Corticoperiosteal flap in the treatment of nonunions and small bone gaps: technical details and expanding possibilities

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KEYWORDS
Nonunion; Pseudoarthrosis; Corticoperiosteal flap; Periosteal flap; Medial femoral condyle; Structural bone graft

Summary The corticoperiosteal flap from the medial femoral condyle (CP) has proved to be highly reliable in the management of persistent, recurrent nonunion. However, much of the related literature has focussed on the flap aspects of the procedure and not so much on bone work-up.

We present a series of 25 patients with nonunions and small bone gaps irreversible to conventional therapy that were successfully treated with a CP with/without the addition of non-vascularised bone graft from the iliac crest. Different technical options of bone reconstruction are possible and discussed: CP plus non-structural bone chips, CP plus structural bi/tricortical struts or CP plus vascularised cancellous bone from the femoral condyle. A stable internal fixation was performed in all cases.

Clinical and radiological evidence of healing was obtained in all the patients. Donor-site complications were few and transient (suture intolerance, seroma and numbness in the saphenous territory). No fracture of the femur, knee instability or stiffness has been observed.

The corticoperiosteal flap from the femoral condyle is an excellent source of vascularisation and osteogenic stimulus to the nonunion site and highly effective in the management of persistent nonunions and small bone gaps. When needed, a structural corticocancellous strut from the iliac crest (along with a stable internal fixation) provides the greatest stability and the possibility of a prompt rehabilitation and functional recovery. The corticoperiosteal flap has succeeded in revascularising these highly demanding grafts and in allowing a 100% union rate.

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<td>20 Long standing nonunion proximal third of ulna</td>
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<td>25</td>
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<td>Fracture of middle third of radius; External fixation + bone graft from iliac crest; Segmental 3 cm; Corticoperiosteal; Tricortical bone graft from iliac crest (structural); Reconstruction plate</td>
<td>5</td>
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*Definition of bone healing based on clinical plus radiological findings.*
It is estimated that an average of 3–4% of all fractures are complicated with nonunion. For adequate healing, a fracture needs stability, bone stock and adequate vascularity. Poor surgical technique, deficient fixation or inadequate premature motion are all factors which compromise the stability of the healing process and can progress to hypertrophic nonunion. Atrophic nonunions, on the contrary, are characterised by the absence of callus, avascular bone ends and poor healing potential and are usually the result of a poorly vascularised environment (high-energy fractures, associated regional injuries or repeated surgeries). Some bones, for reasons not always well understood, have shown an increased nonunion rate (ulna, tibia, scaphoid or humerus). Adequate debridement of pseudoarthrotic tissue followed by rigid internal fixation and bone grafting is the standard primary treatment and can effectively resolve up to 90% of the hypertrophic nonunions but not so of the avascular ones. We present our experience with the combined use of the vascularised corticoperiosteal flap from the medial femoral condyle and bone graft from the iliac crest in the persistent nonunions of the upper and lower extremities.

**Materials and methods**

**Patients**

From October 2007 to January 2010, 25 patients with small bone gaps or persistent nonunion of long bones have been reconstructed with a corticoperiosteal flap from the medial femoral condyle in our unit. The series included 24 males and one female with an age range of 28–53 years. All injuries were work related. Bones involved were eleven ulnas, three radii, two humeri, four tibias, one metacarpal and four phalanxes. Recorded data included type and size of the bone gap, type of flap raised, bone fixation, time of bone healing, postoperative complications and final outcome.
outcome (Table 1). Twenty-one of the patients had previously received one or more surgical treatments for the nonunion (secondary bone fixation with or without bone graft or different kinds of bone substitutes). In four of the cases, the procedure was done as a first treatment considering the low chance of success with a more conservative approach. Fifteen of the patients had associated bone/soft-tissue injuries around the nonunion site at the initial injury with only ten primarily diagnosed of isolated closed bone fracture. Bone gap after debridement ranged from 1.5 to 5 cm. Bone healing was obtained in all the patients in a period of time that ranged from 3 to 9 months. Criteria of bone healing was based on clinical and radiological findings.

**Bone debridement and fixation**

A thorough bone debridement until healthy tissue was first performed with the use of electric blurs or chisel under ischaemia (Figure 1). A piece of the debrided tissue was routinely sent for microbiological study although none of our cases had a previous diagnosis of osteomyelitis. If non-stable, hardware was removed and replaced by a new rigid fixation following AO principles. As a routine, we use plate and screws for upper-extremity bone fixation. Intramedullary nails and plates have both been used in lower-extremity cases and it is a matter of debate which of them is most suitable in this particular group of patients.

**Vascular anatomy of the corticoperiosteal flap (Figure 2)**

The vascular anatomy of the medial femoral condyle has been well described in previous reports. A constant dual blood supply by descending genicular and superomedial genicular vessels has been reported rivalling in the vascularisation of the medial femoral condyle and confirmed in our dissections (Figure 3). A distinct dominance of the former was found in all of our cases with an average pedicle length of 6–8 cm (one artery and one vein) and a variable external diameter (0.7–1.5 mm). We have always found the pedicle to be located close to the femur, under the medial border of the vastus medialis muscle and routinely giving one or two branches to the vastus medialis, allowing the inclusion of small muscle segments that can be useful to collapse dead spaces or provide tissue cover. In none of our cases did the descending genicular vessels give a direct branch to the skin, thus excluding the possibility of raising a skin paddle with this pedicle. In four of the patients, we have found the descending genicular vessels to divide proximally into two branches: one for the femoral condyle running under the vastus medialis and one running above the muscle (and over the adductor tendon) reaching the prepatellar region (Figure 4). A constant distal division of the descending genicular vessels has always been found in two consistent branches that circumferentially nourish the femoral condyle and distal femoral diaphysis (Figure 5). All of our patients presented a saphenous neurovascular bundle, which usually gives one or two branches to the medial knee skin. The saphenous and descending genicular vessels can, or cannot, have a common entrance in the deep femoral artery and vein.

**Figure 3** Descending genicular and superomedial genicular vessels rival in the vascularisation of the medial femoral condyle. The dominance of the first has been present in all of our cases. (1). Descending genicular vessels. (2). Saphenous vessels. (3). Superomedial genicular vessels. (4). Common trunk descending genicular-saphenous vessels.

**Figure 4** Although not predictably, a pedicle of significant size and independent of the saphenous vessels can nourish the medial and anterior knee skin. Small branches of the descending genicular vessels nourishing the vastus medialis allow the inclusion of muscle cuffs in the flap. (1). Common trunk descending genicular-saphenous vessels. (2). Descending genicular vessels in periosteum. (3). Saphenous vessels. (4). Saphenous nerve. (5). Pedicle supplying the medial and anterior knee skin. (6). Vastus medialis muscle. (7). Sartorius muscle. (Arrow). Branch of descending genicular to vastus medialis.
Raising of the corticoperiosteal portion of the flap

The periosteal portion of the flap should be raised with great care to not damage the inner layer (cambium layer) where the osteogenic capabilities of the periosteum reside. Including a segment of cortical bone (Figure 6) has been recommended to avoid the damage of this inner layer despite the cortical part of the flap not being necessary from a reconstructive point of view. We have used a periosteal-only flap in four of our patients and a periosteal diaphyseal extension in the other 18 patients without noticeable differences in the final outcome. We hypothesise that a delicate dissection might not be so harmful to the cambium layer. A larger series, however, should be necessary to make a proper statement on this issue. The addition of cortical segments of the medial femoral condyle seems safe but how much vascularised bone can be extracted from a femoral condyle without damaging its structural support is still unknown. Including part of the femoral diaphyseal cortex in the flap seems dangerous and should be avoided. As much diaphyseal periosteum as possible is usually included in the flap. Bone elevation is performed with straight or curved osteotomes although an appropriate low-speed power saw can be used.

Bone reconstruction

The transferred periosteum is excellent in terms of bringing osteogenic stimulus to the nonunion site. However, its capacity for vascularised bone transfer is limited. Furthermore, tailoring the bone is difficult and might damage its vascularisation. Thus, different options are available in the management of the bone deficiency.

- Non-structural non-vascularised cancellous/cortico-cancellous morselised graft from the iliac crest or from the medial femoral condyle. This is an excellent option for small irregular defects with a preserved structural support (mostly unicortical defects) (Figure 7).
- Structural bi/tricortical non-vascularised cortico-cancellous bone graft from the iliac crest. The graft should be accurately adapted to the gap and compression should be obtained at both fracture ends. Sculting the graft in a ‘mortise and tenon joint’ fashion increases structural support and promotes graft take. Cancellous graft should be used to fill any residual defect. This is our preferred technique when structural support is lost (bi- or tricortical defects). Defects of up to 4 cm have been successfully managed with this technique (Figures 8 and 9).
- Vascularised corticocancellous bone graft from the medial femoral condyle (Figure 10).

Flap inset and transfer

Matching recipient vessels, pedicle length and local three-dimensional (3D) requirements make flap inset demanding. The flap should nicely wrap both fracture sites and, circumferentially, as much of the graft as possible (Figure 11). Folding the cortical portion of the flap is essential for an adequate contact with the graft. Subperiosteal removal of two or three longitudinal 2–3 mm-wide strips of cortex is of great help in flap

Figure 5 A constant distal division of the descending genicular vessels has always been found in two consistent branches that circumferentially nourish the femoral condyle and distal femoral diaphysis. (1). Saphenous neurovascular pedicle. (2). Descending genicular vessels supplying the medial femoral condyle.

Figure 6 A. Although not necessarily, the inclusion of cortical bone (1) allows preservation of the inner layer of the periosteum (cambium layer) where the osteogenic capability resides. B. Corticoperiosteal flap. White line. Medial femoral condyle portion of the flap. Yellow line. Diaphyseal extension of the flap. (1). Skin paddle. (2). Vascular pedicle.
shaping and inset (Figure 12). However, peripheral sutures are necessary to keep the flap in place. Excluding the cortex allows easy flap attachment (not even requiring sutures) and an intimate contact of the periosteum with the graft that might be of benefit. Microvascular anastomoses are made to healthy neighbouring vessels. End-to-side arterial sutures are the routine although a T-configuration is preferable if possible. On the venous side, end-to-end sutures are the rule. Direct vascular anastomoses were done in all cases without the need for interpositional vein grafts. Recipient vessels were selected according to the nonunion site.

Skin closure

Extensive bone manipulation in a scarred environment causes oedema and can yield skin closure risky, especially in the lower limb. All wounds were closed primarily in the upper limb (except for an approach to recipient ulnar vessels whose closure was delayed 1 week). A case of nonunion of the distal tibia required an additional vascularised skin paddle for closure based on the saphenous vessels (Figure 13).

Follow-up

Patient discharge was done 7–10 days after the procedure in the uncomplicated cases. Protective cast immobilisation has been routine during the first postoperative 30 days followed by a progressive rehabilitation. Radiographic follow-up was done with plain radiography at 1-month intervals until bone union (Figure 14). Computed tomography (CT) was not found necessary to confirm consolidation in any of the patients. Postoperative flap monitoring was performed with the hand-held Doppler probe on a daily basis during the first 5–7 days and on a weekly/monthly basis thereafter.
No femoral fracture, knee instability or persistent pain has been encountered. Donor-site complications have been few and transient. Paraesthesia along the saphenous territory was observed in 15 of the patients that resolved after 3–4 months without long-term related disability. Two patients developed a seroma at the donor-site that required uncomplicated evacuation. Five patients presented with intolerance of the buried sub-dermal suture that resolved with local wound care. Painful squatting has always been present but never extending beyond the first 2–4 post-operative months.

Similar to the donor-site, recipient-site complications have been rare and mild. A small-wound dehiscence of the distal tibia required a local flap. Hardware exposure of an

Figure 9 Scultped graft in place and stabilized with an internal rigid fixation.

Figure 10 A vascularized periosteo-corticocancellous flap can be raised from the medial femoral condyle in the reconstruction of small defects of metacarpals, phalanges and carpal bones.

Figure 11 The transferred flap should cover both osteotomy sites and wrap as much of the graft as possible. Dashed line. Corticoperiosteal flap in place.

Figure 12 Subperiosteal resection of two or three 2–3 mm-wide strips of cortical layer allows easier flap wrapping around the bone graft. White dotted line. Periosteal diaphyseal extension. Black dotted line. Corticoperiosteal portion of the flap.

Complications

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ulna nonunion required prompt wound-edge debridement and direct closure. No hardware loosening has been encountered and only one plate (base of proximal phalanx) has had to be removed because of joint impingement.

Results

A bone union was obtained in 100% of our patients. Clinical evidence of consolidation has been observed as soon as 3–5 months postoperatively (absence of pain plus no hardware loosening on the X-ray). Radiologic evidence of bone union (consistent bone bridge across fracture gap), on the contrary, may take more than 6–10 months, especially with larger bone gaps. With protected rehabilitation treatment starting 3–4 weeks postoperatively, all patients have regained a functional range of motion and rejoined work.

Discussion

The association of modern fixation hardware and bone graft from the iliac crest can effectively resolve nearly 90% of nonunion cases. Absence of adequate vascular environment...
at the fracture site remains a major issue in atrophic avascular nonunions and accounts for a much lower success rate in the hands of traditional techniques. Classical techniques to revascularise the fracture site (decoration, petaling or drilling of fracture end) are unreliable. Electric stimulation, ultrasound stimulation and high-energy extracorporeal shock waves have shown good results in hypertrophic nonunions but less so in atrophic nonunions or in the presence of a large gap. Percutaneous injection of autogenous bone marrow and different osteoinductive molecules (transforming growth factor-B (TGF-B) subfamily, bone morphogenetic protein (BMP) subfamily or platelet-derived growth factor (PDGF)) have been used in the treatment of nonunions with promising but still non-conclusive results.

Because of its osteogenic capability, periosteal grafts have a significant potential in the reconstruction of bone defects and it has been shown experimentally that the association of a periosteal flap and cancellous bone is a better means by which to produce compact bone than either a vascularised periosteal flap alone or an isolated cancellous bone graft. Different authors have published excellent clinical results in persistent nonunions of upper and lower extremities. Interesting applications to head-and-neck defects have also been reported. Our series confirms the benefits and the reliability of the procedure.

Much of the related literature has focussed on the excellence of the vascularised corticoperiosteal flap but, in fact, in most of the cases, the corticoperiosteal transfer does not provide enough bone and the addition of a bone graft (preferably from the iliac crest) is necessary. Structural support of the reconstructed bone, when missing, is mandatory to allow a prompt rehabilitation and adequate functional recovery. Morselised cancellous bone grafting offers the best chance of survival but at the expense of no structural support. Bi/tricortical grafts offer the desired structural support but at the expense of a diminished graft intake. Can a surrounding periosteal flap adequately revascularise a structural graft? The answer is yes, and as much graft as can be nicely wrapped by the vascularised peristeum. Bone gaps of up to 4–5 cm have been so managed in the upper limb with no recurrence of nonunion and 100% success. The management of larger gaps might best be managed with fibula or iliac crest free transfer or osteodistraction but not so much because of the amount of required graft than for the availability of vascularised transferrable peristeum. Future studies should be directed towards new, larger periosteal flap transfers considering the good results obtained with the medial femoral condyle cortico-periosteal flap.
Corticoperiosteal flap in the treatment of bone nonunion

The use of a highly vascularized bone-promoting tissue (the corticoperiosteal flap from the medial femoral condyle) is very efficient in the treatment of persistent nonunions and small bone gap reconstruction. Generally required, the association of bone graft from the iliac crest can greatly benefit from this rich vascular environment. Except for non-structural defects, a corticocancellous strut graft and a rigid internal fixation are advisable to provide stability to the reconstruction and allow early rehabilitation and recovery.

Conflict of interest statement

None.

References


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