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TRAUMA SURGERY

Versatility of the medial corticoperiosteal flap: from recalcitrant non-unions up to large bony defects

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Abstract

Background Reconstructive microsurgery techniques using vascularized bone grafts have revolutionized the treatment of complex cases associated with recalcitrant non-unions or osteomyelitis. The medial femoral corticoperiosteal flap (MFCP flap) has emerged as a valuable option in bone reconstruction. Its clinical applications have been extended over the years considering this flap from non-unions with minimal bone lost, up to large intercalary defects of the upper and lower extremities. This article aims to present the clinical applications and outcomes of the MFCP flap in various reconstructive scenarios.
Methods Seventy-nine patients with persistent non-union and bone defects of the upper and lower limb were evaluated from June 2008 to October 2020. All of them were reconstructed with a corticoperiosteal flap from the medial femoral condyle in our hospital. Previous procedures, bone gap and type of flap used were recorded. Postoperative functional status was assessed with time of bone healing, complications and clinical final outcome.
Results Radiological evidence of bone union was observed at 4.09 months (range 2–9). Healing rate was 97% with periosteal corticocancellous flaps (PCC flaps) and 93% with corticoperiosteal flaps (CP flaps). Average follow-up was 14.5 months (range 5–28). There were no significant donor site complications.
Conclusions The MFCP flap offers a versatile and reliable option for bone reconstruction. Its ability to provide vascularized bone tissue with low morbidity enhances the healing process and improves outcomes. The MFCP flap has been increasing its applications and it serves as a valuable option in the treatment of recalcitrant non-unions or bony defects irrespective of site and size up to 5 cm in the upper and lower extremities.

Keywords Periosteal flap · Vascularized bone grafting · Medial femoral condyle · Non-union

Introduction

Current techniques in bone fixation combined with a better understanding of bone vascularity have led to a high success rate in fracture healing. However, it is estimated that an average of 3–5% of all fractures can be complicated with non-union [1, 2].

Fracture healing requires stability, bone stock and adequate vascularity. The periosteum plays an important role providing a rich blood supply with bone forming cells and growth factors. It also contributes due to its structure as a scaffold that helps bridge the gap when missing bone.

The use of bone and periosteum flaps have been well described to treat cases of persistent pseudarthrosis and bone defects [3–5]. The medial femoral corticoperiosteal flap (MFCP flap) is especially useful in complex cases associated with bone loss, recalcitrant non-unions, avascular necrosis or osteomyelitis. This flap provides to the bone gap all the properties of periosteum and its growth capabilities, promoting healing. Additionally, due to its thin and pliable structure, it is well-suited to fill small gaps or irregular-shaped defects, where other vascularized bone flaps, such as the fibula, iliac crest, or scapular flaps, may face challenges.

In recent years, studies of the vascular anatomy of the MFCP flap and perfusion areas of its pedicle have extended its clinical applications. Using it only as a periosteum flap (without cancellous bone included) can be easily tailored to

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fit into the bone or it can be used to drape around tubular bones such as phalanges. When a fair amount of cancellous bone is included, as a periosteal corticocancellous flap, it is especially useful in cases involving intercalary bone loss or three-dimensional defects.

The purpose of this study is to evaluate the versatility of the MFCP flap in the treatment of recalcitrant no-unions and medium to large bone defects of the upper and lower extremities. This report presents the results of its clinical applications using variations of the MFCP harvesting technique.

Materials and methods

Patients

Seventy-nine patients with persistent non-union and bone defects up to 5 cm of the upper and lower limb were evaluated from June 2008 to October 2020. All of them have been reconstructed with a corticoperiosteal flap from the medial femoral condyle in our hospital. The series included 70 males and 9 females with an average age of 40.29 years (18–63). Seventy-five of the patients had previously received one or more surgical treatments for the non-union including secondary bone fixation, bone substitutes or autologous bone graft (Table 1).

Bones involved were most of them from the upper limb, 64 cases and 15 flaps were used for lower limb (Table 2).

Surgical procedure

The first step in every case was wound excision and resection of devitalized tissue until bleeding bone was achieved. If the previous hardware was broken, showed signs of mobility or if there were signs for fracture-related infection (FRI) [6], a new osteosynthesis was performed. However, the hardware was generally not changed as a standard practice.

Table 1 Patient demographics and characteristics of the study population

Variables	Value
No. of patients	79
Patient-related characteristics	
Age, mean (range)	40.3 years (18–63)
Sex, n (%)	
Male	70 (88.6%)
Female	9 (11.4%)
Previously surgical treatments	
0	4 (5.1%)
1–2	52 (65.8%)
≥ 3	23 (29.1%)

N number

Table 2 Bones involved in the non-unions

Upper limb		Lower limb	
Phalanx	14	Metatarsals	1
Metacarpals	4	Subtalar fusion	2
Scaphoid	8	Tibiotalar fusion	2
Wrist fusion	2	Tibia	9
Radius	6	Femur	1
Ulna	17	Total	15
Humerus	9		
Clavicle	4		
Total	64		

We harvested the flap as recommended by Doi and Sakai [4]. A longitudinal incision is made on the medial side of the distal third of the thigh, over the adductor magnus tendon. The vastus medialis is lifted off anteriorly to find the periosteal leash over the condyle leading proximally to the descending genicular artery (DGA). The vascular anatomy of the medial femoral condyle has been well described in previous reports [5–9].

This flap is mostly supplied by the DGA (80–87%) and less commonly from the superior medial genicular artery (SMGA) (13–20%). Our flaps were based in most of the cases on the DGA, but in five patients we used the SMGA due to an absent or small descending genicular vessel. An adipofascial/adipocutaneous flap was harvested chimerically with bone based on the saphenous artery in four patients as we need skin resurfacing and coverage.

Flap selection

We differentiate two types of flaps from the medial femoral condyle in bone reconstruction:

1. Corticoperiosteal flaps (CP flaps) (Fig. 1): include periosteum and the thin underlying cortical layer (so called cambium layer). The cortex is carefully chiseled out from the margins inwards and we usually include cortical bone fragments attached to the periosteum. Including a segment of cortical bone has been recommended to avoid the damage of this inner layer, despite the cortical part of the flap is not being necessary from reconstructive point of view [10, 11]. We use free CP flaps when the structural support is preserved. If necessary, the small gaps are filled with morselized cancellous graft from the iliac crest or femoral condyle. In some cases when structural bone is required, a sculpted structural iliac crest bone graft can be used and the CP flap is then wrapped around to the graft.

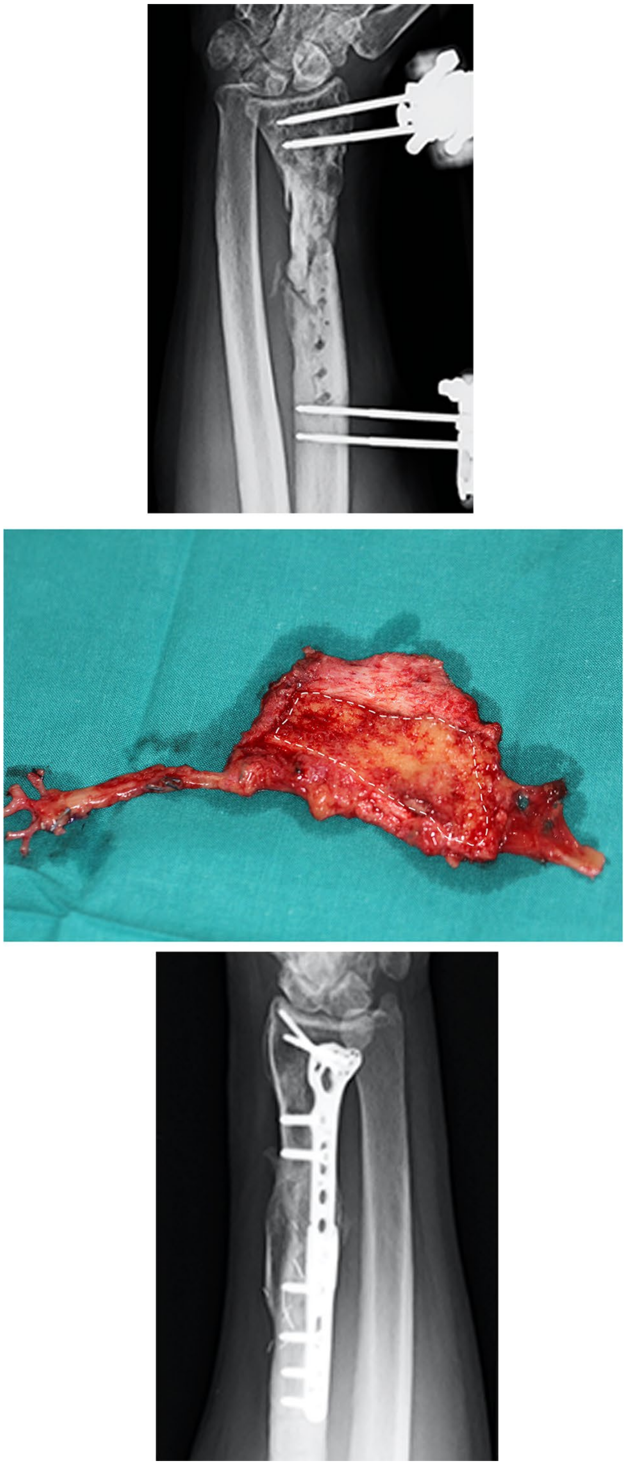

Fig. 1 (Above) A 47-year-old male with chronic osteomyelitis of the right distal radius after type II open fracture 2 years ago. The patient had four previous surgeries including wires and plate fixation, bone debridement and external fixator. (Centre) A corticoperiosteal flap had been harvested including the periosteum and the underlying cortical layer (cambium layer) with small cortical bone fragments attached (dotted in white). (Below) X-ray after 3 months showing bone healing with bone hypertrophy

2. Periosteal corticocancellous flaps (PCC flaps) (Fig. 2): include periosteum and a large portion of corticocancellous bone from de femoral condyle as a semi-structural flap. The bone flap is harvested using angled osteotomes to facilitate removing the flap without shearing the cortical bone from the underlying cancellous bone. We use this flap in bone defects ranging from 1 to 5 cm and in bone reconstructions where the PCC flap was harvested as a bone block with a redundant periosteal flap and then tailored according to the defect.

Once the tourniquet is released to evaluate bleeding from the periosteum and underlying bone, the vascular pedicle is then clamped and ligated.

Surgical considerations

1. An adequate flap contact with the bone is essential to promote bone healing. Thin PCC flaps can be easily tailored to fit into small bone gaps. In cases where there are tubular bones, such as phalanges or the clavicle, the PCC flap should be sculpted prior to bone reconstruction (Fig. 3). This helps in achieving a better fit and alignment of the flap within the bone defect. Maximizing the contact surface area between the flap and the bone increases the probability of successful bone consolidation.
2. The transferred periosteum should overlap the area of bone non-union or both osteotomy sites if a structural iliac crest graft has been used. This ensures adequate vascular supply between the flap and the graft, which is crucial for bone union.
3. For the reconstruction of medium to large-sized bone defects (including defects ranging from 2 to 5 cm), both flaps can be used, either a CP flap with an associated iliac crest graft or a block PCC flap. Over time and with experience, we have observed that better results are achieved in larger defects by reconstructing the entire bone with the vascularized flap tailored as a PCC.
4. To secure the flap in place, we use peripheral sutures or small screws. This helps maintain the proper positioning and stability of the flap during the healing process.
5. The choice of recipient vessels is determined based on the location of the non-union site and the caliber of the vessels. End-to-end anastomosis can be performed if the vessel is small or if there are branches of similar size. However, end-to-side anastomosis are used when there is a significant difference in vessel calibers.
6. Two methods could be used to monitor this flap:

    a. The inclusion of a cutaneous paddle on bone free flaps may improve clinical flap monitoring and pro-

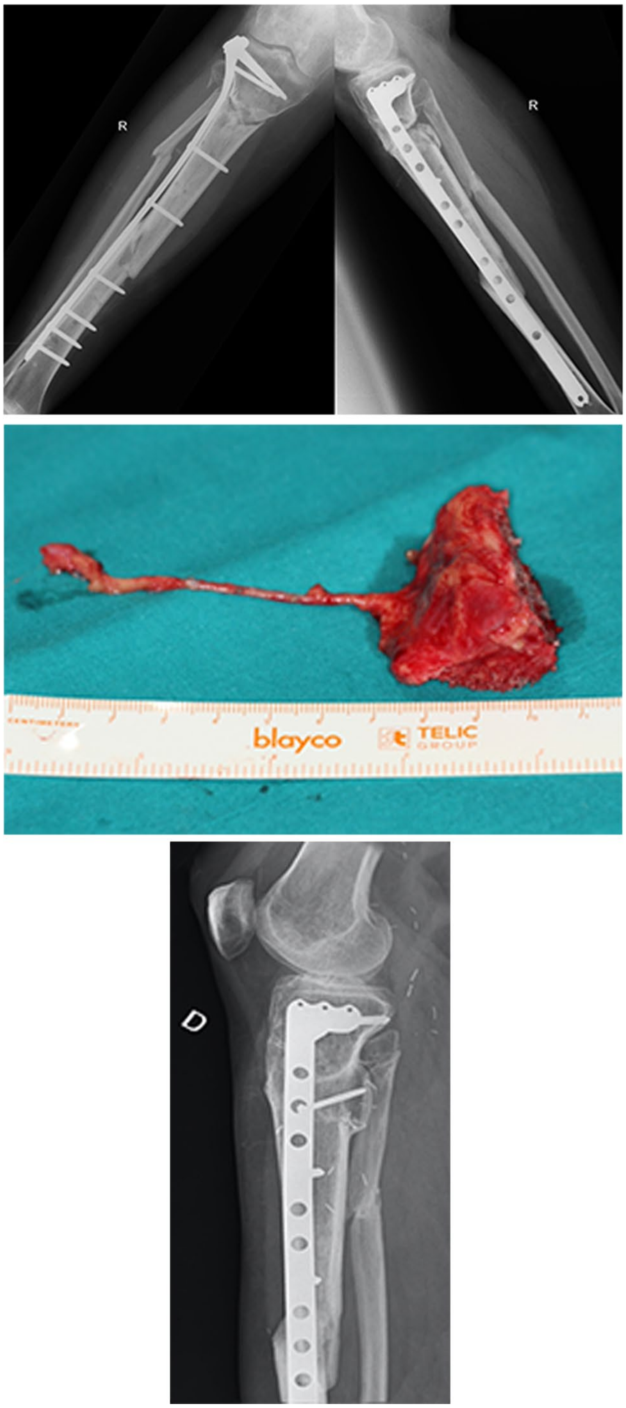

Fig. 2 (Above) A 35-year-old female sustained a grade I open bifocal tibia fracture treated with open reduction and plate fixation. Radiographs after 11 months showing non-union of the proximal fracture. (Centre) A harvested PCC flap including the periosteum and 3.5 cm of corticocancellous bone from de femoral condyle. The flap includes three layers: periosteum, cortical and cancellous bone as one structural block flap. (Below) Full consolidation of the fracture 6 months after surgery

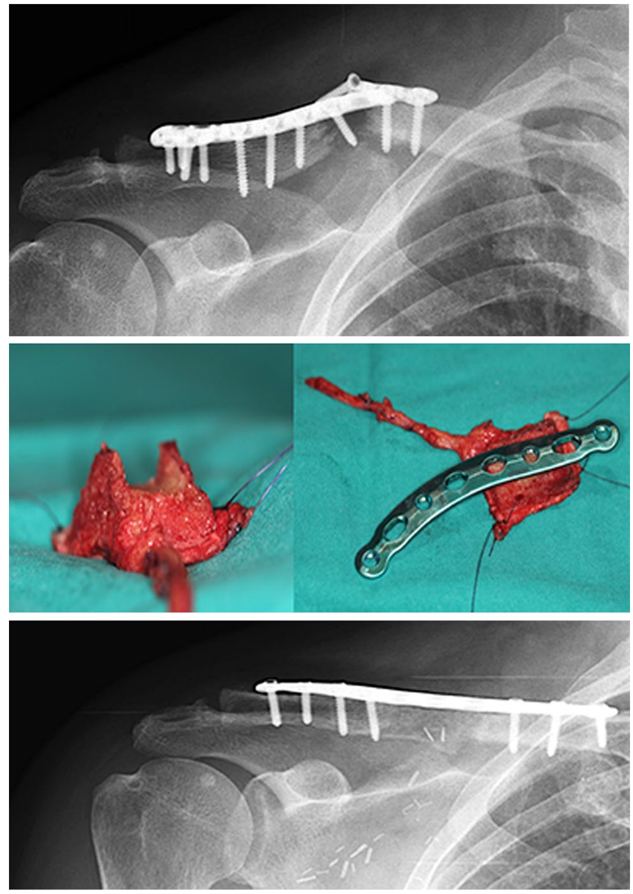

Fig. 3 (Above) Non-union of the right clavicle in a 51-year-old male associated with a hardware failure. (Centre) Bony tailoring of the PCC flap prior to insetting. The plate is placed opposite to the pedicle and the flap is wrapped around the non-union and fixed with nonabsorbable sutures. (Below) Bony healing after 4 months

mote recognition of microvascular compromise. However, this method may not always be feasible if the recipient area has limited space to accommodate the skin paddle.

b. Passing the vascular pedicle of the flap subcutaneously in an area where the Doppler signal has not been detected previously. The pedicle is passed beneath that area and marked with a dot on the skin. This is usually our preferred method of flap monitoring.

Results

Radiographic follow-up was conducted with plain radiography at 4 weeks intervals until bone union. Computed tomography (CT) was not performed routinely to confirm consolidation, although we used it in selected cases. Average follow-up was 14.5 months (range 5–28). Radiological evidence of bone union (trabecular bridging or callus visualized at the fracture site) was observed at 4.09 months (range 2–9). We use CP flaps in 46 patients and PCC flaps in 33 patients. After bone debridement, 62 patients showed bone defects above 1 cm. In this group, a bone gap from 1 to 3 cm was encountered in 43 patients while 19 patients show bone defects above 3 cm up to 5 cm. No defects or below 1 cm were found in 17 cases. Of 19 patients with bone gaps between 3 and 5 cm, we used PCC flaps in 7 cases and CP flaps plus structural iliac crest graft in twelve cases. Recorded data including bone gap, type of flap, additional bone grafts and time to bone healing are shown in Table 3.

One patient in the PCC group (a scaphoid non-union) didn't obtain radiological bone healing, but he didn't present any symptoms. Three patients (1 ulna, 1 radius and 1 tibia) in the CP group who underwent reconstruction using a structural iliac crest graft with CP flap required a second surgery for grafting the proximal site of the bone defect.

Cancellous bone graft from de femoral condyle or the iliac crest was used in 33 cases. No significant difference was found in terms of bone healing between grafts taken from either site. However, the use of iliac crest grafts resulted in increased donor site morbidity.

There were no significant donor site complications. Mild paraesthesia over the medial aspect of the knee was observed in 6 of the patients. One of them presented persistent pain over the knee scar. Three of the patients developed postoperative seroma at the donor site that required arthrocentesis.

Discussion

The advantages of vascularized bone transfer over non-vascularized bone grafts are well documented [12, 13] and include bone growth capabilities, improved mechanical properties, and more rapid union. However, despite these benefits, conventional bone graft techniques remain the preferred procedure in many cases due to their relative simplicity. In fact, almost 90% of non-union cases can be effectively resolved using modern fixation hardware and conventional bone grafts from the iliac crest [14].

When avascular necrosis, persistent pseudarthrosis, irradiation, long-standing infection or even large bony defects complicates the situation, the use of vascularized bone grafts becomes essential to maximize the chances of successful union in this kind of scenarios [15–18]. Four of our patients

Table 3 Patients results

Surgical data				
Defect size, mean (range)				2.26 cm (0–5)
Bone gap	N, patient	Flap type		Structural iliac crest graft (only CP flap group)
		CP flap	PCC flap	
< 1 cm	17	12	5	0
1–3 cm (≤ 3 cm)	43	22	21	13
3–5 cm	19	12	7	12
		46 (58.2%)	33 (41.8%)	25
Outcomes				
Consolidation time, mean (range)		4.09 months (2–9)		
CP flap group		4.60 months (2–9)		
PCC group		3.93 months (2–7)		
Bone healing, n (%)		CP flap		PCC flap
Primary union		43		32
Secondary union (following hardware change or bone graft)		3		1
		93%		97%
Follow up, mean (range)		14.5 months (5–28)		
Complications				
Mild paraesthesia				6
Seroma				3
Persistent knee pain				1

N number, *CP flap* corticoperiosteal flap, *PCC flap* periosteal corticocancellous flaps presented scaphoid nonunion without any prior surgical treatment. However, the fracture characteristics (avascular necrosis with persistent pseudarthrosis) and patient characteristics (young individuals without comorbidities) led us to directly choose a reconstruction using vascularized bone, which increased the chances of successful consolidation. Its thin and pliable nature gives it a further advantage over other vascularized bone grafting techniques, which allows it to conform well to the recipient site or it can be effectively wrapped around nonunion sites in tubular bones with minimal excess bulk. Additionally, when harvested with the underlying cancellous bone, it is particularly suitable for bone loss up to 5 cm (Fig. 4).

Due to of its osteogenic capability, periosteal flaps have shown significant potential in the reconstruction of bone defects [19]. Studies have demonstrated that the inclusion of a vascularized periosteal flap with underlying cancellous bone is more effective in producing compact bone than using a vascularized periosteal flap alone or an isolated cancellous bone graft [20]. The superiority of corticoperiosteal flaps over periosteal alone is based on the importance of the cambium layer (innermost layer of the periosteum) where is the high osteogenic, osteoinductive and osteoblastic capacity of the periosteum. Including a small piece of cortical bone in the flap has been recommended to preserve this layer. Including a small piece of cortical bone in the flap has been recommended to preserve this layer, as injury to the cambium layer while separating the periosteum from the bone can lead to contradictory results.

In the initial stages of our study, bony defects ranging from 3 to 5 cm were reconstructed using sculpted structural tricortical non-vascularized corticocancellous bone grafts from the iliac crest wrapped with CP flaps. However, we have since transitioned to using PCC flaps, as they have demonstrated better results with reduced morbidity. Among the 44 patients reconstructed with the previous technique, three (involving the ulna, radius, and tibia) did not achieve bone union at the proximal site and required a second surgery for bone grafting. Two hypotheses have been proposed to explain these failures: one related to injury of the cambium layer during CP flap harvesting, and the other related to periosteal perfusion. The supracondylar region, which has the largest periosteal source vessel, exhibits thicker and more visible vessels. As the flap extends more proximally, the periosteum becomes thinner and the visible vessels running over the bone decrease. This anatomical feature results in better vascularization of the distal portion of the flap compared to the proximal counterpart, leading to a higher failure rate at the more proximal non-union site. Based on these results, we decided to change our preferred technique to favor the use of PCC flaps instead of iliac crest bone grafts covered with CP flaps for non-unions with bone defects up to 5 cm (Fig. 5).

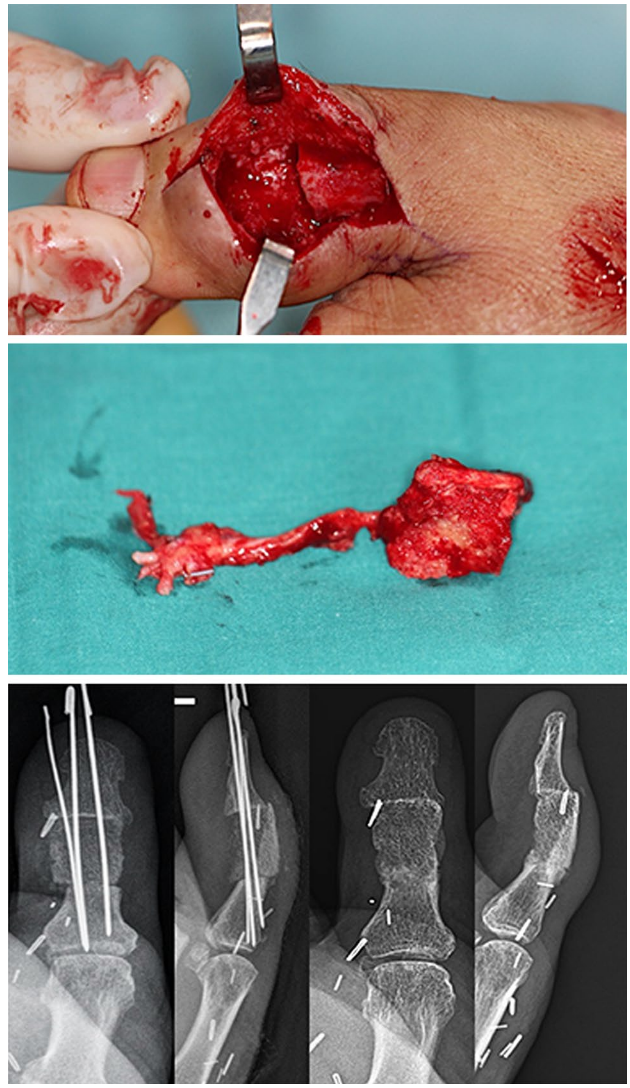

Fig. 4 (Above) Intraoperative image of the proximal phalanx defect after initial osteomyelitis of the thumb and 2 previous surgeries. (Centre) A harvested structural PCC flap with a thickness of approximately 2.5 cm. (Below) Bone flap inset with wire fixation and final healing after 3.5 months

Although vascularized fibula or crest bone flaps have been popular for long bone defects, their use for small gaps can be challenging, particularly in accurately locating the nutrient artery and harvesting a small segment with its pedicle. Furthermore, dealing with hand bone defects may present difficulties in matching the size of recipient and donor vessels. The thinner CP flaps are easier to shape to fit the contours of the recipient site, and we have the flexibility to customize the graft according to the specific defect. Another advantage of this flap is they can be skin grafted if wound closure is too tight to preserve flap perfusion. In recent years, several articles have been published in the literature with excellent clinical results

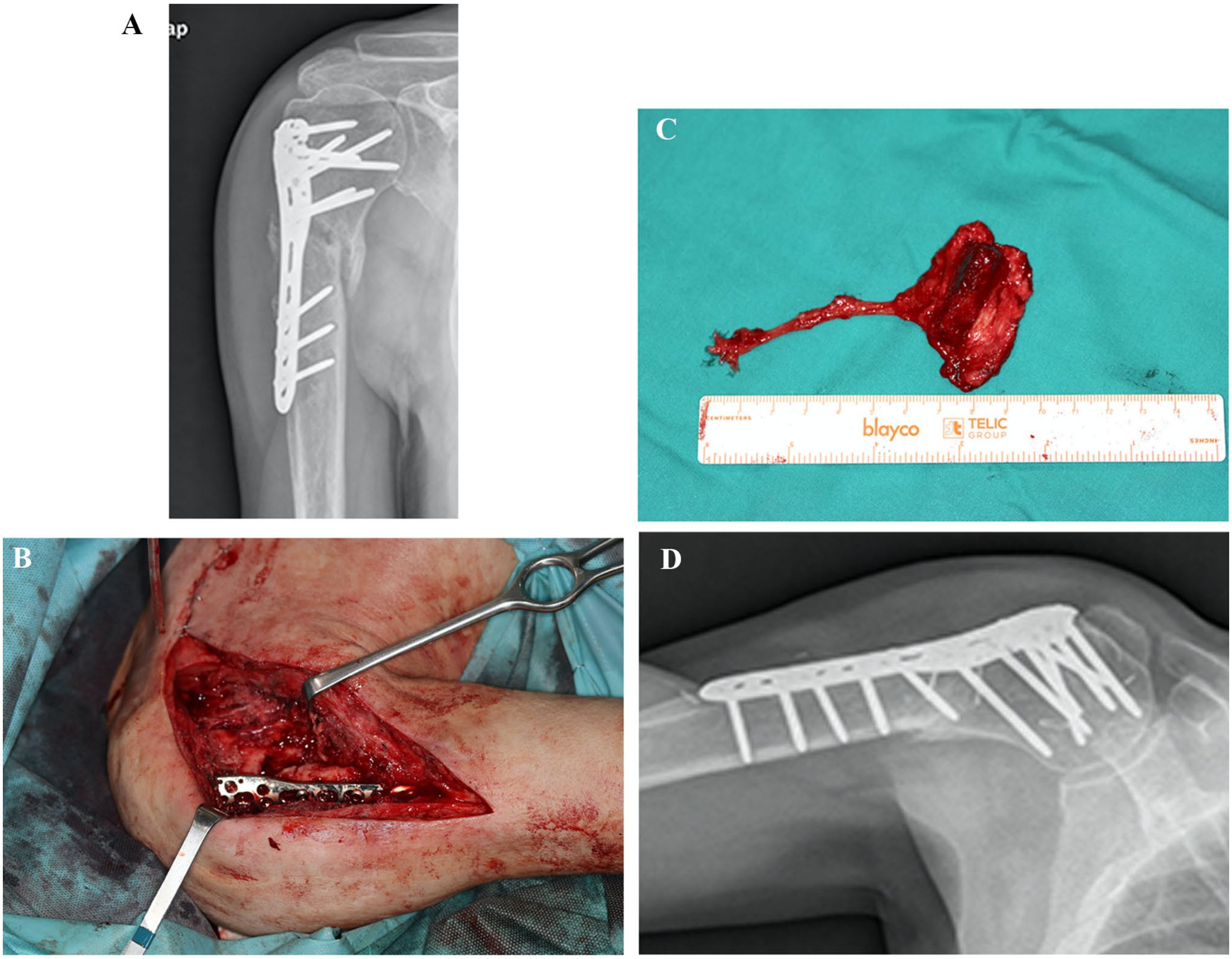

Fig. 5 **A** Proximal humerus fracture nonunion after two previous unsuccessful surgical attempts and 15 months. **B** Bone gap after debridement and preparation of the recipient site. **C** The flap has been harvested with periosteum, in addition to a block of cortical and cancellous bone which was placed into the bone defect of the humerus. During insetting redundant periosteal is recommended to overlap the junction with the recipient bone. **D** Four months after operation X-ray shows complete bone union

of the vascularised corticoperosteal flap in persistent nonunions of upper [21–24] and lower [25–30] extremities. Our results confirm the benefits and the reliability of the procedure.

When a small portion of corticocancellous bone is required along with the flap, it raises concerns about the osseous perfusion of the source vessel. The vascularized bone is first contoured to fit into the previously created cavity, and then it is fixed with screws or K-wires. Despite meticulous tailoring of the flap, these cases are more susceptible to damaging the vascular pedicle or its osseous perfusion. It is difficult to ascertain whether blood flow between the cancellous bone and the periosteum is effectively taking place when such a small bone portion is tailored to the defect. This may explain why one of the eight scaphoid nonunion cases failed.

The dense vascular supply of the MFCP flap with its high osteogenic potential and the ability of been easily shaped make this flap an ideal choice for addressing challenging bony non-unions or defects regardless of their location and size. However, the management of larger gaps (over 4–5 cm) with MFCP flaps raises concerns about donor site morbidity, particularly the risk of iatrogenic femur fracture or knee arthritis. Future studies should focus on exploring new applications and larger periosteal flap transfers, considering the favorable results obtained with the corticoperiosteal flap from the medial femoral condyle.

Conclusions

Vascularized periosteal flap from the medial condyle provides rich blood supply and possesses thin and pliable characteristics making it a versatile flap option. It has enabled surgeons to successfully utilized this flap for reconstructing bone defects in various anatomical locations. Our study demonstrates the expanding applications of this flap in two distinct ways: as a conventionally periosteum flap and as a semi-structural flap, both yielding excellent clinical outcomes in the treatment of challenging non-unions and large bone defects up to 5 cm.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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Informed consent NA.

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