Double-barrel fibular graft for metaphyseal areas reconstruction around the knee

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Summary  The metaphyses around the knee (distal femoral and proximal tibial) are junction areas subject to considerable stress. Double-barrel free vascular fibular graft (D-FVFG) provides good bone augmentation and restores the metaphyseal cone; the present study assessed its capacity to restore metaphyseal anatomy and axis and investigated its impact on the neighboring knee joint.

Material and methods:  Eight D-FVFGs performed for metaphyseal segmental bone defect were followed up for a mean 6.5 years (range, 3—14 years). There were seven femoral nonunions, five of which were septic, and one chondrosarcoma of the tibia. Osteosynthesis used an external fixator (EF) in six cases (four of which bridged the knee), a double plate on the tibia in one case, and intramedullary nailing of the femur in two cases, including one to replace an EF. Adjuvant bone graft was associated in six cases. A protective leg brace was maintained for a mean 16.0 ± 4.0 months. Three arthrolyses were required after final union.

Results:  Union was achieved in all cases, after a mean 6.4 ± 2.1 months. Sixty-four percent of defect volume was reconstructed. The immediate postoperative mechanical femorotibial angle was 180.3 ± 6.0° and 174.5 ± 5.7° at FU. Mean knee flexion was 96.9 ± 36.0° and extension −5.0 ± 10.0°. Three patients showed symptomatic arthritis at follow-up.

Discussion:  D-FVFG satisfactorily restored the anatomy of the metaphyseal area. EF knee bridging seemed to impair varus correction, on top of the systematic problem of stiffness. When possible, internal fixation in first intention or as EF replacement appears to be preferable. Arthritic deterioration of the knee is worsened by initial joint lesions and femorotibial varus. Level of evidence:  Level IV. Type of study: retrospective.

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Introduction

Severe lower-limb bone defect entails problems of reconstruction due to mechanical stress which frequently causes secondary fatigue fracture, and to the “inhospitable”
<table>
<thead>
<tr>
<th>Case</th>
<th>Gender</th>
<th>Age at graft</th>
<th>Etiology - initial lesion location</th>
<th>Septic lesions</th>
<th>Bone defect height (cm)</th>
<th>Interval since initial lesion (mo)</th>
<th>Harvested fibula length (cm)</th>
<th>Associated iliac bone graft</th>
<th>Type of osteosynthesis</th>
<th>Bone healing time</th>
<th>EF time</th>
<th>Time to complete weight-bearing</th>
<th>Complications and surgical revision</th>
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<tr>
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<td>30.4±7.9</td>
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<td>14.0±10.9</td>
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<td>16.0±4.4</td>
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nature of the receiver site commonly induced by a history of infection.

Two main types of technique are reported in the literature: bone transport by progressive lengthening under external fixation (EF) [1] and bone graft. Vascularized bone graft has proved more efficient than autograft or conventional allograft in terms of bone healing rate and time [2,3]. Bone loss exceeding 7 cm is a classic indication for vascularized bone graft [4—9].

De Boer and Wood [10] demonstrated that vascularized bone grafts hypertrophy over time, thereby adapting to mechanical stress and reducing the risk of fatigue fracture.

In the metaphyseal area, the problems of reconstructing a conical junction between a narrow shaft and a wide epiphysis are heightened by the proximity of the knee joint, inducing stiffness.

In 1987 Jones et al. [11] and O’Brien et al. [12] simultaneously reported a double-barrel free vascular fibular graft (D-FVFG) technique that provides considerable bone input with greater adaptability in the reconstruction of the metaphyseal cone.

The present study assessed anatomic restoration of the metaphyses around the knee by D-FVFG and investigated the impact on the neighboring femorotibial joint.

**Patients and methods**

Eight patients (mean age at surgery, 30.4 years [range, 15—40 years]: four male, four female) presenting with severe metaphyseal bone defect were included in a retrospective study (Table 1). There were seven distal femoral nonunions, five of which showed signs of previous infection, and one chondrosarcoma of the proximal tibia.

The mean interval between initial trauma and D-FVFG was 14 months (range, 0—35.1 months). Patients had previously undergone a mean 3.4 (range, 2—6) related operations.

Mean bone loss was 9.8 cm (range, 5—16 cm). Volume (calculated as $V = \frac{(h^2(a + b))}{2}t$, where $V =$ volume, $h =$ height filled or to be filled, $b =$ defect width on diaphyseal side, $a =$ defect width on epiphyseal side, $t =$ thickness) (Fig. 1) was 163.3 cm$^3$ (range, 75—352 cm$^3$).

Fibular graft size was assessed by the ratio between height and mid-part width. Only variations greater than 10% were considered significant.

The five septic lesions had been managed by wide bone resection associated to external fixation and antibiotherapy maintained for at least 1 month after normalization of plasma CRP levels.

**Surgical technique**

Bilateral lower-limb arteriography was systematically performed to explore for anatomic variations in the fibular pedicle and traumatic or septic lesions to the recipient femoral artery.

The contralateral fibula was harvested with a lateral approach, with the patient in dorsal decubitus under pneumatic tourniquet. It was osteotomized in the mid-diaphyseal part, distally to the nutrient foramina, conserving a periosteal hinge containing the fibular pedicle (Fig. 2). Mean harvested fibula length was 23.1 cm (range, 19—27 cm).

The femur (seven cases) was systematically stabilized during previous surgery, once by retrograde intramedullary nail and by EF in six cases: five double Hoffmann frames, including four bridging the knee, and one Orthofix monolateral brace.

The graft was inserted in the extremities of the femur via a lateral thigh approach and stabilized by K-wire or a screw. The two fibular grafts were positioned one against the other. The extremities facing the mid-diaphyseal osteotomy were fixed onto the diaphyseal area of bone loss and the proximal and distal extremities onto the metaphyseal part. Microsurgical terminolateral arterial anastomosis onto the femoral artery was systematically performed with a medial approach, using a medial and a lateral plate and anastomosis onto the popliteal artery.
Metaphysis reconstruction by double-barrel free vascular fibular graft

Adjuvant iliac crest corticocancellous bone graft was associated in six cases.

Technetium bone scan on day 3 consistently confirmed fibular vascularization [13].

In case of initial septic lesion, adapted antibiotherapy was systematically associated for 1 month postoperatively.

In one case (case 4), EF was relayed by an intramedullary nail at 6 months, when X-ray showed bone healing to be achieved.

Data collection

All patients underwent a medical check-up by an independent (non-operating) physician at a mean 6.3 years (range, 3–14 years) after bone graft. Postoperative bilateral whole lower limb AP and lateral X-ray views were systematically taken, associated on follow-up to AP, lateral and schuss views.

Data analysis

Statistical analysis used non-parametric Wilcoxon tests to compare matched variables and Spearman rho coefficients to assess correlations. Analysis was performed onExcelstat® software. The significance threshold was set at \( P = 0.05 \). Correlation at 8 degrees of freedom is significant at \( P = 0.05 \) when Spearman’s rho is greater than 0.63 on the Fisher-Yates table.

Results

Tables 1 and 2 present the results.
Complications

During bone healing process, there were no complications requiring surgical revision. Four patients showed effusion around fixator pins, resolved by local treatment.

Following bone healing, four knee arthrolyses were required in patients with EF bridging the knee and who showed less than 80° flexion.

No stress fractures were observed during follow-up.

No donor-site morbidity such as secondary paresthesia of the peroneal nerve territory was observed. The only other complication was a systematic reduction in hallux flexion strength, without retraction [14].

Bone healing rate and time

EF was maintained for a mean 8.5 months (range, 4.9–13.6 months), relayed by leg brace for a mean 6.1 months with the knee mobilized. Mean interval to complete weight-bearing without protection brace was 16.4 months (range, 11–22 months). Radiologic bone healing was achieved at a mean 6.4 months (range, 4–10 months). This time showed slight correlations with trauma-to-treatment interval (rho = 0.295) and bone-defect volume (rho = 0.299) and height (rho = 0.299). In contrast, the femorotibial angle at FU showed an inverse correlation with healing time (rho = 0.730). Bone healing time was longer in case of residual varus.

Anatomic restoration

Mean immediate postoperative frontal mechanical femorotibial angle was 180.3 ± 6.0° (range, 6° varus to 10° valgus), and 174.5 ± 5.7° (range, 17° varus to 2° valgus) at FU; this correction loss induced a mean 5.8° variation. Correction loss in case of femoral metaphysis nonunion approximated significance (P = 0.089). Sagittally, correction loss was negligible, (0.1°).

Mean bone defect was 163.3 ± 96.3 cm³, and was restored by a mean 104.6 ± 64.4 cm³ at FU. Only metaphyseal volume and width were not fully restored, at respectively 64% and 71% of the defect values.

There was hypertrophy of both grafts in four cases, of the lateral graft corresponding to the distal part in three, and medial hypertrophy in one (Fig. 3).

Mean lower-limb length discrepancy at follow-up was 1.8 cm (range, 0–3 cm).

Analytic and functional results

Mean knee mobility at follow-up comprised 97° flexion (range, 45° to 140°) and −5° extension (range, 0 to −20°); four of the eight patients showed greater or equal to 100° flexion. Statistical analysis identified stiffness factors as not only EF duration (rho = −0.841), but also frontal varus deviation (rho = 0.847).

There was a weak correlation (rho = 0.400) between knee mobility and defect dimensions. There were no cases of knee instability.

Mean International Knee Society scores (IKS) were 51/100 for the clinical score and 75/100 for the function score, with three poor, three good and two very good results. These scores correlated only with EF duration (rho = −0.781), bone healing time (rho = −0.771), and frontal correction loss at FU (rho = 0.771).

At follow-up, three patients had developed symptomatic osteoarthritis of the knee, two having initially presented with intercondylar joint fracture. One 18-year-old woman (case 3) showed medial condyle necrosis at the time of assessment, and later underwent arthrodesis of the knee. All patients with osteoarthritis of the knee showed greater than 5° varus at follow-up.

Discussion

The present D-FVFG series, unlike those of Chen et al. [15], Dautel et al. [16], Hou and Liu [17], Jones et al. [11], Maratmatsu et al. [18], and Chu et al. [19], was restricted to posttraumatic reconstruction of mainly femoral metaphyses around the knee. This homogeneity, even apart from comparison with the literature, allows statistical analysis of prognostic factors for the final result.

Consolidation was achieved in all cases, at a mean 6.4 months; in other reports, rates vary from 83 to 100%, at 5.1 to 7.5 months [15,17,20,21]. The present good results may be due to the absence of any recurrence of infection, the incidence of which ranges from 5.9 to 20% in the literature, and also to the metaphyseal location of the bone defects, which is more favorable than a diaphyseal location for bone healing, and also probably to the use of an adjuvant graft in six out of eight cases.

Statistical analysis found bone healing time to be fairly independent of defect size and interval to treatment. As it concerns only bone-contact areas, it is less affected by defect length. Moreover, a vascularized bone graft makes reconstruction less sensitive to receiver site trophicity.

The frontal reduction loss found on follow-up, on the other hand, correlated significantly with longer healing time. This is not a directly causal relationship, but the result of deficient fixation stability causing slower consolidation.

The present series shows that D-FVFG enables reconstruction of defects that are severe in terms of volume and especially of metaphyseal width, although with a limit which in the present series lay at a volume of 200 cm³.

In agreement with De Boer and Wood [10], fibular hypertrophy was observed, and was usually symmetrical (Fig. 3b). This is determined by two parameters: graft vascularization, and axial stress on the graft.

The need for fibular revascularization is a matter of debate. El Sayed et al. [22] reported comparable consolidation rates in mainly posttraumatic tibial reconstruction for bone defect not exceeding 10 cm; for defects over 8 cm, it seemed preferable to conserve fibular vascularization, especially as the receiver site was "inhospitable". To avoid resort to microsurgery, Cariou et al. [23], based on clinical observation, and Delia et al. [24], in an anatomic study, showed that the fibular pedicle, even when folded, could be used to reconstruct distal femoral metaphyseal defects.

No studies have focused on the quality of anatomic, and notably axial, defect restoration. In the present series,
Although height was conserved up to bone healing, five of the eight cases showed frontal malalignment, with almost constant varization. This loss of angulation seemed to be directly related to the type of fixation: when stabilization by plate or intramedullary nailing was possible, correction loss was negligible (cases 1, 4 and 7). Assembly stability appears fundamental as, on the medial side where stress is greatest, the fibular cortical bone meets with no resistance from the epiphyseal cancellous bone, especially under reloading. Fixing the graft extremities, as recommended by Mathoulin et al. [8], is necessary but not sufficient. Angular loss may be partly explained by insufficient external fixation, but more probably by a certain plasticity on reloading in the absence of internal fixation. The present study could not settle this point, as axial X-ray measurements were not taken before resumption of weight-bearing.

The medium- and long-term impact of metaphyseal reconstruction on the knee is considerable. Only two out of eight patients showed greater than 90° flexion at healing time (Fig. 3c). Compared to the 65% reported by Chen et al. and the 60% by Hou et al. in series basically involving shaft reconstruction, our finding shows the severe impact of loss of metaphyseal substance on the knee. The four patients requiring external fixation bridging the knee all showed stiffness at consolidation; the three who conserved a satisfactory knee joint line underwent secondary arthrolysis.

It also, logically, emerged that knee mobility correlated inversely with bone healing and external fixation times. Non-weight-bearing time following removal of the external fixator and the period of protection brace, on the other hand, did not correlate with stiffness so long as knee mobility was maintained.

With a mean follow-up of more than 6 years, the present study sheds light on the joint impact of this kind of reconstruction. At follow-up, three patients showed osteoarthritis: medial femorotibial in two cases and tricompartmental in one. The deterioration was secondary to initial joint fracture in two cases and to severe residual varus in the third. These cases raise difficult issues of management: the 18-year-old woman (case 3) with medial condylar necrosis required secondary arthrodesis.

Stress fracture is a classic complication of fibula transfer, especially in femoral reconstruction. Even with D-FVFG, the rate ranges from 0 to 67% according to the series [15,18,25]; in the present series, there were no such cases, D-FVFG restoring the conical form of the metaphysis and thereby providing sufficient resistance to mechanical stress.

There are few alternatives to D-FVFG for the reconstruction of severe posttraumatic metaphyseal defect, often with previous infection. Allograft associated to internal fixation has few indications except in case of tumor [6], even when associated to vascularized fibular transfer [26]. Only bone graft after proximal osteotomy and lengthening may be recommended. Other than those by El Gammal et al. [9] and Song et al. [3], there have been few real comparative studies, and it is difficult to compare very heterogeneous series. It can be said that bone transport finally has comparable consolidation and complication rates, but is more adapted to the diaphyseal area and the tibia; surgery is less heavy, but consolidation takes longer and directly depends on defect height. Moreover, an adjuvant bone graft is frequently required. Generally speaking, bone transfers are recommended only for defects of less than 8 cm.

The present series shows that D-FVFG can restore severe bone defects, with fairly rapid radiologic bone healing of the union areas, independently of defect size. Lengthy protection of the reconstruction area, however, is mandatory.

External fixation during the initial phase is often unavoidable in such contexts of frequent infection (six cases out of eight in the present series), and knee bridging is often required.
required due to the distal location of the defect. This kind of assembly often induces stiffness of the knee and correction loss (usually in varus) on reloading. Whenever history of sepsis and epiphyseal height allowed, the present findings testify to the interest of internal fixation, which is perfectly compatible with subsequent D-FVFG (Fig. 4). The fixator, when required, should respect the knee and, if need be, once consolidation allows, be relayed by a protection brace maintained beyond the 18th month [15], or if possible by internal osteosynthesis.

Secondary varus malalignment is to be screened for, as the present findings found it to be particularly threatening to cartilage that has already undergone initial trauma then prolonged immobilization.

Conflict of interest statement

None.

References

Metaphysis reconstruction by double-barrel free vascular fibular graft


