The Vascularized Medial Femoral Corticoperiosteal Flap for Reconstruction of Bony Defects within the Upper and Lower Extremities

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ABSTRACT

The periosteum of the medial femoral condyle and supracondylar region is supplied by branches of the descending genicular artery and can be harvested as a corticoperiosteal free flap with or without cancellous bone. This flap offers an alternative to other types of vascularized bone grafts providing a thin and pliable sheet of osteogenic tissue that can be transferred to sites of problematic fracture nonunions. The highly osteogenic nature of the periosteum combined with its excellent vascularity after microvascular or pedicled transfer achieves a high success rate in treating difficult nonunions where conventional bone grafts have either failed or are not suitable. Donor-site morbidity is minimal. This article provides an overview of the anatomic basis, indications, and operative technique for the use of this flap.

KEYWORDS: Vascularized periosteal graft, medial femoral condyle, nonunion, free flap

Fracture nonunions in the extremities associated with small bone defects can often be treated with nonvascularized bone grafts. Nonunions with minimal bone loss but which are unsuitable for conventional nonvascularized bone grafting include those secondary to avascular necrosis, radiation osteonecrosis, osteomyelitis, and recalcitrant fracture nonunions in poorly vascularized soft tissue beds. Nonunions in these situations are more challenging problems that require the reliable transfer of vascularized osteogenic tissue for the best chance of achieving bony union. Although larger bone defects are now routinely treated with a variety of vascularized bone grafting techniques such as the free fibula, rib, or iliac crest graft, these techniques are generally difficult to use in cases with minimal bone loss and can be limited by

their size, shape, and rigidity, as well as by donor-site morbidity.

Vascularized periosteal flaps provide a versatile approach to treating poorly vascularized nonunions. Potential sites of periosteal flap elevation for limb reconstruction include the humerus, ulna, radius, iliac fossa, tibia, and femur.¹ The medial femoral condyle has recently become a popular choice for periosteal flap harvest due to its reliable anatomy, flexibility, size, and donor-site profile. Although periosteal flaps can be elevated alone without including the underlying bone, disrupting the strongly adherent Sharpey fibers between the periosteum and cortex risks injury to the cambium layer. As such, in their original clinical series, Sakai et al suggested that including a thin layer of adherent cortex

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when the periosteum is harvested minimizes risk to the underlying blood supply and ensures that the osteogenic potential of the periosteum is preserved.² Corticoperiosteal flaps harvested from the medial condylar region of the femur provide thin, pliable, highly osteogenic vascularized tissue that conforms to the recipient site, leaving minimal donor-site morbidity.

ANATOMY

The blood supply to the periosteum of the medial supracondylar femoral region is derived from the descending genicular artery (DGA) and the superomedial genicular artery (SGA) (Fig. 1). The medial femoral periosteal flap is usually based on the DGA, which is the longer and larger of the two vessels. The DGA is a medial branch of the superficial femoral artery (SFA) and arises just proximal to the hiatus in the adductor magnus, ~15 cm proximal to the knee. Its three terminal branches are the articular branch (supplying the periosteum), the saphenous branch (which supplies the overlying skin and can be preserved to include a skin paddle), and a muscular branch to the vastus medialis. Perforators from the saphenous branch are located posterior to the midlateral line in the distal third of the medial thigh and can be identified and marked prior to surgery using a hand-held Doppler probe.

Martin et al demonstrated the vascular anatomy in 36 cadaveric dissections and found that the pedicle of the periosteal flap based on the DGA ranged from 60 to 130 mm in length (mean, 80 mm), with a diameter of 1.5 to 3.5 mm at its origin.³

The SGA is a medial branch of the popliteal artery. Although it is possible to harvest the flap based on the SGA, this is a shorter vessel that is more difficult to dissect, and it lacks a cutaneous branch (Fig. 1).

Venous drainage of the periosteal flap is provided by paired venae comitantes, which often unite to form the short descending genicular vein. Additional venous drainage of the skin can be ensured by including the long saphenous vein.

SURGICAL TECHNIQUE

The patient is placed supine with the leg externally rotated and flexed at the hip and knee. After identifying the perforators with a Doppler probe, a longitudinal incision is made medially along the posterior border of the vastus medialis, extending from the adductor hiatus proximally to the medial collateral ligament distally. If required, a skin flap based on the saphenous branch can be included. The fascia of the vastus medialis is incised, and the muscle is retracted anteriorly. This exposes the descending genicular vessels, which can be seen emerging from the adductor hiatus proximally (Fig. 1). Posterior retraction of the sartorius may be necessary to facilitate dissection of the vessels, which are mobilized until their termination in the periosteum overlying the medial condylar and supracondylar region of the femur. If the descending genicular vessels are too small for reliable microvascular anastomosis, the superomedial genicular vessels can be used. Otherwise, the superomedial genicular vessels are ligated before they reach the periosteum. With the network of genicular vessels fully exposed, the required size of graft is drawn on the condyle. Corticocancellous grafts ranging from 1 × 1.5 cm up to 8 cm long and 6 cm wide have been described.^{3–5} Thin corticoperiosteal flaps can extend across the whole medial surface of the condylar and supracondylar region measuring as large as 13 × 8 cm.⁶ The size of the flap is limited by the medial patellar facet anteriorly, the posterior border of the femur posteriorly,

Figure 1 (A) Vascular anatomy of the medial femoral condyle periosteal flap. The major blood supply to the flap comes from the DGA, a branch of the femoral artery. Alternatively, the SGA may be used if the DGA is of inadequate caliber. The SGA has a shorter pedicle length. (From Choudry UH, Bakri K, Moran SL, Karacor Z, Shin AY. The vascularized medial femoral condyle periosteal bone flap for the treatment of recalcitrant bony nonunions. *Ann Plast Surg* 2008;60:174–180. Reprinted by permission). (B) DGA as it exits adductor canal. The vastus medialis has been retracted superiorly, and the clamp points to the hamstring tendon retracted inferiorly.

Figure 2 (A) Flap harvest proceeds from distal to proximal. Once the vessels have been clearly identified, the medial collateral ligament is identified and protected. The DGA is isolated, and the graft is then templated to the medial femoral condyle. The graft is harvested with an osteotome proceeding from distal to proximal to avoid injury to the vessels. The entire condyle may be harvested as a broad flap or (B) as a segmental graft. (C) Up to 7 cm of pedicle length is possible.

and the origin of the medial collateral ligament distally⁷ (Fig. 2).

The outline is cut with a cautery, and the cortex is then carefully chiseled out from the margins inwards. Thinner corticoperiosteal grafts are easy to shape and conform well to the contours of the recipient site; however, care should be taken to preserve the cambium layer, which is easily injured if the periosteum is stripped from the cortex. If a larger volume of bone is required, the graft can include the full thickness of the cortex and the underlying cancellous bone, removed as a wedge to avoid fracturing the cortex.

The descending genicular vessels are then dissected proximally until their origin at the adductor hiatus is reached. For free microvascular transfer, the vessels are divided at this level, and a segment of the proximal muscular branch can be included if an interpositional flow-through anastomosis is required. Alternatively, the graft can be pedicled on the DGA for use in defects involving the distal and middle third of the femur. After hemostasis is achieved, a suction drain is placed in the thigh, and the donor site is closed. The DGA and its venae comitantes are anastomosed to the recipient vessels; grafts are shaped with the help of fine bone rongeurs and fixed with sutures, K-wires, or screws (Fig. 3). Flap circulation is monitored by external Doppler, an implanted Cook-Swartz probe, or (if included) by examination of the skin paddle.

INDICATIONS

The advantages of vascularized bone transfer over non-vascularized bone grafts are well documented and include superior osteocyte survival, improved mechanical properties, and more rapid union.⁸ Despite this, because of the relative simplicity of conventional bone graft techniques, they are still the procedure of choice for many circumstances and enjoy excellent success rates in uncomplicated, aseptic, well-vascularized cases of small bony defects or nonunions. When avascular necrosis, irradiation, or long-standing infection complicates the situation, vascularized bone grafts have been used to maximize the chances of union.

This corticoperiosteal flap is indicated in similar situations, due to its well-vascularized, highly osteogenic character. Its thin and pliable nature gives it a further advantage over other vascularized bone grafting techniques, allowing it to conform well to the recipient site or to be effectively wrapped around nonunion sites of tubular bones with a minimum of excess bulk. Alternatively, when harvested with the underlying cancellous bone, it can be used to fill small segmental defects. This is especially useful in situations where the size of the defect does not justify use of conventional techniques for vascularized bone transfer such as a vascularized fibula or iliac crest flap, which may be difficult to tailor to the recipient site.

The free medial femoral condyle corticoperiosteal flap was first popularized by Doi et al^{2,9,10} who initially

Figure 3 Radiographs of a 56-year-old gentleman with long-standing nonunion of the tibia after osteomyelitis and 15 other surgical procedures. (A) A vascularized corticoperiosteal graft has been harvested and anastomosed to the anterior tibial artery. The graft is inset into the bony defect and held in place with circumferential sutures. (B) A broad periosteal sleeve can be seen covering the entire osteotomy site. (C) Early consolidation and union is apparent at 9 weeks after surgery. (D) Appearance at the donor site at the time of fracture consolidation shows good reconstitution of the cancellous and cortical component of the medial condyle.

used it for the treatment of humerus, ulna, and metacarpal fracture nonunions in six patients. It has since seen success in cases of recalcitrant nonunions, infected bone defects, avascular necrosis, and osteoradionecrosis in several other sites including the clavicle,⁶ scaphoid,¹¹ distal interphalangeal joint,⁴ as well as in cases of bone loss of the mandible,³ orbit,⁵ and skull.⁶

DISCUSSION

The osteogenic potential of the periosteum was first proposed by Duhamel in 1742¹² and has been studied extensively. The innermost layer of the periosteum, which is adjacent to the bone, is known as the cambium layer. This layer consists of osteogenic progenitor cells that are capable of differentiating into osteoblasts and forming new bone. The important role of the periosteum as a source of osteochondral progenitor cells in new bone formation is now well established¹³ and provides a rationale, at a cellular level, for the use of periosteal grafts as an alternative or adjunct to bone grafting.¹⁴ Several studies have confirmed this experimentally, demonstrating that predictable new bone formation can be induced by grafting periosteum to a bony defect provided adequate vascularity is maintained.¹⁵⁻¹⁸ Combining this technique with bone allografts has been shown to significantly increase the amount of bone formation when compared with either technique alone.¹⁹ Periosteum-derived osteoprogenitor cells are now also regarded as an important source of cells in bone tissue engineering.²⁰

The use of the free medial femoral condyle periosteal flap was first reported in a series of six patients where it was used for treatment of upper limb fracture nonunions.² These patients had all undergone previous conventional procedures to treat a fracture nonunion without success, including one free fibular transfer that failed to unite; however, all patients achieved union

within 2.5 months after treatment with this flap. Doi's group has published two further series of the secondary use of this flap in the management of upper-limb long-bone nonunions with similar results^{9,10} and has also reported their success using it to treat 10 cases of established scaphoid nonunion, all of which went on to heal.¹¹ Fuchs et al have described their use of this corticoperiosteal flap in three clavicle nonunions, including two primary procedures for the treatment of pathologic fractures secondary to osteoradionecrosis.⁷ The thin, pliable nature of the flap allowed it to be wrapped around the nonunion site with minimal visible bulk, avoiding tension in the overlying irradiated skin, and all patients achieved union.

Recently, the successful use of this flap has also been described for recalcitrant, long-standing nonunions.²¹ Grant et al reported their success in a single case of arthrodesis of the index finger distal interphalangeal joint in a patient who had undergone eight previous failed arthrodeses over 8 years.⁴ With the use of this flap, the patient achieved union and regained pain-free use of the digit within 3 months. We recently reviewed our experience with 12 vascularized medial femoral condyle periosteal flaps that were used to treat nonunions of the femur, tibia, clavicle, humerus, and radius. All fractures had undergone previous conventional procedures but had remained un-united for a mean period of 52 months (range, 10 to 276 months). Despite this, 9 (75%) cases went on to achieve early union with a mean time to union of 3.8 months (range, 2 to 7 months). Two further fractures healed within 12 months, after a further procedure. One flap that was performed in a patient with severe peripheral vascular disease failed.²¹

Review of all series published to date identified 46 cases of vascularized medial femoral condyle periosteal flaps used to treat fracture nonunions^{2,4,7,9-11} (Table 1). Forty (87%) of these achieved bony union

Table 1 Reported Outcomes for Use of the Medial Femoral Condyle Periosteal Flap to Treat Fracture Nonunions

First Author (Year)	Site (n)	Total (n)	Bone Loss	Mean Period of Prior Nonunion (Months)	Mean Number of Previous Operations	Postoperative Primary Union Rate, n (%)	Mean Time to Union after MFC Flap (Months)
Doi ⁹ (1994)	Ulna (4) Humerus (5) Metacarpal (1) Clavicle (1)	11	Small or none	N/A	2.2	9 (82)	2.8
Doi ¹¹ (2000)	Scaphoid (10)	10	None (AVN)	N/A	1.2	10 (100)	2.8
Muramatsu ¹⁰ (2003)	Humerus (10)	10	0-1 cm	14.2	1.8	9 (90)	4
Fuchs ⁷ (2005)	Clavicle (3)	3	None (ORN)	13.3	0.3	3 (100)	5
Moran ²¹	Femur (4) Tibia (2) Humerus (3) Clavicle (2) Radius (1)	12		51.8	1.7	9 (75)	3.8
Total		46				40 (87)	3.5

AVN, avascular necrosis; N/A, nonapplicable; ORN, osteoradionecrosis; MFC, medial femoral condyle.

Figure 4 Typical appearance of the donor site at the medial femoral condyle after resection of corticocancellous graft for correction of humeral nonunion. Bony defect is small resulting in little postoperative pain and little morbidity.

without the need for further procedures, and the mean time to union was 3.5 months. Three further fractures united within 12 months after a single further procedure, 2 fractures failed to unite, and 1 flap failed completely. Other reported complications were rare but included two cases of ectopic bone formation, donor-site seroma, and transient saphenous nerve paresthesia. No other significant donor-site morbidity has been observed (Figs. 3D and 4).

CONCLUSION

The medial femoral condyle provides a thin, vascularized corticoperiosteal flap that is effective in promoting early bony union in conditions where conventional bone graft techniques have failed. It is especially useful in situations where thin, pliable, osteogenic tissue is required to wrap around or conform to the recipient site. Indications for this procedure include recalcitrant nonunions, radionecrosis, avascular necrosis, and other cases with a poorly vascularized soft tissue bed where nonvascularized bone grafts are unlikely to succeed. Donor-site morbidity and other complications are rare, and more extensive procedures that carry excessive morbidity can potentially be avoided.

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