Management of combined nonunion and limb-length discrepancy after vascularised fibular grafting

H. Abdel-Ghani, W. Ebeid, H. El-Barbary

From Cairo University, Kasr EL Aini, Cairo, Egypt

We describe the management of nonunion combined with limb-length discrepancy following vascularised fibular grafting for the reconstruction of long-bone defects in the lower limb after resection of a tumour in skeletally immature patients. We operated on nine patients with a mean age of 13.1 years (10.5 to 14.5) who presented with a mean limb-length discrepancy of 7 cm (4 to 9) and nonunion at one end of a vascularised fibular graft, which had been performed previously, to reconstruct a bone defect after resection of an osteosarcoma.

Reconstruction was carried out using a ring fixator secured with correction by half pins of any malalignment, compression of the site of nonunion and lengthening through a metaphyseal parafocal osteotomy without bone grafting. The expected limb-length discrepancy at maturity was calculated using the arithmetic method. Solid union and the intended leg length were achieved in all the patients. Excessive scarring and the distorted anatomy from previous surgery in these patients required other procedures to be performed with minimal exposures and dissection in order to avoid further compromise to the vascularity of the graft or damage to neurovascular structures. The methods which we chose were simple and effective in addressing these complex problems.

Limb reconstruction by vascularised fibular grafting, either free or with a pedicle, is a good option for bridging defects of long bones after resection of a tumour in skeletally immature patients. It provides a permanent reconstruction and offers the best opportunity of return to an active lifestyle without the necessity of subsequent revision surgery. In order to maximise the union of the fibular graft, external fixation or intramedullary fixation are preferable to the use of plates and screws or Kirschner (K-)wires for stabilisation.

We present our experience in the management of nonunion combined with limb-length discrepancy which may complicate vascularised fibular grafting undertaken to reconstruct defects of the long bones of the lower limbs after resection of a malignant tumour in skeletally immature patients. The management of these problems in such patients is not well established.

Patients and Methods

We identified nine patients (five girls, four boys) with a mean age of 13.1 years (10.5 to 14.5) at presentation. They were referred from the orthopaedic oncology department at our hospital. All the patients had a history of osteosarcoma (five distal femur, four proximal tibia) with a mean age at primary reconstruction of ten years (8 to 12.5) (Table I).

At the primary reconstruction all patients received peri-operative chemotherapy with a wide margin of clearance at resection of the tumour. Primary reconstruction of the defects was performed using free vascularised fibular grafting in five patients with distal femoral osteosarcoma and in four with proximal tibial osteosarcoma (Table I).

The fibulae were used to bridge the defect with the intention of facilitating fusion of the knee. The transposed fibular grafts had been fixed by either a plate and screws or K-wires and the application of a cast or a combination of the two (Table I).

The mean interval from the primary reconstruction to our secondary procedure was 2.2 years (1.0 to 4.0).

The indications for referral and secondary reconstruction were a combined limb-length discrepancy and nonunion of one end of the fibular graft with secondary malalignment (Fig. 1). In seven patients the nonunion was located at the graft-cancellous junction at the knee and in two (patients 2 and 6) at the graft-cortical junction.
### Table I. Details of the nine patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age at presentation (yrs)</th>
<th>Gender</th>
<th>Primary tumour</th>
<th>Primary procedure</th>
<th>Interval to secondary reconstruction (yrs)</th>
<th>Problems at presentation</th>
<th>Secondary reconstructive procedures</th>
<th>Follow-up (mths)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.5</td>
<td>M</td>
<td>OS distal femur</td>
<td>Wide marginal intra-articular resection, FVFG with intended knee fusion fixed by long plate</td>
<td>4.0</td>
<td>LLD 9 cm Nonunion at tibial junction</td>
<td>Removal of plate Fixation and compression of nonunion site, lengthening 9 cm through proximal tibial metaphyseal osteotomy</td>
<td>13.0</td>
</tr>
<tr>
<td>2</td>
<td>11.0</td>
<td>F</td>
<td>OS distal femur</td>
<td>Wide marginal intra-articular resection, FVFG with intended knee fusion fixed by long plate</td>
<td>3.0</td>
<td>LLD 4 cm Nonunion of proximal end of the graft with the femur with anterolateral bowing</td>
<td>Removal of the long plate, correction of alignment, augmentation of Ilizarov fixation with 7 mm Kirschner nail. Tibial lengthening of 5 cm (correction of bowing added 1 cm of length)</td>
<td>38.0</td>
</tr>
<tr>
<td>3</td>
<td>13.5</td>
<td>F</td>
<td>OS proximal tibia</td>
<td>Wide marginal intra-articular resection, PVFG with intended knee fusion fixed by wires</td>
<td>2.0</td>
<td>LLD 9 cm Nonunion of femur-graft junction with varus internal rotational malalignment</td>
<td>Closed correction of malalignment, compression of nonunion site, Ilizarov fixation and lengthening 8 cm through distal femoral metaphysis</td>
<td>57.0</td>
</tr>
<tr>
<td>4</td>
<td>10.5</td>
<td>F</td>
<td>OS proximal tibia</td>
<td>Wide marginal intra-articular resection, PVFG with intended knee fusion fixed by wires</td>
<td>1.0</td>
<td>LLD 8 cm Nonunion of femur-graft junction</td>
<td>Closed correction of malalignment, compression of nonunion site, Ilizarov fixation and femoral lengthening 8.5 cm</td>
<td>36.0</td>
</tr>
<tr>
<td>5</td>
<td>14.5</td>
<td>M</td>
<td>OS distal femur</td>
<td>Wide marginal intra-articular resection, FVFG with intended knee fusion fixed by long bridging plate which became infected and required removal</td>
<td>3.0</td>
<td>LLD 6 cm Nonunion of tibial-graft junction and flexion deformity at the graft-femoral junction</td>
<td>Extension osteotomy at the graft-femoral junction and acute correction of flexion deformity, compression of nonunion site and tibial lengthening 5 cm (correction of flexion deformity restored 2 cm of shortening)</td>
<td>16.0</td>
</tr>
<tr>
<td>6</td>
<td>13.0</td>
<td>F</td>
<td>OS distal femur</td>
<td>Wide marginal intra-articular resection, FVFG with intended knee fusion Proximal femorofibular fixation with plate and distal fibulotibial fixation by wires</td>
<td>2.0</td>
<td>LLD 7 cm Proximal nonunion at graft-femur junction with flexion deformity, varus malunion of tibia with the graft</td>
<td>Correction of proximal malalignment and Ilizarov fixationTibial lengthening 6.5 cm with correction of distal varus through the lengthening segment</td>
<td>24.0</td>
</tr>
<tr>
<td>7</td>
<td>14.0</td>
<td>M</td>
<td>OS proximal tibia</td>
<td>Wide marginal intra-articular resection, PVFG with intended knee fusion fixed by Kirschner wires and cast</td>
<td>2.0</td>
<td>LLD 9 cm Nonunion at femur graft junction, varus external rotation malalignment</td>
<td>Correction of malalignment, femoral lengthening 9 cm</td>
<td>23.0</td>
</tr>
<tr>
<td>8</td>
<td>14.0</td>
<td>M</td>
<td>OS distal femur</td>
<td>Wide marginal intra-articular resection, FVFG with intended knee fusion fixed by wires and cast</td>
<td>1.5</td>
<td>LLD 8.5 cm Nonunion of tibial-graft junction</td>
<td>Tibial lengthening 9 cm Closed compression and fixation of nonunion site</td>
<td>21.0</td>
</tr>
<tr>
<td>9</td>
<td>12.5</td>
<td>F</td>
<td>OS proximal tibia</td>
<td>Wide marginal intra-articular resection, FVFG with knee fusion fixed by plate which became infected and required removal</td>
<td>1.5</td>
<td>LLD 6 cm Nonunion at femur-graft junction</td>
<td>Fixation of the nonunion site, lengthening of 3 cm at the distal femoral metaphysis and 3 cm at distal tibial metaphysis</td>
<td>20.0</td>
</tr>
</tbody>
</table>

* OS, osteosarcoma
† FVFG, free vascularised fibular graft; PVFG, pedicled vascularised fibular graft
‡ LLD, limb-length discrepancy
The mean limb-length discrepancy was 7 cm (4 to 9). All the patients were able to walk using two crutches, but could not bear any weight on the affected leg. In all patients the nonunion was grossly mobile, except one (patient 5, Fig. 2), which made pre-operative measurement of the malalignment/deformities difficult.

Each patient underwent computerised radiography of the lower limbs to measure the limb-length discrepancy. The radiographs showed that the transplanted fibulae had not become hypertrophied in all except one (patient 5) which had a stiff nonunion (Fig. 2). All the plates which had been used for fixation at the primary surgery were broken or the screws were broken and the plates detached from the bone.

**Management of limb-length discrepancy.** We used the arithmetic method of Menelaus to calculate the expected limb-length discrepancy at maturity. We aimed to improve this and to obtain a correction to within 2 cm at maturity to allow easy clearance of the foot during walking in the absence of a knee.

We treated the nonunion by removal of the plates and sometimes removal of any K-wires if these were accessible without excessive dissection and achieved acute correction of the deformity by closed manipulation of the sites of nonunion or by a corrective osteotomy (Table I). The intention was to restore the axis of the limb so that it was aligned to allow a line from the anterior superior iliac spine to the centre of the ankle which would pass through the centre of the knee. Radiologically, this should make the mechanical axes of both tibiae and femora collinear without consideration of the orientation of the knee because fusion of the knee was intended in all patients. We achieved stable fixation by using a ring fixator and performed a parafocal osteotomy around the site of the nonunion, but not through the transplanted fibula. This osteotomy served also for lengthening. The osteotomies were carried out through minimal exposures using a low-energy technique. Seven parafocal osteotomies were performed in the metaphysis adjacent to the nonunion and in the two patients with nonunion at the graft-cortical junction they were undertaken away from the site of the nonunion at the proximal tibia.

We secured the ring fixator using half pins rather than thin wires when possible in order to avoid the neurovascular bundle which may have been displaced from the previous surgery. In addition, pins were not inserted into the fibular graft if it had not undergone hypertrophy to minimise the risk of causing a stress fracture.

Lengthening was carried out in all patients at a rate of 1 mm per day divided into four daily episodes after a seven day period of latency.

The pin sites were maintained by daily washing in running water using antiseptic soap. Weight-bearing was allowed as tolerated by the patients at the consolidation phase of lengthening, with gradual progression from using crutches to unaided walking.

Removal of the fixator was undertaken after union had been achieved at the site of the previous nonunion and there was radiological evidence of regeneration of at least three cortices of the lengthened segments in two perpendicular radio-
Before removal of the frame, gradual dynamisation was achieved by removing the connecting rods across the lengthened segment one by one at weekly intervals.

All the patients were kept in a light orthoplastic brace after removal of the fixator while waiting for hypertrophy of the fibula to occur to almost the diameter of the recipient cortical bone.

Results
The mean follow-up was for 27.6 months (13.0 to 57.0). All the patients achieved skeletal maturity (boys over 16 years and girls over 14 years) during follow-up with a mean age, at the final follow-up, of 15 years (Figs 3 and 4) and further limb-length discrepancy was not expected. Removal of the former fixation plates when required was found to be difficult since they were encased in extensive fibrosis and in most cases removal of the proximal and distal screws through small proximal and distal incisions did not allow the plate to be withdrawn without a full exposure through the original incision.

By the end of the follow-up period, all the patients had limb-length discrepancy within 1.5 cm and bony union had been obtained with correction of the malalignment. The healing index was calculated as the days needed to achieve lengthening of 1 cm. The mean healing index was 33 days (30 to 37) in six patients. Delayed consolidation occurred in three patients with a mean healing index of 47 days (45 to 49). By the time of consolidation of the lengthened segment, all the patients had union of the non-united end of the fibula.

All patients required bracing post-operatively except one (patient 5) (Figs 2 and 4). The mean duration of wearing the brace was 17 months (12 to 30) and at final follow-up, only one (patient 6) still needed a brace while awaiting completion of hypertrophy of the fibular graft.

Pin-track infection occurred in nearly every patient and was managed by local antiseptic cleaning and intermittent oral antibiotics. Three patients had a stress fracture; in one patient (patient 1) this occurred seven months after removal of the fixator and was treated with reapplication of the fixator. One of these fractures (patient 3) occurred through a pin site in the fibula two weeks after the removal of the fixator. One patient developed a stress fracture of the fifth metatarsal two months after removal of the fixator which healed spontaneously without the application of a cast (patient 3). Patient 8 had a persistent residual valgus deformity at the ankle which occurred secondary to excision of the fibula for transfer at the time of the primary reconstruction and another (patient 7) developed an equinus deformity after tibial lengthening which necessitated correction by gradual Ilizarov distraction. All the patients were able to walk without crutches even during the period of bracing.

Discussion
Vascularised fibular transfer is a reliable technique for reconstruction of a lower limb after resection of a tumour with predictable union, good functional outcome and a low rate of complications.1,7 Compared with the high cost of the use of expandable endoprostheses, it offers a means of reconstruction of bony defects in a less affluent community.
The use of a vascularised fibular graft has its own problems such as malunion, nonunion and limb-length discrepancy which may result from a short graft and/or retarded growth secondary to loss of a physis. The method of primary stabilisation of the fibula may be a factor in the development of these complications.1,2,5 In the series reported by Enneking et al1 the highest rate of nonunion occurred in defects around the knee with union best promoted by good supplementary fixation at the graft-host junction rather than by the additional onlay of cancellous grafts at the sites of potential nonunion. Supplementary fixation of a cortex-to-cortex junction was most effective using longitudinally pinned fixation rather than unicortical screws or wires. All our patients had their initial stabilisation of the fibula secured by plates and screws or K-wires.

The main disadvantage of the fibular transfer is its small cross-section which may not have sufficient strength for loading in reconstruction of the lower limb.6 Time is needed for hypertrophy to occur during which repeated stress fractures may occur after union of both ends of the graft.1,3 Stress fractures occurred in one-third of our patients which was less than the incidence of 45% reported previously.1

Although a number of studies have documented the complications which may occur during the healing and incorporation of a microvascular osseous transfer,3-7 little has been written about the treatment of late complications such as limb-length discrepancy or the operative manipulation of a completely incorporated and remodelled vascularised graft. Jupiter et al12 recorded their experience in the secondary reconstruction of a mature vascularised fibular graft in five adult patients. They showed that during secondary reconstruction, the mature vascularised fibular graft responded in a manner similar to that of normal cortical bone. Enneking et al1 reported an incidence of 12% of primary nonunion of the graft in skeletally mature patients. Chen et al13 described the same incidence of nonunion and of limb-length discrepancy in 8% in their series but did not discuss the management of these problems. Chung-Soo et al13 reported a rate of union of 61% after vascularised bone transfer which increased to 81% after secondary conventional bone grafting or external electrical stimulation in combination with immobilisation in a cast. Enneking et al1 observed a success rate of 91% when bone grafting was combined with internal fixation to address nonunion. However, in our patients, bone grafting would not have addressed the associated limb-length discrepancy which co-existed with the nonunion.

When treating these problems the presence of previous incisions from the resection of the tumour, the excessive scarring from previous attempts at reconstruction, malposition of the neurovascular bundle and the presence of internal fixation should all be considered. We avoided exposure of the site of nonunion and the ununited ends of bone since this would have stripped the soft tissue with the risk of local devascularisation of bone and endangered the blood supply of the transplanted fibula. Additionally, it is difficult to place grafts at these sites if the nonunion is around the knee because of the lack of supple soft tissues. In the series reported by Enneking et al,1 all the cases of nonunion occurred at one end of the graft, mostly at the graft-cortical junction rather than at the graft-cancellous junction. This was attributed to devascularisation of the ends of the bone during resection of the tumour and preparation of the fibular graft and was not secondary to problems of fixation since the other end of the graft had united. This was not the situation in our patients with most experiencing nonunion at the graft-cancellous junction. This might have been due to the more stable fixation of the graft-cortical junction rather than the graft-cancellous junction.

The ring external fixator is our preferred device to achieve fixation, correct malalignment and to obtain lengthening without excessive dissection and bony stripping. The parafocal osteotomy is intended to stimulate the osteogenic potential of the bone in cases of delayed union or nonunion and to obtain healing of the nonunion through a single or double osteotomy performed some centimetres away from the level of the nonunion, either proximal or distal to the lesion.11 This osteotomy has a dual role, namely to remove all mechanical stimulation from the site of nonunion, transferring it to the osteotomy, and to restore the axis to normal by correcting single or complex deformities.9-11 In this manner, well-vascularised bone can be deposited, replacing the formerly non-vascularised connective tissue interposed between the ends of the bone.9,10 On lengthening through this osteotomy, vascularisation of the whole bone segment increases greatly, allowing good regeneration at the site of distraction and the development of callus at the nearby site of nonunion. Further, it is recognised to have a stimulating effect on the surrounding soft tissues.10 In the two patients with osteotomies at the metaphyses away from the site of nonunion, we cannot assess whether union occurred secondarily to the effect of the distant parafocal osteotomy or secondarily to proper stabilisation.

Our results showed that prediction of expected limb-length discrepancy at maturity was easily and accurately calculated by the use of the Menelaus (arithmetic) method.8 Lengthening proceeded satisfactorily despite previous exposure to chemotherapy in all the patients. The relationship of chemotherapy and lengthening is complicated and after completion of chemotherapy there may be no residual effect on lengthening.14 In our three patients with delayed bony consolidation after lengthening, this might be related to the previous history of chemotherapy or possibly to the lack of weight-bearing during distraction.14,15 In this small series it was not possible to provide a definitive opinion.

Correction of malalignment is important to avoid abnormal stresses which may predispose to nonunion or stress fractures of a fibula lacking hypertrophy. Prolonged postoperative bracing is mandatory in these patients to avoid insufficiency or stress fracture of the non-hypertrophied fibula.1
We think that the techniques which we chose regarding calculation of the expected limb-length discrepancy at maturity and addressing nonunion by parafocal osteotomy and application of a ring fixator offer a simple solution to a complicated problem with a good outcome.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References