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Vascularized Bone Graft in Mangled Hand Reconstruction

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Extensive bone defects, especially in conjunction with associated coverage involvement in mangled hands, pose notably challenges to hand and upper-extremity surgeons. Vascularized bone grafts often play a vital role in effective treatment now a days. It not only bypasses the drawbacks of conventional grafts but also allows for simultaneous one-stage reconstruction of its coverage as well as repairs other injured structures. Preoperative evaluation of mangled hand is crucial; the injury extent, including circulation, patient expectations, and clinical reality, should be all taken into consideration before finalizing the reconstruction plan. The fibula bone, along with other vascularized bone flaps such as iliac crest bone, medial femoral condyle, and some others, as well as corresponding spare parts, can provide effective solutions. Considerations such as surgeons' experience and expertise, donor site morbidity, postoperative care, and rehabilitation are essential for optimal outcomes. In this article, we would like to share our current practicing vascularized bone flaps in mangled hand reconstructions.

High-functioning hands are often subject to traumatic injuries, with their severe forms referred to as mangled hands. Timely, adequate fracture reduction, fixation, or bridging of the bone gap helps achieve early bone union, which is crucial for faster and better functional recovery.

Conventional bone grafts rely on a slow process of creeping substitution at the graft–host junction, which requires good vascular be to heal.[1]

In contrast, vascularized bone grafts bring their own blood supply and are therefore less dependent or not dependent on the recipient site, which theoretically has a similar mechanism to fracture healing. Most vascularized bone grafts can be harvested with surrounding soft tissues, which can be used simultaneously for coverage reconstruction. Furthermore, it often becomes the last resort when conventional bone graft fails.[2]

Preoperative Evaluation and Special Consideration

Extent of injury

Complete physical examination of the mangled hand for its circulation, damaged skin, muscle, tendon, bone, and nerves provides basic but critical information for planning the reconstruction. Timely restoration of circulation is of utmost importance. Image including angiography is often necessary. Ideally, early one-stage reconstruction of all injured or defective tissue components including bone gaps can be completed. However, when it is not feasible or favored, staged reconstruction should be planned.

Patient factors

Patient factors, such as age, wound condition, function need, motivation, and overall health status, play a significant role in determining the surgical plan.

Selection of Various Vascularized Bone Graft Donor Sites

The selection of a vascularized bone graft is determined by criteria such as the size of the bone defect, pedicle length, soft tissue defect size, potential donor site morbidity, and the surgeon's preference. In this context, we present various vascularized bone graft options that are beneficial for treating mangled hands, including the fibular bone flap, iliac crest transfer, medial femoral condyle flap, and spare part surgery. The surgical indications, strengths, and weaknesses of these grafts are elucidated.

Fibula bone flap

The fibula bone flap is a commonly used vascularized bone graft known for its straight, strong, and lengthy bone structure. With rich

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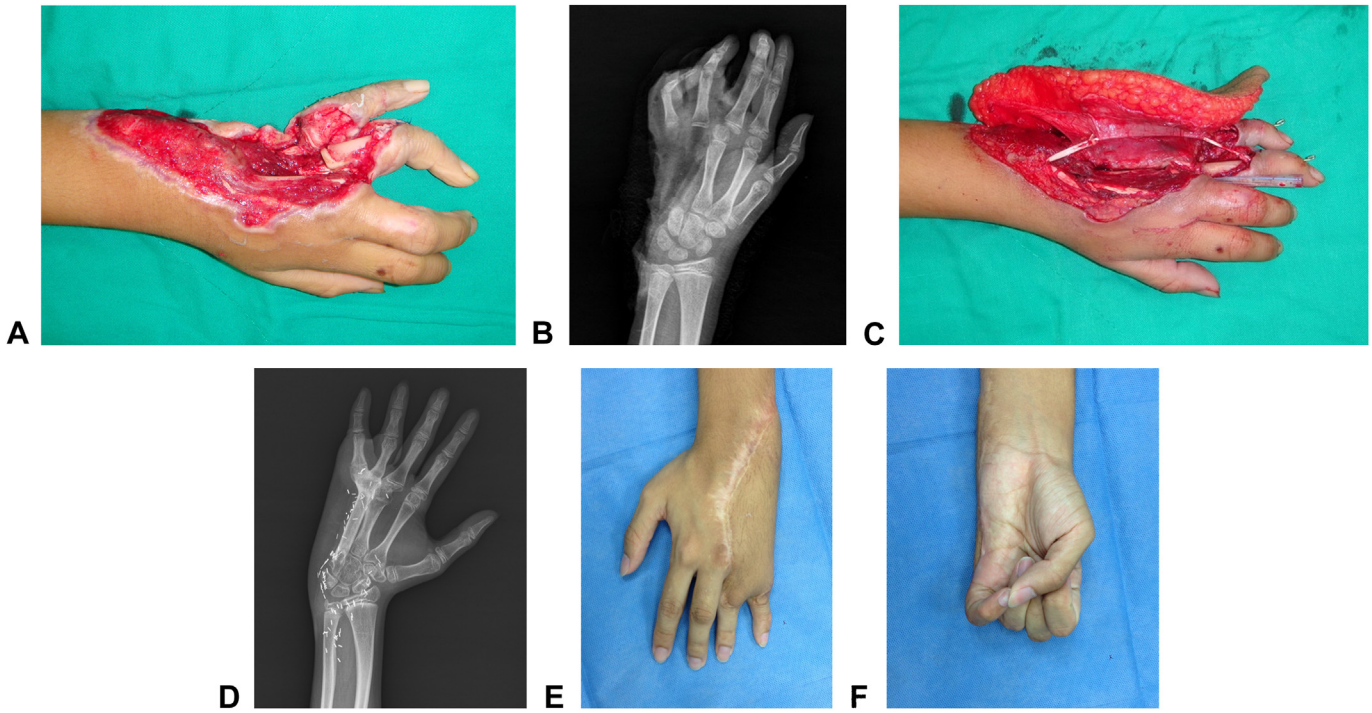

Figure 1. **A** Left dorsal hand soft tissue defect along with defects in the fourth and fifth metacarpal and extensor tendons. **B** Preoperative X-ray revealed the fourth and fifth metacarpal defect. **C** Extensor tendons of the fourth and fifth fingers were reconstructed with plantaris tendon after osteosynthesis. **D** X-ray at the 2-year follow-up. **E**, **F** Acceptable grip function at the 7-year follow-up.

cortical bone quality, this type of graft is particularly well-suited for reconstructing long bones in the extremities. It can be transferred using either the anterior tibial artery or peroneal artery, with lengths of 22–26 cm typically available in adults.[3] The anterior tibial artery is specifically used for reconstructions involving major joints or growth plates with the proximal fibular epiphyseal flap. The skin paddle on the lateral aspect of the leg, supplied by the septal artery from the peroneal artery, offers effective coverage for large soft tissue areas.[4] Inclusion of the soleus and flexor hallucis longus muscle flap can aid in dead space obliteration, whereas the plantaris near the flap's dissection plane can be used for tendon reconstruction.[5,6] The pedicle peroneal artery, known for its length, has the potential to serve as a flow-through flap for major artery reconstruction. The drawbacks of the fibular flap include the sacrifice of a major artery and the potential for damage to the attached muscles, especially flexor hallucis longus muscle.

Preoperative fibula flap septal artery mapping

The septal arteries are typically identified at the posterior edge of the fibular crus. The use of a handheld Doppler device, sonography, computed tomography angiography, and indocyanine green angiography can guide the selection of suitable septal vessels for fibular osteocutaneous flaps.[7,8]

Surgical procedure

Meticulous planning and the fibula flap harvest involve a series of precise surgical steps guided by anatomical landmarks and imaging techniques, which have been well-documented.[9] Some skill pearls must be emphasized. Preservation of excessive muscle thickness can impede subsequent flap inset and osteotomy procedures. The length of the fibula bone harvested should account for the desired bone segment, pedicle length, and spacing between neighboring struts to create a smoother curve for the pedicle. Following osteotomy, the surplus periosteum sleeve can be used to cover the osteosynthesis sites, promoting bone regeneration and enhancing the healing process.[10]

In cases involving the harvest of a fibula bone flap, it is essential to implement short leg splinting to maintain ankle immobilization at a 90-degree angle and ensure toe extension for a period of 8 weeks. This approach aims to facilitate the secure reattachment of the muscles surrounding the fibula bone and support optimal postoperative recovery.[9] Written informed consent was obtained from the patient for publication of this case report and accompanying images.

Case presentation

Case 1

An 11-year-old boy was admitted with a crush injury on the ulnar side of his left hand, impacting the fourth and fifth metacarpals as well as the dorsal hand structure. A fibular osteoseptocutaneous flap with an 8 × 18 cm skin paddle was harvested. The fibular bone was divided into struts and arranged in T-configuration to reconstruct both the missing fourth and fifth metacarpals. Additionally, a plantaris tendon graft was used for the reconstruction of the extensor digitorum communis in both affected digits. The 7-year follow-up revealed acceptable grip function, notwithstanding the limited metacarpophalangeal (MCP) joint range of motion (Fig. 1).

Case 2

A 43-year-old woman sustained a left forearm punch injury resulting in soft tissue damage in the dorsal forearm and a segmental defect in the radius. Following unsuccessful replantation of the affected tissue, a fibular osteoseptocutaneous flap was employed to reconstruct the compound radial bone defect. The 1-year follow-up demonstrated satisfactory wrist and MCP joint range of motion. The patient also exhibited uninhibited wrist supination and pronation functionality (Fig. 2).

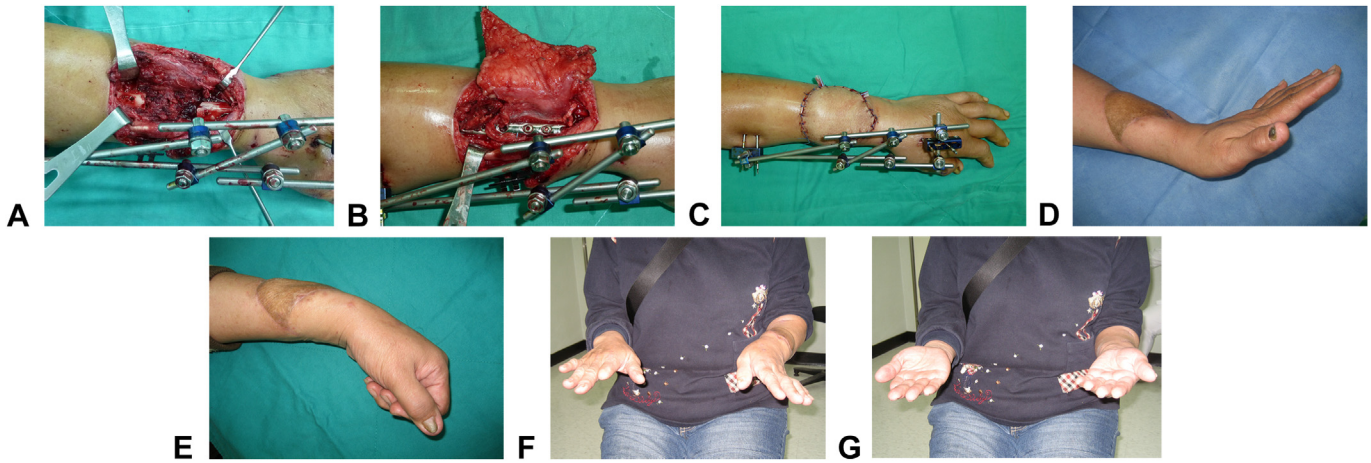

Figure 2. **A** The bone defect about 4 cm was well exposed. **B** Osteosynthesis with a plate. **C** Immediate postoperative picture. **D**–**G** Acceptable wrist range of motion, MCP joint extension at the 6-month follow-up.

Iliac bone transfer

The groin osteocutaneous flap has historically been preferred for soft tissue and bone reconstruction of the hand because of its reliability. The advantages of using an iliac crest transfer lie in its abundant bone supply and adaptable shape, with an impressive maximum graft length of 10.5 cm.[11] The iliac crest bone flap offers adequate cortical and cancellous bone volumes, providing essential mechanical support and creating an optimal microenvironment for osteogenesis, promoting faster bone union compared with the fibular flap.[3] Additionally, the iliac crest is easily accessible by pedicle flap or free flap fashion. However, potential weaknesses of this flap may include donor site morbidities, such as pain, scarring, risk of hernia formation, and relatively short and small caliber pedicle. Over the decades, advancements have been made to adapt to our evolving understanding of iliac crest vascularity. This insight has led to the development of different flap designs based on various arterial supplies (direct periosteum perfusion from overlying groin flap, deep circumflex iliac artery (DCIA), or deep branch of superficial circumflex iliac artery (SCIA), which are introduced as follows).

Based on direct periosteum perfusion from overlying groin flap

The iliac osteocutaneous flaps consist of a groin flap and a strongly attached iliac bone component nourished by the periosteal artery. The bone volume is restricted because of weaker perfusion of the iliac crest. The flap can offer flexibility in the placement of the bone inset. Care should be taken to avoid damaging the sartorius muscle's origin and the lateral femoral cutaneous nerve.[12]

Case presentation

A 43-year-old man sustained a left hand crush injury resulting in ulnar dorsal soft tissue damage and a segmental defect in the fifth metacarpal. A traditional pedicle iliac osteocutaneous flap was used for reconstruction. At the 7-month follow-up, the patient presented good grasp function and bone union (Fig. 3).

Based on DCIA

The DCIA serves as the primary nutrient artery for the iliac bone, ensuring reliable perfusion of large bone flaps. Despite this advantage, the DCIA pedicle is characterized by a shorter length, and the overlying skin supplied by small vessels through the iliac bone may lack consistency in perfusion, impacting the maneuverability of the flap. Alternative reliable skin flap options, including the groin flap, DCIA terminal branch perforator flap, or a combined pedicled anterolateral thigh flap, may be considered.[13]

Case presentation

A 57-year-old man experienced a severe crush injury to his right hand, resulting in the preservation of only the first ray. A pedicled groin flap with iliac crest based on the DCIA perfusion was used for osteoplasty to establish an opposer to the thumb. This procedure enabled the patient to regain basic hand function. Additionally, the flap can serve as the foundation for transferring toe flaps if the patient desires further reconstructive surgery (Fig. 4).

Based on a deep branch of SCIA

The SCIA perforator flap, first introduced by Koshima et al[14] in 2004, has since become a valuable option in reconstructive surgery for various indications. The SCIA gives rise to two main branches: a superficial branch that traverses through the superficial and deep fascia into the subcutaneous fat layer and a deep branch that courses along the iliac crest beneath the deep fascia. The findings from Yoshimatsu et al[15] have demonstrated that the deep branch of the SCIA contributes to the perfusion of the superficial portion of the iliac bone located approximately 1.5 cm from the iliac crest.

Medial femoral condyle flap

The medial femoral condyle (MFC) flap was first described by Sakai et al[16] in 1991. Compared with the fibula bone flap, the MFC flap offers a higher corticocancellous ratio, indicating superior osteogenic properties and bone regeneration potential.[17] This corticocancellous flap has various advantages such as easy dissection and bone inset, a long pedicle length, reduced donor site morbidity, and preservation of major lower-extremity arteries, enabling chimeric flap designs. However, the MFC flap is limited to small bone defects, with a maximum bone extraction dimension typically restricted to 5 cm and a relatively small pedicle size.

The MFC flap is supported by a dual arterial perfusion system, consisting of the descending genicular artery (DGA) from the superficial femoral artery and the superomedial genicular artery from the popliteal artery. Although the superomedial genicular artery is present in all patients, the DGA is preferred because of its notably longer length, making it the optimal pedicle selection for flap harvesting.[18]

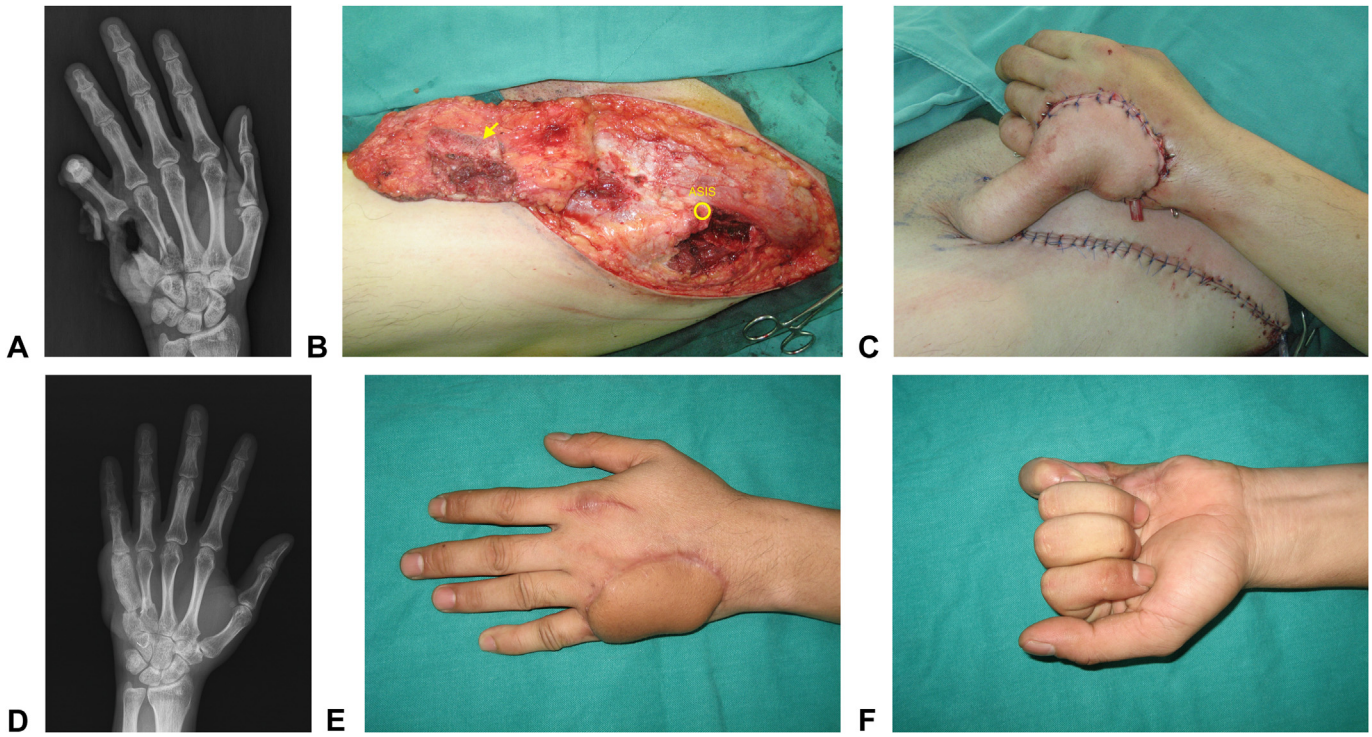

Figure 3. **A** Left hand crush injury with fifth metacarpal defect and fourth metacarpal base fracture. **B** An iliac osteocutaneous flap was harvested, including the iliac crest bone with the periosteum still attached, as marked by an arrow. The anterior superior iliac spine (ASIS) was marked with a yellow circle. **C** Immediate postoperative picture. **D**–**F** X-ray and MCP joint range of motion at the 7-month follow-up.

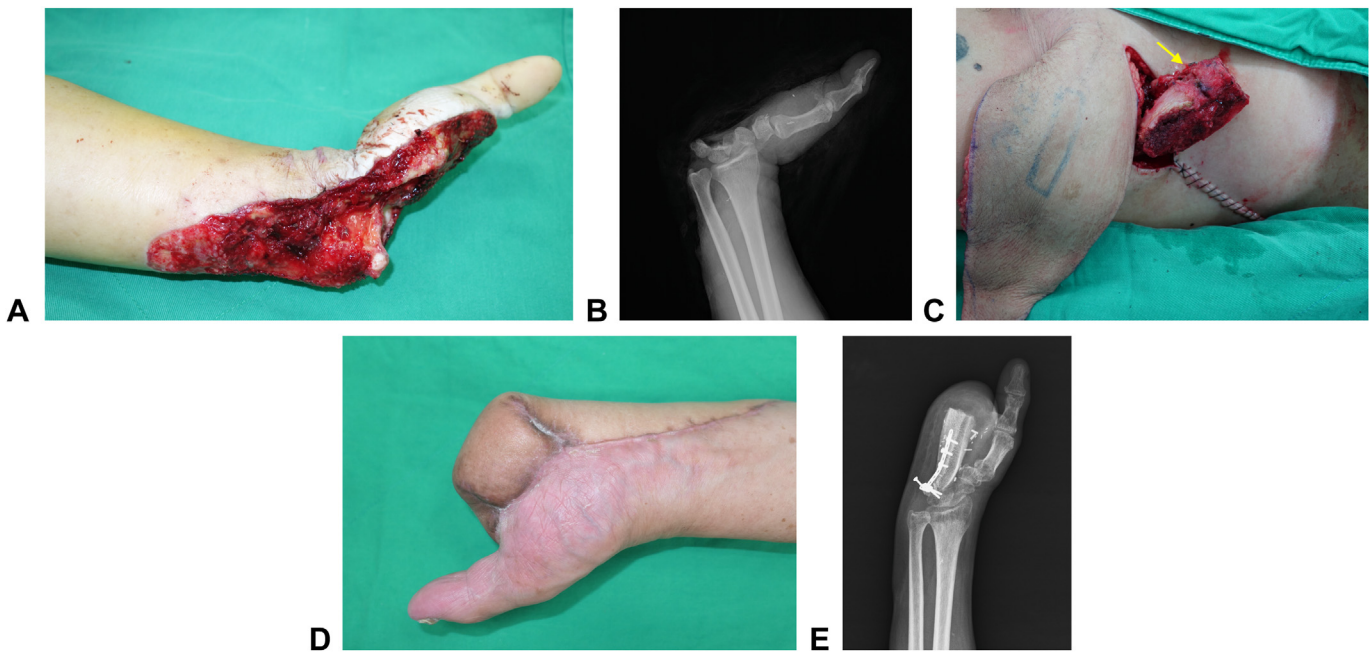

Figure 4. **A** Left hand crush injury with partial hand amputation, only first ray could be preserved. **B** Preoperative X-ray. **C** Pedicled groin flap with vascularized iliac crest based on DCIA (arrow). **D**, **E** X-ray and basic hand function at the 1-year follow-up.

The MFC flap contains two terminal branches of the DGA, known as the longitudinal and transverse branches, that provide avenues for extracting corticocancellous bone grafts. These branches facilitate the isolation and provision of bone material for reconstruction of adjacent metacarpal or phalangeal bone defects. Alternatively, a single large bone graft can be obtained by using both branches.[19]

Case presentation

A 27-year-old woman sustained a crush injury to her left hand, resulting in dorsal soft tissue and the fourth and fifth metacarpal defect. The bone structure was maintained using minicondylar plates, and a chimeric MFC flap was harvested for

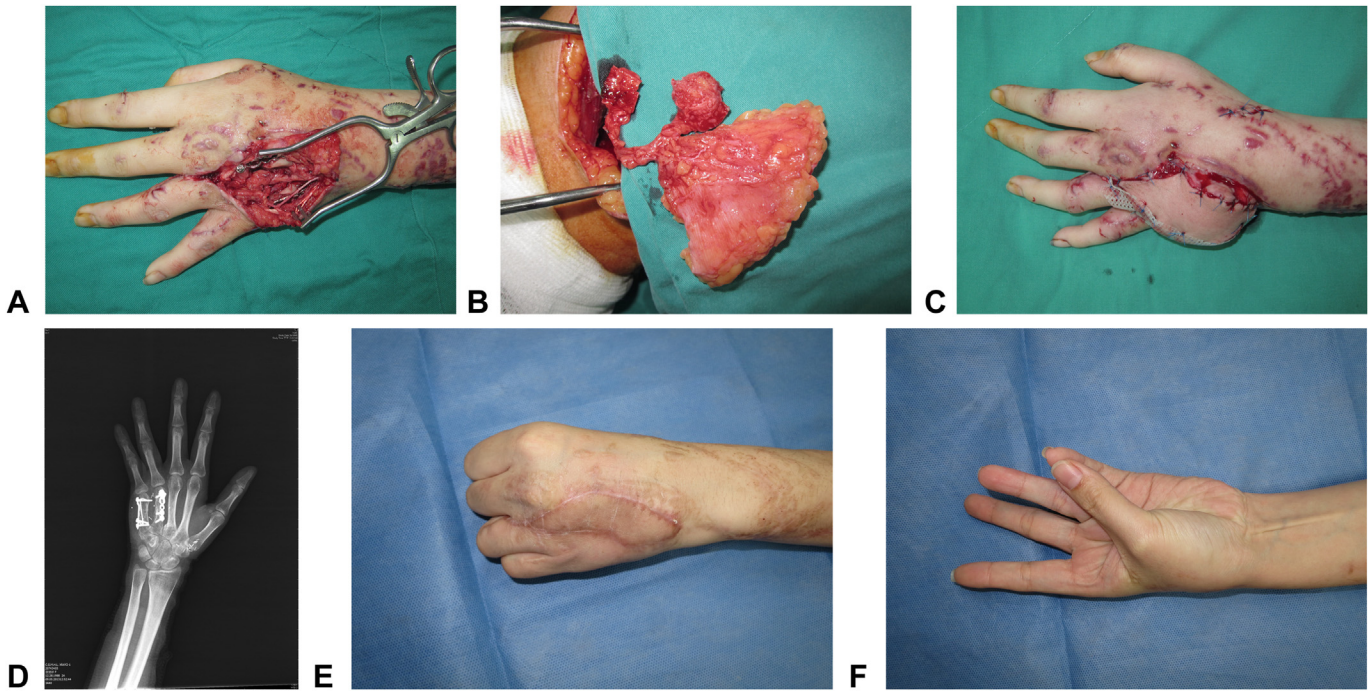

Figure 5. **A** Left hand crush injury with damage to the dorsal soft tissue and the fourth, fifth metacarpal defect; the skeleton was stabilized with minicondylar plates. **B** Chimeric MFC flap including two separated bone grafts and a skin paddle perfused by direct cutaneous branch was harvested. **C** Immediate postoperative picture, the bone grafts were fixed with suture only. **D** Six months after reconstruction, the bone had healed and remodeled successfully. **E**, **F** One-year follow-up, acceptable grip and opposition function.

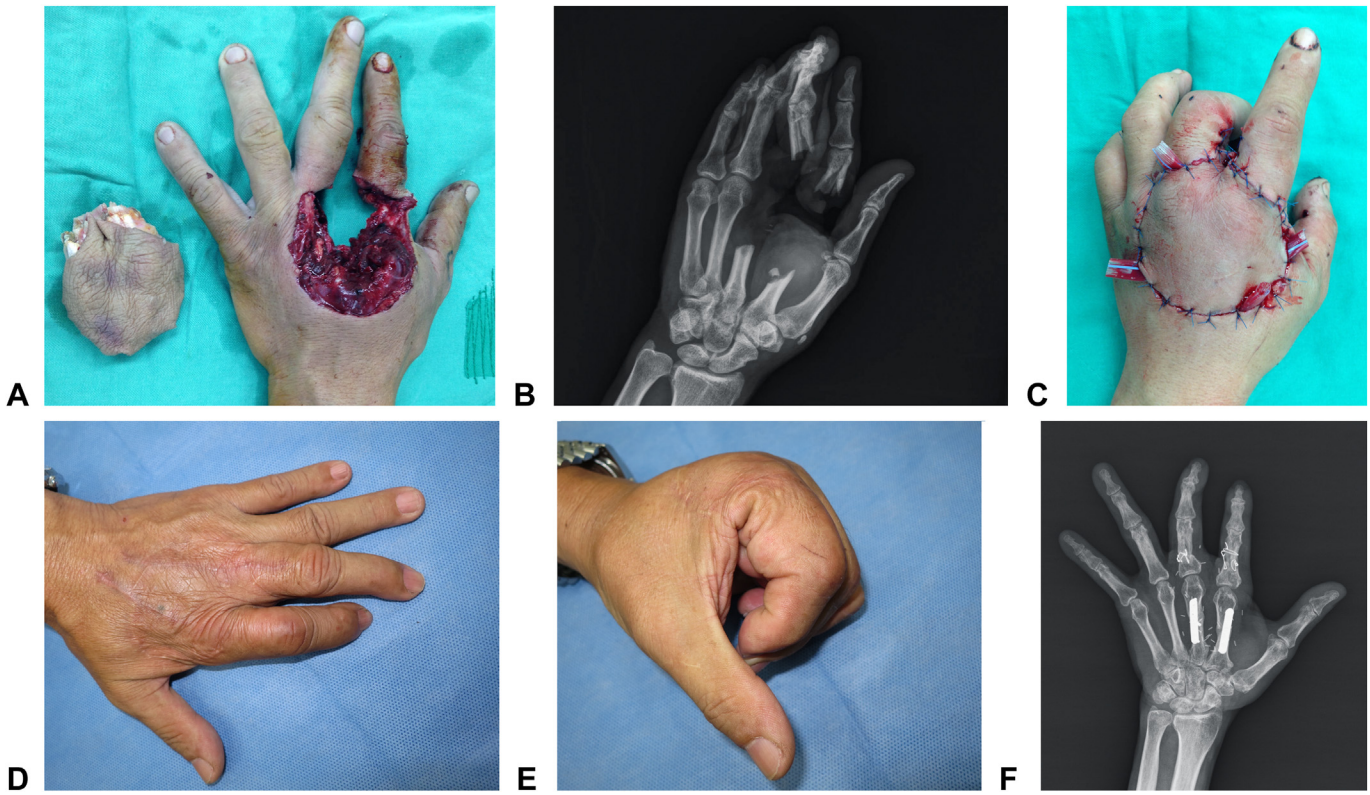

Figure 6. **A** Left hand punch injury with partial palm complete amputation. **B** Preoperative X-ray revealed bone and MCP joint defect on second and third rays. **C** Orthotopic replantation was performed, metacarpals were fixed with plates, and the phalangeal bones were repaired with intraosseous wires. **D**–**F** At the 2-year follow-up, the hand exhibited satisfactory function.

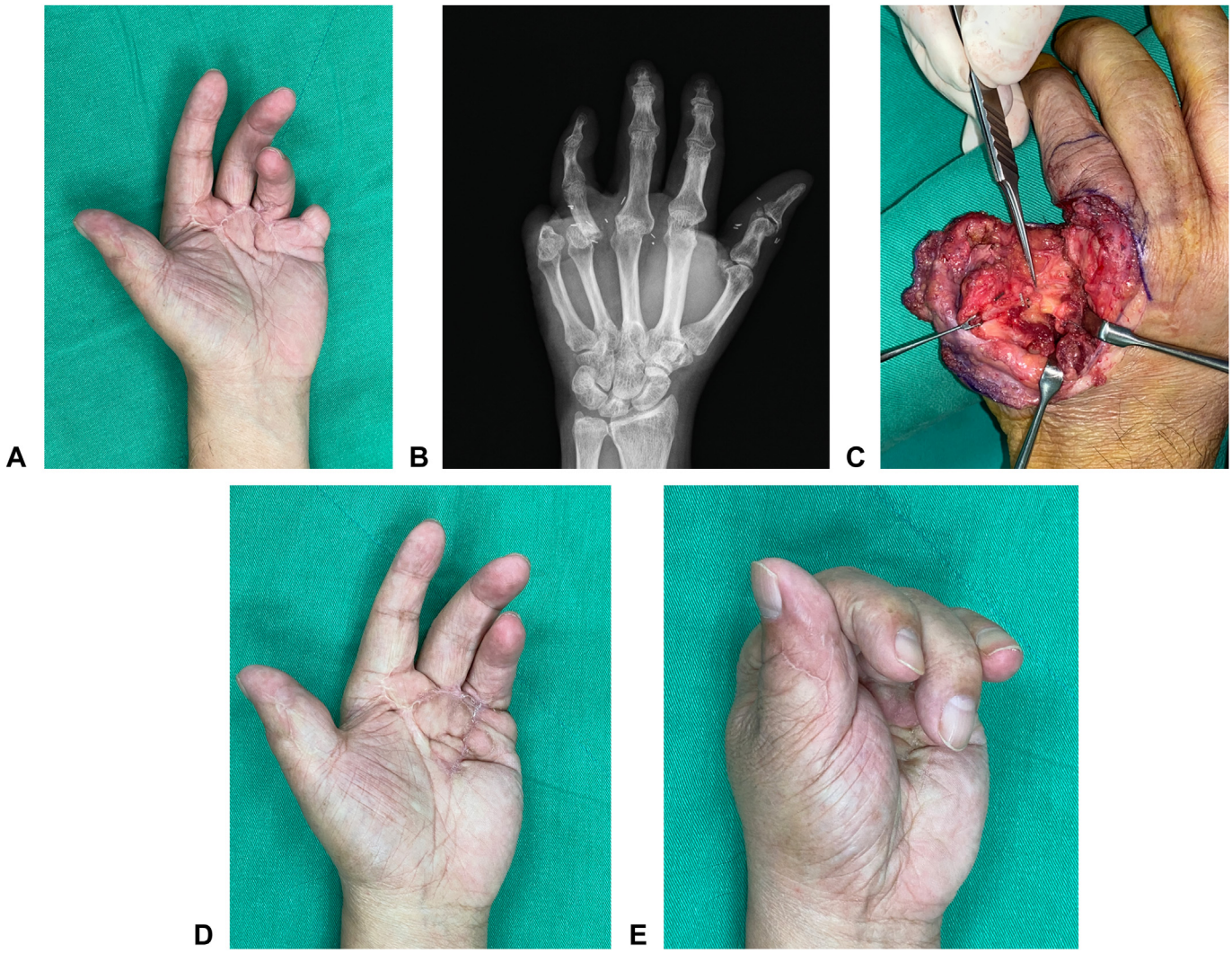

Figure 7. **A** Severe flexion contracture and malrotation of the ring finger and a short amputation stump of the little finger. **B** The X-ray revealed absence of the forth MCP joint, but the fifth MCP joint remained intact. **C** The tip of microsurgical forceps indicated the vessel supplying the spare MCP joint flap. Transferring the intact vascularized fifth MCP joint to replace the missing forth MCP joint. **D**, **E** Improved function and appearance of the left hand.

both soft tissue and bone reconstruction. The flap's skin paddle was perfused by the direct cutaneous branch of the DGA, whereas the bone grafts were supplied by the transverse and longitudinal branches of the artery. Hardware removal and debulking were performed 6 months after the flap reconstruction. Following the procedure, the patient demonstrated satisfactory grip strength, opposition function, and successful bone remodeling (Fig. 5).

Replantation or spare part surgery

When facing significant hand mutilation with devascularization, debridement of the unsalvageable structures and replantation or revascularization of the yet healthy parts often offers the best approach for functional preservation as the skeletal structure of the hand is unique in its alignment and shape, closely intertwined with the surrounding tendon and neurovascular systems. This complexity makes it challenging to substitute with any other composite tissue flap.

If the entire amputated part is unable to be replanted as a whole because of evident tissue damage, spare parts can be carefully dissected. In case where the mutilated hand presents with segmental bone, bone with joint, or associated soft tissues including tendons and nerve defects, corresponding spare part tissues from unsalvageable amputees can be a good source for reconstruction. Spare part surgery plays a vital role in improving finger length, range of motion, and aesthetic outcomes, ultimately enhancing pinch and grip function. The strategic transfer of spare parts can be achieved through various techniques, including pedicle or free flaps, tailored to address the specific needs of each individual patient and their functional deficits.[20]

Case presentation

A 57-year-old man experienced a left palm punch injury resulting in a complete composite tissue amputation involving the second and third ray from midpalm to proximal phalanx level including MCP joints and connecting bone. Following debridement and excision of the damaged intrinsic muscle, orthotopic replantation of the amputated bones, associated MCP joint, and overlying tissue was performed. At the 2-year follow-up, the hand exhibited a satisfactory function (Fig. 6).

A 66-year-old man sustained a crush injury to his left hand. Initial management was performed elsewhere. He presented to us 1

year later with severe flexion contracture and malrotation of the ring finger, along with the absence of its MCP joint. The remaining amputation stump of the little finger was short but had an intact MCP joint. Computed tomography angiography revealed that the fifth MCP joint received blood supply from superficial arch—common digital artery axis. The decision was therefore made to transfer the fifth MP joint with its intact blood supply to replace the missing fourth MCP joint. Follow-up at 6 months revealed improved range of motion of the ring finger and its aesthetic appearance (Fig. 7).

Postoperative care and outcome evaluation

Postoperative flap monitoring can be accomplished through direct flap visualization, needle stick testing, and Doppler device utilization.

When the flap is inset in a pedicled fashion, as commonly seen with pedicled iliac bone transfer procedures, postoperative monitoring of the flap is crucial to prevent pedicle kinking. However, if the flap demonstrates adequate perfusion, early ambulation may be permitted to promote patient recovery. Evaluation of bone healing typically depends on the X-ray imaging evidence.

Revision or subsequent procedures

The reconstructed thickness of the skin paddle may lead to a bulky appearance during follow-up evaluations. In such cases, a debulking procedure can be considered to enhance aesthetic outcomes. This process entails partially elevating the skin flap and possibly removing internal fixation hardware if bone union has occurred. Additional staged reconstruction techniques, such as tenolysis, tendon or nerve grafting, tendon or nerve transfer, and bone graft insertion for resistant bone nonunion, can also be performed if required.

Other procedures may be recommended to optimize hand function. For example, glabrous toe flaps can be transplanted onto a vascularized bone thumb tip to replace the nonglabrous skin coverage that is provided by an osteocutaneous flap.

In the realm of mangled hand complex upper-extremity management, vascularized bone flaps serve as an irreplaceable tool to restore large segments of bone defect, especially when it is associated with coverage defect or when there is a nonhealing osteosynthesis to expedite the rehabilitation process. In selecting an appropriate vascularized bone flap, it is imperative for surgeons to possess a comprehensive understanding of the distinctive attributes of available options.

Conflicts of Interest

No benefits in any form have been received or will be received related directly to article.

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