The Use of a Free Fibular Strut as a “Biological Intramedullary Nail” for the Treatment of Complex Nonunion of Long Bones

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Background: Nonunion of long-bone fractures is difficult to treat, especially when the bones are osteoporotic or there is a large bone gap as a result of repeated failure of the metallic nails or implants. In such cases, the use of an autologous intramedullary fibular strut graft may be a viable treatment option.

Methods: Twenty-two patients with a complex nonunion of the shaft of the femur, humerus, or tibia were managed with a free autologous fibular strut graft for intramedullary fixation with use of closed or open methods. All patients had evidence of moderate to severe local osteoporosis and had a bone gap ranging from 4 to 20 mm. Nineteen patients had had 1 to 4 prior operations. The mean age was 51.5 years. The duration of nonunion ranged from 9 months to 4 years.

Results: The mean time to union was 17 weeks (range, 8 to 26 weeks), and the mean duration of follow-up was 4 years (range, 6 months to 17 years). All but 2 patients had healing at the time of the latest follow-up.

Conclusions: The identification of a viable option for the treatment of difficult nonunion in osteoporotic bones has been a challenge. The insertion of a free autologous intramedullary fibular strut graft provided mechanical stability, and osteogenesis occurred inside the medullary canal of the host bone.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Treatment of complex nonunion of the long bones is a challenge. A variety of operative techniques, including those involving intramedullary nails and compression plates with bone grafts, have been tried, with variable results. The concept of biological internal fixation for the treatment of nonunion is still developing, with emphasis on the biomechanics of stability, the biology of the blood supply, and the impact on clinical use. Biological fixation has been advocated as a way to induce union by promoting osteogenesis. The aim is to produce the best biological conditions for healing rather than to achieve absolute stability of fixation.

New technology provides potential benefits related to the surgical treatment of nonunion in osteoporotic bone. With the increasing incidence of osteoporosis, the stabilization of fractures in patients with soft bones is a priority. Osteopenia and severe soft-tissue damage with extensive skin scars increase the likelihood of repeated failure of metallic implants and/or persistent disuse osteoporosis, which can result in the widening of the medullary canal of long bones such as the femur, tibia, and humerus.

A metallic nail or plate of any type may not provide adequate fixation in an ailing bone with severe osteopenia and a wide medullary canal. To achieve union of osteopenic bone, a stimulating factor in the form of an autologous bone graft may encourage the initiation of osteogenesis.

In the present report, a simple biological technique is proposed in which a free fibular strut graft is used as a biological intramedullary nail for the treatment of complex nonunion.

Materials and Methods

Twenty-two patients with a complex nonunion of the humerus (8 patients), femur (9 patients), or tibia (5 patients) were managed with intramedullary fibular fixation between 1992 and 2011. The study group included 15 male...
patients and 7 female patients ranging from 12 to 78 years of age. The mean time from fracture to treatment of nonunion was 17.5 months (range, 9 to 48 months). Ten patients (5 with a humeral nonunion and 5 with a femoral nonunion) were managed with a closed technique and 12 were managed with an open technique (Table I). All patients had evidence of moderate to severe local osteoporosis and had a bone gap ranging from 4 to 20 mm. The mean time to union was 17 weeks (range, 8 to 26 weeks), and the mean duration of follow-up was 4 years (range, 6 months to 17 years).

Radiographs were made in each case. All fractures were initially closed. Three patients had radial nerve palsy, and 5 had Sudeck atrophy of the hand. Twelve patients had had 1 prior procedure, 5 had had 2, 1 had had 3, and 1 had had 4; the remaining 3 patients had not had any prior operative procedures but still had a wide medullary canal (Table I). At the time of the first examination, all patients had pain and considerable disability. Four patients had obvious deformity in the arm (2 patients) or leg (2 patients) that could be corrected clinically. No additional cancellous grafting was attempted for any patient.

**Surgical Technique**

The basic principles are similar to those of metallic nail fixation. In cases in which the bone fragments are aligned, closed fibular fixation is recommended (Figs. 1-A, 1-B, and 1-C).

First, the host site is prepared with a closed or open technique. The required autologous fibular strut (with a length of 10 to 20 cm) is removed, with the distal 8 to 9 cm of the fibula being left in place for ankle stability. If a long strut is required, the head of the fibula can also be taken after protecting the peroneal nerve. This fibular strut, or “biological nail,” is fashioned to fit the host medullary canal. The biological strut should be inserted into the host bone as early as possible.

**TABLE I Patient Characteristics**

| Case | Sex, Age (yr) | Nonunion Site | No. of Prior Procedures | Duration of Nonunion (mo) | Operative Technique* | Time to Union (wk) | Complications | Notes |
|------|--------------|---------------|-------------------------|--------------------------|---------------------|-------------------|--------------|-------|
| 1    | M, 12        | Tibia         | 1                       | 12                       | Fibular strut graft  | 20                | —            | Severe osteoporosis with gap |
| 2    | M, 52        | Femur (middle) | 2                       | 36                       | Fibular strut graft + K wire | 14              | —            | —     |
| 3    | M, 56        | Femur (proximal) | 4                       | 48                       | Fibular strut graft + K wire | 13              | —            | Nail plate applied twice before and removed each time |
| 4    | M, 62        | Humerus (middle) | 1                       | 24                       | Fibular strut graft  | 8                 | —            | —     |
| 5    | M, 33        | Humerus (middle) | 1                       | 24                       | Fibular strut graft + K wire | 10              | —            | —     |
| 6    | M, 44        | Femur (middle) | 2                       | 16                       | Fibular strut graft + K wire | 8               | Superficial infection | —     |
| 7    | M, 59        | Humerus (proximal) | 0                       | 9                        | Fibular strut graft  | 17                | —            | Earlier conservative treatment had failed |
| 8    | F, 47        | Femur (middle) | 2                       | 18                       | Fibular strut graft + K wire | 12              | —            | —     |
| 9    | F, 39        | Tibia (middle) | 1                       | 17                       | Fibular strut graft + K wire | 16              | —            | —     |
| 10   | M, 46        | Femur (distal) | 1                       | 16                       | Fibular strut graft  | 19                | —            | Bilateral |
| 11   | M, 55        | Tibia (middle) | 1                       | 15                       | Fibular strut graft  | 22                | —            | —     |
| 12   | M, 49        | Femur (proximal) | 1                       | 13                       | Fibular strut graft + K wire | 26              | —            | —     |
| 13   | F, 35        | Humerus (middle) | 3                       | 18                       | Fibular strut graft + K wire | Failed          | Superficial infection failed | Needed plating and bone-grafting |
| 14   | M, 58        | Femur (middle) | 0                       | 15                       | Fibular strut graft with screws | 14              | —            | Conservative treatment had failed |
| 15   | F, 35        | Humerus (middle) | 1                       | 14                       | Fibular strut graft  | 18                | —            | —     |
| 16   | M, 72        | Femur (middle) | 2                       | 18                       | Fibular strut graft + K wire | 22              | —            | —     |
| 17   | M, 68        | Tibia (middle) | 1                       | 11                       | Fibular strut graft  | 24                | Superficial infection | —     |
| 18   | F, 78        | Humerus (middle) | 2                       | 19                       | Fibular strut graft  | Failed            | Failed       | Needed plating and bone-grafting |
| 19   | F, 64        | Humerus (proximal) | 1                       | 14                       | Fibular strut graft + K wire | 20              | —            | —     |
| 20   | M, 53        | Femur (middle) | 1                       | 9                        | Fibular strut graft + K wire | 16              | —            | —     |
| 21   | M, 64        | Tibia (middle) | 0                       | 9                        | Fibular strut graft + K wire | 22              | —            | Conservative treatment had failed |
| 22   | F, 54        | Humerus (distal) | 1                       | 11                       | Fibular strut graft  | 14                | —            | —     |

*K wire = Kirschner wire.
Figs. 1-A, 1B, and 1-C Radiographs of the femur in a 54-year-old man, illustrating the principles of the technique. **Fig. 1-A** Anteroposterior radiographs showing a subtrochanteric non-union after 4 surgical procedures, including 2 attempted applications (and subsequent removals) of plate and nail fixation. **Fig. 1-B** Anteroposterior radiographs made 3 weeks after treatment with a fibular graft, showing signs of healing. At the time of the procedure, a Kirschner wire was passed through the fibular graft, and the graft was then inserted into the femur. Black and white arrows indicate the location of the fibular strut in the femur. **Fig. 1-C** Radiographs made 11 weeks postoperatively, showing complete union.

Figs. 2-A, 2-B, and 2-C A 12-year-old boy who was managed with an autologous fibular strut graft for the treatment of a complete circumferential injury of the distal aspect of the lower limb. **Fig. 2-A** Preoperative photographs. **Fig. 2-B** Anteroposterior (left and middle panels) and lateral (right panel) radiographs showing gap nonunion with severe osteoporosis.
to maximize its viability. If the surgeon thinks that the fibular strut should be strengthened, a Kirschner wire can be passed through the medullary canal of the fibular strut. Following procedures involving the femur or tibia, the extremity is supported with use of a Thomas splint. Following procedures involving the humerus, the arm is initially supported with a U-cast.

For closed insertion of the fibular strut into the humerus or femur, a 3-cm incision is made over the greater tuberosity or...
the greater trochanter. If required, the medullary canal is minimally reamed. An appropriately sized fibular strut is removed subperiosteally and is shaped to be driven first into the proximal fragment and then into the distal fragment after the fracture has been stabilized. In cases involving a relatively narrow medullary canal, the edges of the fibula are shaved before being inserted. The full length of the graft is inserted into the proximal fragment in a retrograde fashion and then is advanced into the distal fragment like a metallic nail to the extent that half of the strut is placed on either side of the fracture.

In the tibia, fixation can be attempted with an open method, with the nonunion site minimally exposed. The strut graft is passed on the proximal side and can be slowly inserted into the distal fragment after the nonunion is reduced. The lower limb is initially supported with a splint.

**Advantages of the Technique**

This technique is associated with several advantages. First, the technique is simple and is based on the principles of Kuntscher nailing. Second, the technique involves bone-in-bone fixation and is totally biological. As a result, the large contact area between the fibula and the endosteal surface of the host bone facilitates early union and strengthens the osteopenic host bone. Third, the autologous fibular strut also provides much-needed osteogenesis at the site of the nonunion and throughout the length of the graft in the parent bone. Fourth, no reaming is typically required. The triflanged fibula adequately engages both of the nonunion fragments, so no additional fixation is necessary. Once incorporated, the fibular strut does not require removal. Fifth, if it is considered necessary to strengthen the fibula, a Kirschner wire can be inserted into the fibula before the fibula is inserted into the parent bone. Sixth, the periosteum of the host bone is minimally disturbed.

**Results**

The results of the treatment were assessed on the basis of clinical and radiographic evidence of union, time to union, and the function of the extremity. All but 2 nonunions healed; the mean time to union was 17 weeks (range, 8 to 26 weeks).
Two humeral nonunion had failed to unite and required plating and autologous bone-grafting. Both failures occurred in earlier in the study following procedures in which no Kirshner wire was inserted into the fibular graft.

In 3 cases (2 involving the humerus and 1 involving the femur), the fibula could be inserted in the distal fragment only for nearly 2 cm. However, a Kirschner wire was passed through the fibula down the whole length of the bone. Suitable splints were applied for a few days. In all 3 cases, union was achieved in 4 months. Complications included 1 case of transient radial nerve palsy and 2 cases of transient peroneal nerve palsy. All 3 patients improved subsequently. Three cases of superficial infection (1 each in the humerus, femur, and tibia) were treated successfully.

At the time of the latest follow-up, 2 patients had a slightly limited range of motion of the shoulder. The mean range of elbow flexion-extension was from 32° to 110°, and the mean range of forearm rotation was from 80° of pronation to 70° of supination. Seventeen of the 22 patients had returned to work. Fifteen patients had no pain, 5 patients had occasional pain that was relieved with analgesics, and the remaining 2 patients had pain and mobility at the nonunion site that were successfully treated with plate fixation and autologous cancellous bone.

Discussion

Open internal fixation may contribute to injury of the soft-tissue envelope. A high degree of skill and expertise is required to minimize the biological complications following traumatic and iatrogenic osteonecrosis. Nonunion of the long bones is a difficult condition to treat and is fraught with complications. After repeated implant failures, nonunions are resistant to treatment. In such cases, the bone is often osteoporotic, with a large gap between the bone segments, and fixation is usually difficult to achieve.

The advent of “biological internal fixation” is an important development in the surgical treatment of fractures and nonunions. Ordinarily, a metallic nail acts as an internal splint and does not abolish motion completely, and the fracture heals through peripheral callus formation. Even the best implants
may not be adequate in severely osteoporotic fractured bone with wide medullary canals and a thin cortex\textsuperscript{11,16}. Cementation has been advocated as a way to bridge the fracture gap and to fill areas of bone deficiency; however, it inhibits osteogenesis, and loosening is known to occur over time\textsuperscript{1,3,9}. The use of a small fibular strut with compression plating has been reported to provide better fixation\textsuperscript{3,24}. In this technique, the fibula functions as a triflanged nail and engages the host bone firmly. In bones with a wide medullary canal, reaming is not necessary for the placement of the fibular strut\textsuperscript{21}. Another advantage is that the periosteum of the host bone is undisturbed, as with closed internal fixation.

Reaming, if required, may assist in establishing contact between the endosteum of the host bone and the fresh autologous nail graft. The 3 borders of the fibula fix firmly to the inner cortices of the fractured fragments. In the present study, union was achieved even when there was damage to the soft tissue surrounding the bone gap and there was potential need for amputation (Figs. 2-A, 2-B, and 2-C). Evidently, the intramedullary graft sufficiently reduced the rotational and...
other undesirable movements that are sometimes observed in association with nonlocking intramedullary nails. Our technique has some of the advantages of both closed and open fixation. In cases in which the nonunion had occurred after the failure of a metallic nail, the fragments were in alignment and the fibular strut could be easily inserted into the same track of the parent bone as the metallic nail after minimal reaming with use of a closed method (Figs. 3-A through 3-E). With this technique, there is no need to use additional screws or a plate because the strong fibular strut can be hammered into the parent bone. If desired, a Kirschner wire can be inserted into the fibular graft, creating further support and anchorage to the repaired bone (Figs. 4-A and 4-B).

Free fibular grafts are known to be at risk for necrosis resulting in absorption and non-incorporation to the host bone[2,22]. The fibular struts were inserted immediately after removal from the donor site in order to encourage the retention of viable properties[7,17,19,27]. It has been reported that if the autologous bone graft is fixed to the recipient bone immediately after it is retrieved, the osteogenic cells on and in the graft survive[17,24]. Immediate fixation of the graft at the recipient site allows the cells in and over the graft to draw oxygenation and nutrition from the blood, thereby preserving their osteogenic properties[18,23,28]. Moreover, with this type of intramedullary fixation, the fibular strut is in contact with the viable parent bone throughout the length of the graft, with intact osteogenic potentials.

The large contact area between the fibular strut graft and the host bone encourages union. With a firmly fixed autologous graft, compression may not be necessary. However, in cases involving a very wide medullary canal and a thin cortex, screws
can be utilized to achieve 4-cortex fixation (Figs. 5-A and 5-B). These minor modifications to the basic technique can be employed when necessary.

In the present study, 20 of 22 nonunions healed after treatment with a biological intramedullary nail, without additional intervention. Bone healing occurred with adequate mechanical stability and a continuous process of osteogenesis. This technique is most appropriate for the treatment of established nonunions, especially when the bone is osteopenic and when previous fixation methods have failed (Figs. 4-A and 4-B). The host bone length was maintained, early mobilization was possible, and union occurred.

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