticoperiosteal flap to cover the width and length required to achieve bony union. In these cases, the cortical bone is applied dorsally. The fixation construct required will need to be contoured to protect the dorsal periosteal vessels. If the distal defect extends to the level of the metacarpals (without any remaining carpus), the fixation technique will likely require multiple small plates to bridge the defect and achieve stability of each metacarpal. A skin segment is harvested with the medial femoral condyle and inset to permit closure without tension. The arterial anastomosis is performed either into the radial artery in the snuffbox or the distal volar forearm in an end-to-side fashion (**Fig. 5**).

In these cases, very specific challenges are encountered. If the entirety of the carpus has been lost and fixation is pursued on multiple metacarpals, the surgeon must pay particular heed to ensuring that the rotation of each digit is appropriate. Because of the inherent instability of this defect, the risk of encountering some scissoring of the digits due to malrotation after healing is achieved is substantial.

Because of the size and shape of these defects, additional bone grafting may be helpful. In particularly large defects, the author will harvest the medial femoral condyle flap as a thin pliable corticoperiosteal flap and augment this with additional cancellous autograft, typically harvested from the proximal tibia. The author avoids excessive cancellous bone harvesting from the distal femur with the associated undermining of the support of the condyle. The author has encountered a single case of distal femur pathologic fracture from medial femoral condyle harvest.[32] It is the author's opinion that this risk was created due to the depth

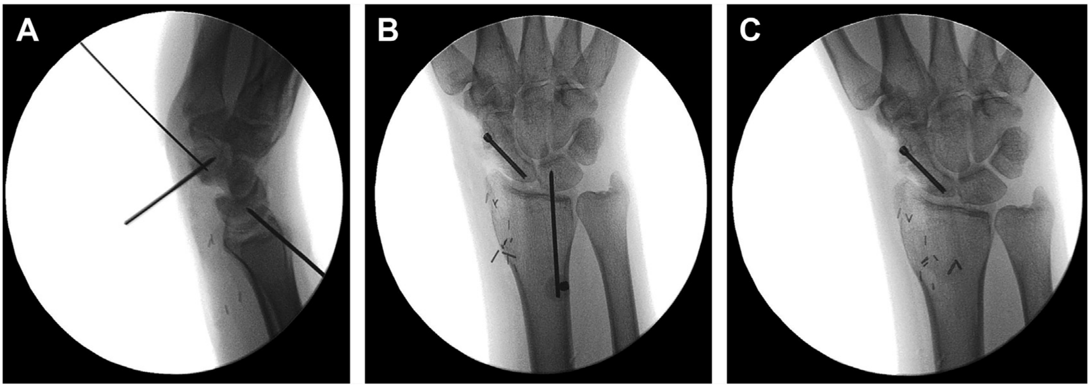

Fig. 4. Intraoperative fluoroscopy demonstrating the correction of scaphoid waist nonunion with collapse using a corticocancellous MFC flap. The scaphoid and lunate are inspected under fluoroscopy for any scaphoid flexion/lunate extension. (*A*) After the reduction of the lunate into neutral posture, an intraoperative radiolunate K wire is placed. Another K wire is used as a joystick in the distal pole for the reduction of the scaphoid and inset of the MFC. (*B*) The defect is filled with the osseous MFC flap and screw fixation is obtained while the radiolunate preserves neutral lunate posture. (*C*) Once scaphoid reconstruction is complete, the radiolunate pin is withdrawn. (*From* Assi PE, Giladi AM, Higgins JP. Chapter 18: Medial Femoral Condyle Corticocancellous and Osteochondral Flaps. In: Wiesel SW, Albert T, eds. Operative Techniques in Orthopaedic Surgery. 3rd ed. Lippincott Williams & Wilkins; 2021. p. 3138-3152.; with permission. (Tech Figure 1C-E in original).)

of the cancellous harvest (rather than the width or length of the cortical harvest).[33–35]

Cases of large wrist nonunion reconstructions are typically approached on a semi-elective basis and performed through an intact skin envelope. A surgeon may be tempted to conclude that no additional skin is needed. It is the author's experience that such a reconstruction will provide a substantial challenge of skin closure and thus harvest of a skin paddle in conjunction with the MFC flap is highly recommended.

FOREARM NONUNIONS

The treatment of radial and ulnar nonunions is addressed in other articles in this publication. A brief commentary on the use of the medial femoral condyle flap for these indications is provided here.

The MFC, while versatile, low morbidity, and clinically effective, should be employed in upper limb long bone nonunions with some specific guidelines. The MFC flap is ideal for onlay corticoperiosteal flap application. It provides a powerful means of correction of nonunion with remarkable osteogenic capability. However, when being used for intercalary defects, it should only be used *when structural bone is not required*. The advent of fixed-angled fixation and locking screw technology has enabled the surgeon to rely on the fixation construct for structural support. However, the surgeon should consider the value of using a stouter structural graft/flap when there is a substantial length of defect that would lead the surgeon to anticipate a prolonged period of healing, or if the site of reconstruction will be submitted to substantial postoperative stresses (torsional, loading, or varus/valgus stress). This is encountered when the surgeon is faced with intercalary defects of the humerus. The reconstruction may be exposed to substantial multidirectional stress with load forces compounded by the weight and position of the distal arm. This concern is also encountered in cases of massive forearm trauma with intercalary defects of both the radius and ulna. Without the structural support of an intact parallel forearm bone, the reconstruction will be submitted to greater postoperative stress than a single forearm bone intercalary nonunion. These are cases where the surgeon should consider the structural benefit of fibular flap reconstruction.[36]

In smaller defects where the corticocancellous flap will have the support of locking plating constructs and/or an adjacent intact long bone, corticocancellous and intercalary MFC flaps are a useful tool. The author has experience in over 50 cases utilized for long and tubular bones of the extremities and has witnessed rapid bony healing in these cases. However, even years after the reconstruction, the unicortical nature of the MFC flap will not typically achieve the radiodensity of a radius or ulna (where cylindrical cortical surfaces provide a much denser radiographic appearance). Whether due to the stress shielding afforded by the plating constructs, or simply the limited nature of the unicortical flap to hypertrophy, the MFC flap does not typically assume the appearance of a normal radius or ulna.

Like the tubular bones of the hand, the strategy for the application of the MFC corticocancellous

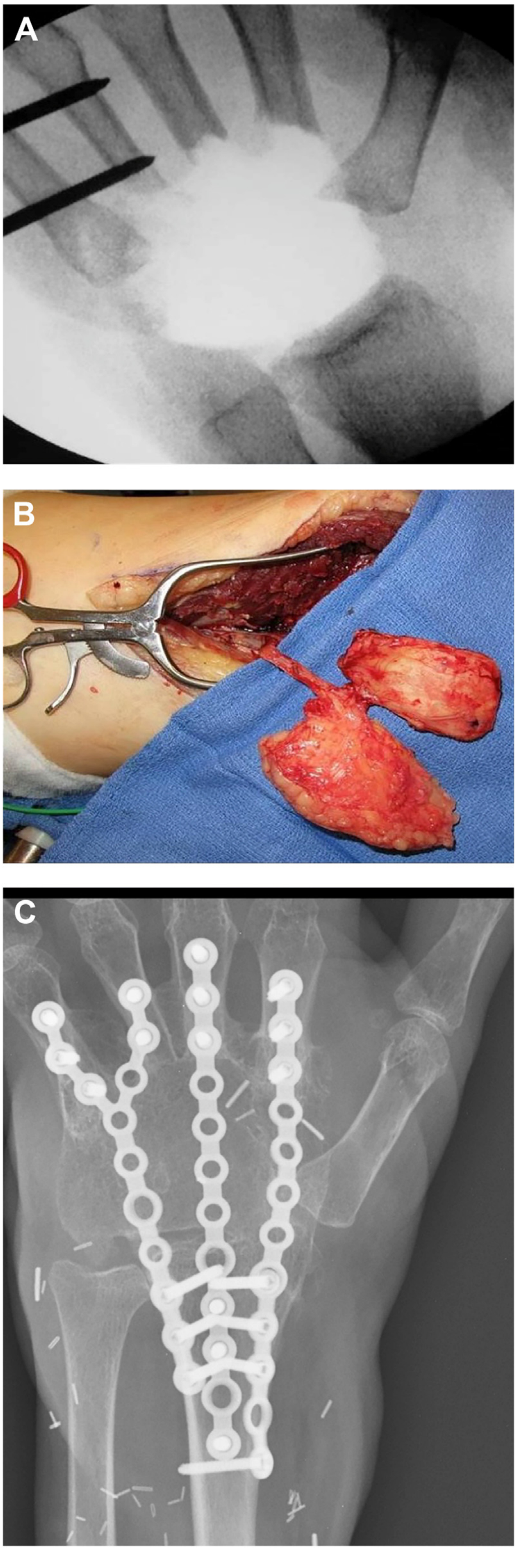

Fig. 5. Example of MFC reconstruction of large bone defect of the wrist. (*A*) Patient transferred to our institution after the radical resection of carpus for osteomyelitis. Fluoroscopic image demonstrates complete loss of carpal structures. (*B*) Thin, rectangular shaped corticocancellous MFC is harvested from the ipsilateral leg with the large skin paddle to facilitate closure and permit postoperative monitoring. (*C*) X-rays showing consolidation at 12 weeks. Lengthy malleable plates were used to arch over the dorsal MFC periosteum and avoid compression of the periosteal vessels. These plates were used to achieve fixation and osteosynthesis of metacarpals 2-5 and the distal radius. The distal ulna and the thumb metacarpal are purposely maintained free of the fusion mass. (*From* Assi PE, Giladi AM, Higgins JP. Chapter 18: Medial Femoral Condyle Corticocancellous and Osteochondral Flaps. In: Wiesel SW, Albert T, eds. Operative Techniques in Orthopaedic Surgery. 3rd ed. Lippincott Williams & Wilkins; 2021. p. 3138-3152.; with permission. (Figure 6 in original).)

flap to upper extremity long bones is specific to the site. In cases of distal or diaphyseal radius nonunions, the surgeon will most often encounter a previous volar incision and will most likely approach the radius through the same volar approach. When this is performed, the plating is applied volarly and the cortical surface of the MFC is applied orthogonally on the radial column of the radius. The vessel is draped toward the radial artery for end-to-side anastomosis and the skin paddle is typically inset along the same volar incision to provide ease of closure and ability for postoperative monitoring. Because of the configuration of the skin paddle and position of the radial artery, the author finds it easier to harvest an osteocutaneous ipsilateral medial femoral condyle flap as this will result in the skin paddle insetting ulnar to the flap pedicle in the forearm. This will provide ease of positioning of the descending geniculate artery to the radial artery.

In the setting of ulnar shaft nonunion, the surgeon most often encounters a previous incision created on the subcutaneous border of the ulna. This is typically the same incision that is used to re-access the nonunion site. In this setting, a surgeon should consider the planned site of microsurgical anastomosis. The ulnar artery in the proximal half of the forearm is deep to the pronator and becomes relatively inaccessible in the forearm musculature. Thus, the arterial anastomosis is typically performed to the distal ulnar or distal radial artery. The corticocancellous MFC flap is thus inset in such a manner that the pedicle drapes in a distal direction. The skin paddle that is inset will be placed in the longitudinal skin incision along the subcutaneous border of the ulna. In order to have the artery lie volar to the skin paddle and drape appropriately to the distal anastomotic site, selection of the contralateral medial femoral condyle osteocutaneous flap is indicated.

In cases of humeral nonunions, commonly there is a previous lateral brachial incision that is utilized for the nonunion reconstruction. The skin paddle is inset longitudinally into the lateral brachium along the pathway of the incision. However, the anastomosis was performed on the medial aspect of the brachium via a counter incision. Thus, the descending genicular artery pedicle is tunneled medially. This may require that the surgeon create a tunnel through a previous scarred bed or the capsule created by the use of the cement spacer. The microscope is brought onto the field to provide a view of the medial brachial exposure. The vascular pedicle is encountered arising from the depth of the exposure. The microvascular anastomosis is most easily performed in the distal brachium and thus the flap is inset such that the pedicle is draped medially and distally, rather than medially and proximally. This inset of the bone flap in an "upside down" positioning, while counter intuitive, is very helpful in the facilitation of the vascular pedicle and has no impact on the function of the microvascular anastomosis.

Lastly, for the clavicle, the author has found that it is particularly difficult to apply the fixation in any other location than the superficial most aspect of the bone. Likewise, it is difficult to inset the MFC with the cortical surface directed orthogonally. Thus, the author has typically performed these cases by first plating the clavicle in the appropriate position and then applying an onlay corticocancellous malleable MFC flap around the entirety of the clavicle and the plate, typically using additional cancellous graft if needed within this nonunion site. The vessels are typically anastomosed to the thoracoacromial artery and cephalic vein. The skin paddle is applied along the axis of the incision.

SUMMARY

Vascularized bone flaps from the descending genicular artery system are versatile and effective for the use of recalcitrant nonunions from the tubular bones of the hand to the long bones of the upper extremity. Familiarity with the vascular pedicle, various techniques of harvest and inset, and skin paddle harvest and application are essential for the reconstructive surgeon.

CLINICS CARE POINTS

- The MFC flap can provide corticocancellous, corticoperiosteal, and osteocutaneous options for commonly encountered nonunions of the upper extremity.
- The MFC flap has been shown to be effective in the treatment of upper extremity tubular and longbone nonunions as well as scaphoid nonunions.
- The MFC flap provides a unicortical flap that has less structural value than a fibular flap but provides numerous other advantageous.
- The upper extremity reconstructive surgeon utilizing the MFC flap should be familiar with the vascular anatomy, various harvest techniques, and insetting techniques at various locations of the upper limb.

DISCLOSURE

The author has no relevant disclosures.

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