Treatment of post-traumatic humeral diaphyseal nonunion with bone loss

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Four patients with post-traumatic nonunion and shortening of the humeral diaphysis were treated with a hybrid advanced Ilizarov technique. The mean age of the patients was 32 years, and the mean total amount of humeral shortening was 6.63 cm. Three nonunions were atrophic and infected, and one was hypertrophic. All patients obtained union of the humeral fracture with resolution of infection at a mean external fixation time of 8 months. Restoration of normal humeral length was achieved in two patients, with a third having a residual discrepancy of 1 cm. The final patient, who had an infected nonunion with 11 cm of total humeral shortening, had a residual limb length discrepancy of 3 cm. All had improvement in shoulder and elbow motion after treatment. Superficial pin tract infections were seen in all patients, but all responded to pin-site care and oral antibiotics. Two patients had three refractures after removal of the fixator, two of which were treated by a second application of an Ilizarov frame and one by a cast. All patients had reduced pain and improved function at completion of the treatment. The Ilizarov method, though not a panacea for all humeral nonunions with extensive bone loss, does offer a viable salvage procedure in this unusual and often complex clinical problem. (J Shoulder Elbow Surg 2003;12:436-41.)

Nonunion of a humeral fracture with significant segmental bone loss is uncommon.[4,8,9] Etiologic factors that can lead to significant shortening include open fractures, infection, tumor resection, or bone resorption associated with failed internal fixation.[4] The treatment of these combined lesions is complex, and a number of treatment options have been proposed. These include bone graft and plate fixation,[4,9,11] allograft,[4] and a bone transport technique with an external fixator.[2,4,6]

The advantages of the Ilizarov method include the ability to obtain stable fixation, adjust axial alignment during treatment, compress the nonunion site, and perform humeral lengthening by distraction osteogenesis. In addition, with the hybrid advanced Ilizarov fixator, immediate full shoulder and elbow range of motion is possible. This study presents our experience with a hybrid advanced Ilizarov fixator in treating nonunion of the humerus with shortening.

MATERIALS AND METHODS

Four patients with post-traumatic nonunion and shortening of the humeral shaft were treated with a hybrid advanced Ilizarov fixator between 1991 and 2000 (Table I). Debridement of the nonunion site and the limb length discrepancy at presentation combined to give the total humeral shortening. The mean total amount of humeral shortening was 6.63 cm (range, 2.5-11 cm). The mean age of the patients was 32 years (range, 19-42 years). There were 2 women and 2 men. Three patients had originally had a closed midshaft fracture of the humerus at presentation, and one patient had an open fracture. The primary treatment was an intramedullary nail in two patients, external fixation in one patient, and plate and screw fixation in the other.

The time from fracture to Ilizarov treatment averaged 21.5 months (range, 12-36 months). In all patients the nonunion was situated in the diaphyseal region of the humerus. Three patients had atrophic nonunion (Figure 1), and one had a hypertrophic nonunion. Three patients had a history of infection, with evidence of active infection in one. In each patient the infecting organism was *Staphylococcus aureus*. Two patients had radial nerve palsies at presentation, and one had undergone treatment comprising multiple tendon transfers and a wrist fusion. All patients were symptomatic, complaining of pain and abnormal mobility at the nonunion site. They all had limitation of activities of daily living.

Surgery was performed with patients under general anesthesia after administration of prophylactic antibiotics. The operative technique varied depending on the type of nonunion encountered. With an atrophic nonunion, the nonunion site was first explored by an appropriate surgical approach. All hardware was removed and devitalized bone and intervening fibrous tissue excised, which involved resection of 1 to 2 cm of bone. The bleeding bone ends

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Table 1 Demographic data and treatment of 4 patients with humeral nonunion and bone loss treated by the Ilizarov method

				Ilizarov treatment		
Patient No.	Age (y)/ gender	Diagnosis	Previous operations	Index operation	Total humeral shortening (cm)	Additional operations
1	19/female	Infected atrophic nonunion diaphysis	Intramedullary rod Removal of nail	Resection of nonunion site and proximal metaphyseal lengthening	6	None
2	29/male	Infected atrophic nonunion diaphysis Radial nerve palsy	Multiple debridements and irrigations Monolateral external fixator Wrist fusion and tendon transfer for radial nerve palsy	Resection of nonunion site and distal metaphyseal lengthening	11	(1) Compression of nonunion site (2) Compression of nonunion site and bone graft
3	42/male	Hypertrophic nonunion diaphysis	Intramedullary rod	Distraction of nonunion site	2.5	(1) Replacement of broken half-pin (2) Compression of nonunion site and bone graft
4	38/female	Infected atrophic nonunion diaphysis Radial nerve palsy	Plate and screw fixation	Resection of nonunion site and proximal metaphyseal lengthening (as well as radial nerve grafting)	7	Bone graft to nonunion site

were then approximated and either aligned with a guidewire or fixed temporarily with percutaneous crossed Kirschner wires. The wound was then closed. The patient with a hypertrophic nonunion had the fixation devices removed but did not have the nonunion site explored. Specimens were sent for microbiologic examination and culture in all cases.

We used a hybrid advanced Ilizarov technique[1,2,10] combining Kirschner wires and half pins with circular rings, half rings, and a proximal arch (Figure 2). This construct allowed almost unrestricted motion of the shoulder and elbow. The Ilizarov frame was preassembled before starting surgery, sizing the rings directly on the patient's arm. The frame was constructed with the use of a proximal 90° small-sized arch, one or two diaphyseal full rings, and a distal 5/8 ring placed posteriorly. The diaphyseal and distal rings were connected by threaded rods and the proximal arch by a combination of two oblique supports and threaded rods.

Proximal frame application was achieved with three 5.0-mm anterolateral half-pins inserted at different levels and connected to the proximal arch. The majority of neurovascular structures lay medially at this level and were protected by an anterolateral insertion point. The axillary nerve and circumflex humeral vessels, however, are at risk. Insertion of the first two half-pins 90° to each other at the level of the greater tuberosity and lateral to the bicipital groove placed them above the axillary nerve. The third half-pin was inserted distally and between the first two, inferiorly to the axillary nerve.

The diaphyseal rings were fixed with a single oblique Kirschner wire and one half-pin. The structures at risk at this level include the brachial artery, ulnar nerve, and median nerve, which lie anteromedially between biceps and triceps. The radial nerve laterally between the brachialis and biceps and the musculocutaneous nerve between the biceps and brachialis also need to be protected. Half-pin insertion at this level was done in a posterior-to-anterior direction through the triceps, posteriorly to the radial nerve. The Kirschner wire passed anteriorly to the radial nerve but posteriorly to all other neurovascular structures in a medial oblique direction through the medial triceps and the anterolateral aspect of the biceps.

Distal fixation was achieved with two Kirschner wires and one half-pin. The structures to be avoided at this level are the ulnar nerve in the groove on the medial epicondyle, the brachial artery, the median nerve anteromedially, and the radial nerve anterior to the lateral humeral condyle on the surface of the brachialis. The first wire was passed transversely at the level of the humeral epicondyles perpendicular to the bone axis. This wire was introduced through the medial epicondyle anteriorly to the ulnar nerve, which was palpated during insertion. It was directed toward the anterior aspect of the lateral condyle, exiting deep to the brachialis and the radial nerve. A second wire was inserted anteriorly to the first on the medial epicondyle and directed posteriorly toward the posterior aspect of the lateral humeral condyle. The half-pin passed obliquely through the lateral condyle from the posterolateral aspect posteriorly to the neurovascular structures.

A proximal metaphyseal osteotomy was performed in two of the patients with an atrophic nonunion through a separate anterolateral incision. The third patient in this group had a supracondylar osteotomy. Lengthening was

Figure 1 Radiograph of a 19-year-old woman with an infected nonunion of the humerus.

performed at a rate of 0.25 mm three times a day after a latency period of 7 days (Figure 3). Compression of the nonunion site was initiated immediately postoperatively at 0.25 mm per day and decreased to 0.25 mm twice weekly after 20 days. The final patient with a hypertrophic nonunion had progressive distraction of the nonunion site without osteotomy. Autologous cancellous bone grafts were used in 3 patients. In the patient with the hypertrophic nonunion, bone graft was applied to the nonunion site at the end of distraction to enhance bone formation. After bone transport, two patients with atrophic nonunions had bone graft to the docking site.

Clinical evaluation was conducted at follow-up with assessment of pin sites, patient satisfaction, wound site, humeral length, and functional limitations. Union was evaluated both on serial radiographs and by clinical examination. The radiographic criteria for successful healing of the nonunion was complete bone bridging on at least two projections. Union was assessed clinically by loosening the connecting rods and applying stress to the nonunion site. If solid union was confirmed clinically and radiologically, the fixator was removed in the clinic.

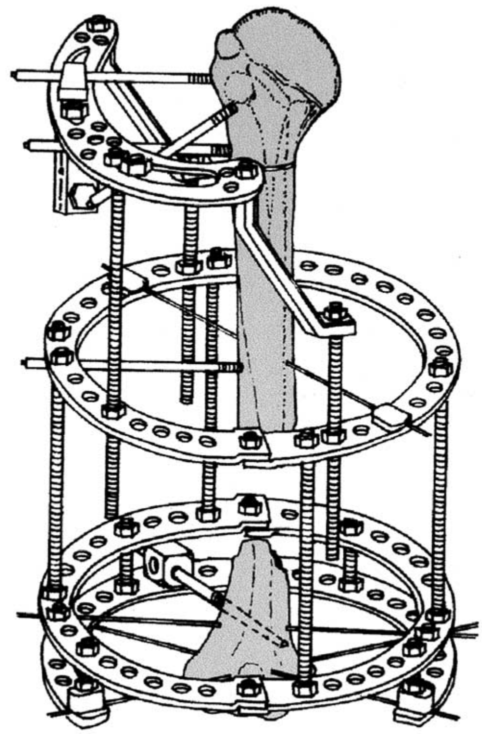

Figure 2 Diagram of a typical Ilizarov frame construction used to treat nonunion of the humerus with shortening.

RESULTS

Solid union was achieved in all patients (Table II). The mean external fixation time was 8 months (range, 4-12 months). The mean amount of lengthening performed was 5.63 cm (range, 2.5-8 cm). Equalization of humeral length was achieved in two patients (Figure 4), with 1 cm of residual limb length discrepancy in a third. The final patient, who had the largest segmental bone loss, had a residual limb length discrepancy of 3 cm.

The mean follow-up after frame removal was 47.5 months (range, 1-6 years). All of the patients were satisfied with the treatment and returned to a more normal lifestyle. No patient complained of pain at the nonunion site after treatment. None had recurrence of their infection, and complete soft-tissue recovery was achieved in all patients.

All patients had improvement in shoulder and elbow motion after treatment. The mean shoulder abduction increased by 37° (range, 85°-150°) and flexion increased by 41° (range, 85°-105°). Range of motion at the elbow improved by a mean of 45°. The mean postoperative flexion was 105° (range, 75°-135°), and the mean flexion contracture was 23° (range, 15°-35°).

Superficial pin-site infections were seen in all patients during treatment, but all responded to oral

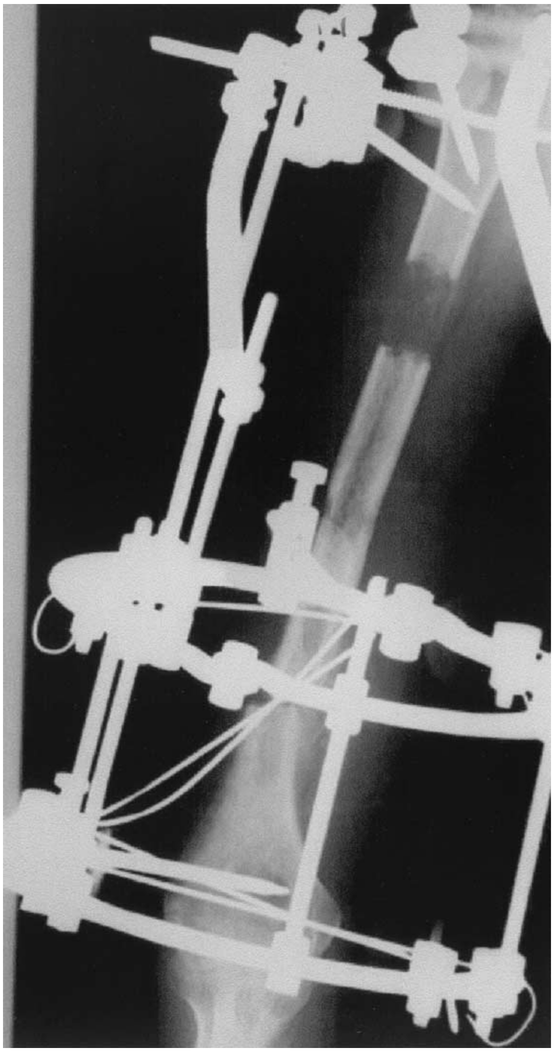

Figure 3 Radiograph of the same patient shown in Figure 1 after application of a hybrid advanced Ilizarov fixator.

antibiotic treatment. No patient required admission for a pin-site infection, and no wires or pins required removal because of infection. In one patient a broken half-pin required replacement during treatment.

In 3 patients, consolidation of the nonunion site progressed slowly, requiring autologous cancellous bone graft to promote union. One was a 42-year-old man with a hypertrophic nonunion who had been treated 6 years earlier with an intramedullary nail. Bone grafting in this case led to substantial formation of bone and rapid union. The second patient was a 29-year-old Ethiopian man who had an infected atrophic nonunion with 11 cm of bone loss after a gunshot wound 4 years earlier. In this case a second fracture occurred on two occasions through the area of the nonunion after removal of the fixator. This required a further period of treatment and reapplication of an Ilizarov frame on both occasions for 6 months. On the last occasion, fixator application was combined with autologous bone grafting, and the nonunion eventually healed without subsequent recurrence. Consolidation of the docking site was achieved in the third patient after bone grafting. A fracture also occurred on one occasion through the regenerate bone at the lengthening site. On this occasion, 1 month in a cast led to an uneventful recovery.

DISCUSSION

Humeral nonunion with significant bone loss or shortening is an unusual and complex clinical problem. Etiologic factors include bone loss resulting from open fractures, infection, tumor resection, and resorption of bone associated with failed internal fixation.

Not all humeral nonunions with shortening require specific management of the limb length discrepancy. A number of factors are important in deciding the most appropriate treatment in a specific case.[4] First, shortening of less than 5 cm can often be accepted, obviating the need to treat certain bone defects, and is usually compatible with good function in the upper limb. Second, reconstruction may not be advisable given the poor quality or limited extent of diaphyseal bone remaining. Third, the close proximity of the articular and neurovascular structures places significant limitations on the use of internal and external fixation devices and the ability to correct a limb length discrepancy.

Several reconstructive techniques have been used for the treatment of humeral nonunions with significant shortening or bone loss.[4,6,9,11] Ring et al[9] treated 15 patients with humeral nonunions and associated bony defect using autogenous bone graft and a plate to bridge the defect. All but one nonunion healed, and the authors suggested that this was a good alternative to more demanding surgical techniques. This technique, however, is only suitable for patients with relatively small limb length discrepancies where no soft-tissue or infection problems coexist.

Microvascular free bone graft and plate fixation can be used to reconstruct a significant loss of diaphyseal bone length.[6] The major advantage of this technique is the ability to treat large humeral diaphyseal bone defects largely independently of the integrity of the local soft-tissue envelope. Gaining stable fixation of the graft, establishing and maintaining the vascularity of the graft, the lengthy operative time, and donor-site morbidity are all problems associated with this technique.[4,6]

Allografts have been used successfully in the reconstruction of humeral diaphyseal bone defects, either to enhance screw purchase as cortical strut grafts[3] or by being transplanted into large defects after tumor resection.[7] This technique allows reconstruction of

Table 2 Complications and outcomes of 4 patients with humeral nonunion and bone loss treated by the Ilizarov method

			Outcome	
Patient No.	**External fixation time (mo)**	**Complications**	**Residual humeral length discrepancy (cm)**	**Fracture union**
1	4	Fracture through regenerate bone	0	Yes
2	12	Two re-fractures at the nonunion site Broken half-pin (1)	3	Yes
3	9	Late consolidation of nonunion site	0	Yes
4	7	None	1	Yes

Figure 4 Radiograph of the same patient shown in Figures 1 and 3 after Ilizarov frame removal showing a healed nonunion and restoration of normal humeral length.

large humeral defects without the problems of graft vascularity or donor-site morbidity. Disadvantages include the long incorporation time, relative fragility of the graft during incorporation, risks of disease transmission, and inability to use this technique in cases with infection.

The Ilizarov method is a well-established technique for the treatment of humeral nonunion.[1,5,8,10] The application of this technique to the combination of nonunion and shortening of the humerus has been much less commonly documented in the literature.[2,6,10] An Ilizarov fixator can be used in the treatment of large bone defects independently of the status of the surrounding soft tissues.[5,8] Unlike other techniques that involve extensive dissection, application of the frame involves minimal disruption to the local blood supply. It is a relatively safe technique in the presence of infection and has been used successfully in cases of active infection.[5] A ring fixator provides good stability even in osteoporotic bone but still allows some axial micromotion that reduces stress shielding.[5] By application of distraction and compression forces, the frame allows a progressive mechanical stimulus for bone formation and provides the opportunity to modify alignment during treatment.[8] Finally, with the use of a hybrid advanced construct, immediate and full range of motion of both the elbow and shoulder joints is possible.[1,5]

External fixation and distraction osteogenesis with an Ilizarov fixator can be technically demanding and does involve a lengthy period in the frame. However, for many patients, the period of time in the Ilizarov fixator is relatively short when the full treatment course is considered. The Ilizarov method is undoubtedly labor-intensive and can be costly. However, the management of these complex long-standing problems is invariably demanding on resources regardless of the treatment modality chosen. The Ilizarov fixator can cause some patient inconvenience and discomfort, but by using the hybrid advanced technique, these problems can be minimized.[1,2,5,8,10] Pin-site infections are very common with this type of treatment but rarely cause major difficulties and usually respond to treatment.

With the use of a hybrid advanced Ilizarov fixator and distraction osteogenesis, simultaneous humeral lengthening and healing of the nonunion were achieved in all patients. Normal humeral length was restored in two patients, with a residual limb length discrepancy of 1 and 3 cm in the other two patients. The frame used, substituting arches for rings and reducing the number of wires, contributed to the patient's level of comfort. None of the patients described any difficulties with the frame, and all were satisfied with the treatment.

All patients had improved shoulder or elbow range of motion at the end of treatment. Although marked restriction of shoulder and elbow motion remained, the patient with the most severe preoperative deformity had a significant improvement in upper limb function.

A small number of pin-site infections did occur with the treatment, but all responded to oral antibiotic treatment and pin-site care. A fracture through the regenerate bone at the lengthening site healed rapidly in a cast and possibly reflected premature frame removal. One patient had two refractures through the nonunion site after removal of the Ilizarov fixator. The nonunion eventually healed but only after a further period in the fixator and autologous cancellous bone grafting. This problem has been previously documented in the treatment of humeral nonunion with internal fixation and an Ilizarov fixator.[7] It reflects the severely compromised ability of some atrophic nonunions to heal, rather than an inadequacy in the Ilizarov technique.[8] The Ilizarov method, though not a panacea for all humeral nonunions with extensive bone loss, does offer a viable salvage procedure for this unusual and often complex clinical problem.

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