Uninfected nonunion of the humeral diaphyses: Review of 21 patients treated with shingling, compression plate, and autologous bone graft

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Summary
Introduction: Controversy continues around selecting the best strategy for managing nonunions of the humeral diaphysis. The objective of this retrospective study was to analyse the results of management of this complication using a uniform surgical technique.

Hypothesis: The rate of union obtained in the present series is comparable to the results reported in the literature.

Patients and methods: Twenty-one patients were surgically treated at the Geneva University Hospital for nonunion of the humeral diaphysis between 1995 and 2005 with a mean follow-up of 50 months. Open reduction and internal fixation in compression using plates and screws with autologous bone graft enhancement was used. Eight cases were revisions of nonunions following a closed orthopaedic treatment and 13 cases were revisions following a failed surgical treatment.

Results: All the patients obtained union within a mean 4.5 months. The functional scores for the shoulder (Constant) and the elbow (Mayo) were 77 and 97 points (mean), respectively. Two patients developed transient paresis related to radial nerve and musculocutaneous nerve injuries and one had a recurring fracture. A single patient required a second intervention for delayed union.

Discussion: Of the surgical techniques for managing nonunion of the humerus, plate osteosynthesis is the most widely used. This simultaneously allows anatomic reduction, fracture compression, and osteogenesis stimulation. However, it can lead to infectious complications (although absent in our series) and neurological complications (10% transient paresis...
Introduction

Humeral diaphysis fracture nonunions remain worrisome, as shown by the nonunion rates ranging from 8 to 12% [1] reported in the literature, making the humerus one of the leading sites of nonunion among the long bones. This prevalence of humerus nonunion is mainly due to the specific biomechanics of the upper limb. The torsion and distraction forces applied to the unloaded upper limb tend to favour nonunion as emphasized by Pauwels [2], whose work confirmed that nonunion heals when all stresses other than compression are removed.

The controversies that reign around the treatment of nonunion of the humeral diaphysis remain lively. The defenders of closed treatment recommend locked intramedullary nailing or an external fixator to reduce the risk of sepsis and radial paralysis. On the other hand, open treatment with screws and plates is preferred by those wishing to correct existing anatomic deformity and to obtain absolute stability with a powerful stimulus of osteogenesis essential for attaining solid bony union.

Faithful to the principles of the Association for the study of Osteosynthesis (AO), we describe a homogenous cohort of 21 cases of nonunion of the humeral diaphysis treated with open reduction and internal fixation using screws and plates under compression associated with cortical shingling and autologous bone graft. We evaluate the time to and quality of bone union as well as the complications related to this treatment as compared to the current literature.

Patients and methods

Patients (Table 1)

Twenty-eight patients were operated for aseptic nonunion of the humeral diaphysis in the Orthopaedic Surgery and Traumatology Department at the Geneva University Hospital between 1995 and 2005. Seven patients were excluded (two were lost to follow-up and five died) so that finally 21 patients were included in the study. There were 11 males and 10 females, with a mean age at injury of 52 years (range, 22–86 years). Seven patients were initially managed in other institutions and three patients had already been unsuccessfully operated on elsewhere for their nonunion. In 11 patients, the injury was to their dominant upper limb. Six patients had a manual occupation, six a nonmanual occupation, and nine were not gainfully employed.

Eleven of the injuries were low-energy fractures (fall) and 10 were high-energy fractures (five traffic accidents, one fall from a window, one fall from a horse, one fall while skiing, one fall from a height, and one victim of the 2004 tsunami in Thailand).

Only four fractures were open fractures. Ten fractures involved the middle third, nine the proximal third, and two the distal third of the humerus. The fracture lines were classified using the AO classification [3]: three A1 (spiral), two A2 (oblique), five A3 (transverse), one B1 (spiral wedge), five B2 (bending wedge), one B3 (multifragmentary wedge), two C1 (complex spiral), one C2 (complex segmental), and one C3 (complex irregular).

The initial treatment consisted in eight patients having undergone conservative treatments (cast, bandage) and 13 cases of surgical treatment (three ascending intramedullary pin placements, three locked intramedullary nailing procedures—one Seidel antergrade nail, one retrograde nail, and one UHN antergrade nail—six screw and plate placements, and one external fixator).

There was one case of synovial nonunion (Fig. 1A), four cases of hypertrophic nonunion, and 16 cases of atrophic or oligotrophic nonunion (Fig. 2B).

In one case a persistent and complete radial nerve palsy remained present up to the time of the intervention for humeral nonunion.

The mean time elapsed from initial injury to operation for nonunion was 39 weeks (range, 12–180 weeks). Four of the patients were operated before the 6-month delay theoretically necessary for establishing nonunion.

Surgical technique

Humeral diaphysis nonunions were all revised according to the principles established by the AO, i.e., by open reduction and stable internal fixation using a compression plate. The anterolateral approach was used for the proximal and middle thirds of the humerus. The posterior approach was used when the nonunion involved the distal third. In the present series, 17 anterolateral approaches and four posterior approaches were used.

In all cases, the radial nerve was identified at the onset. In cases of preoperative radial nerve palsy, neurolysis was performed to ensure that the nerve was in continuity.

After removal of any previously placed material, cortical shingling was done (pedicle grafts on the soft tissue) using the technique reported by Judet and Patel [4], 5 cm on either side of the fracture site, on the side of the humerus that did not receive the plate.
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AE: anteroexternal; AO: AO classification; Ortho: orthopaedic treatment; Dist: distal; EF: external fixator; m: month; P: posterior; Prox: proximal.
Figure 1  A 32-year-old man, fracture of the distal third of the right humerus with plate osteosynthesis. Removal of the material 1 year later was followed progressively by painful function impotence with gross mobility at the nonunion site. A. Synovial nonunion of the right humerus 3 years after ablation of the plate. B. Failure of the nonunion cure with pins. C. Union 5 months after new surgical treatment via posterior approach.

Most often, the interposed fibrous tissue from the nonunion area (capable of transforming into bone provided a favourable mechanical and biological environment) was respected so as not to compromise local vascularisation and not prolong the time to union. This interposition tissue was excised in exceptional circumstances to the healthy and bleeding zone to permeate the medullary canal in the presence of synovial nonunion or excessive angulation.

Autologous bone graft from the iliac crest was systematically added.

Osteosynthesis using either Low Contact-Dynamic Compression Plate 4.5 plates (LC-DCP) or Locking Compression Plate (LCP) 4.5/5.0 (Fig. 2C), narrow or wide depending on the humerus morphology. The plate was slightly prebent in its middle and applied to the humerus to produce dynamic compression and to absorb the tension forces (tension band plate).

As far as possible, fracture compression was attempted either by the dynamic compression unit of the DCP plate or the isolated lag screw through the plate (Fig. 1C).

Revision method

All patients were called in for a clinical and radiological follow-up, which included an evaluation of pain, shoulder and elbow mobility and a sensory-motor examination of the limb in search of a deficit.

Three functional scores were recorded during this visit: the first was subjective and globally assessed the upper limb (QuickDASH [5]) and the two others were objective measurements specifically evaluating the functional results of the shoulder [6] and the elbow (Mayo [7]).

The radiological follow-up included an AP and lateral image of the humerus concerned.

Union was considered acquired when pain had disappeared and when there was radiological evidence of bony bridging between the two ends of the united area. The radiological study of the initial treatment of humerus fractures and the failed cure for nonunion allowed us to identify the technical errors that had led to the onset or the recurrence of the nonunion.

Results (Table 1)

The mean revision follow-up was 50 months (range, 6 months to 10 years). Twenty patients out of 21 showed union after a mean lapse of 4.5 months (range, 3–6 months), for a 95% union rate. Only one patient required a second intervention to change the osteosynthesis material and add complementary bone material because of a lack of bone callus at 9 months, with final healing obtained at 6 months.

In 18 cases out of 21, the result was considered anatomic with restoration of the axes. One case resulted in a solid union but with a malposition in 20° of varus.

Eleven of the 12 patients exercising a profession were able to resume work at the same level.

The QuickDASH questionnaire on the disabilities related to upper limb injury resulted in a mean 18 points (range, 0–60 points). This questionnaire showed 14 excellent results, four good, and three fair.

For the shoulder, at the last follow-up, the mean elevation was 140° (range, 70°–180°). The mean raw Constant joint function score obtained was 77 points (range, 100–41 points), with 10 excellent results, nine good results, and two fair results.

For the elbow, at the last follow-up, in flexion–extension the mean elbow mobility was 130/15/0 (range, 100°–140° flexion; 0°–30° loss of extension). The mean Mayo joint func-
Figure 2  A 65-year-old woman with a spiral fracture of the proximal and middle third of the right humerus with two long intermediary fragments. Failure of orthopaedic treatment by immobilization in a U-shaped sling, relayed by functional bracing. A. AP Radiograph the day of injury. B. Follow-up at 3 months: proximal union but distal oligotrophic nonunion. C. Union 3 months after surgical treatment via the anterolateral approach.

The complications related to fixation of the nonunion included one case of transient paresis in the territories of the radial nerve and the musculocutaneous nerve (both resolving spontaneously), one stress fracture at the level of the proximal end of the plate treated conservatively, leading to malunion with 20° varus, with no functional repercussions.

Morbidity at the autologous bone graft site was minimal, manifested by occasional discomfort in only two patients. A single patient presented paralysis of the radial nerve that persisted during the nonunion treatment. Surgical exploration and neurolysis of the radial nerve demonstrated that the nerve was in continuity and recuperation progressed to completion at the last follow-up.

Discussion

Although the literature has reported an abundance of clinical studies, the definition of nonunion remains arbitrary. Theoretically, humeral healing occurs between 12 and 16 weeks after injury. Delayed healing is defined by the absence of union before 3 full months and nonunion is defined by the absence of union after 6 full months [8]. This passive approach undoubtedly prolongs morbidity, the inability to resume work, and compromises elderly subjects. Currently, delayed union or nonunion is diagnosed as soon as the surgeon deems that the clinical and radiological profile of progression shows little or no potential for healing. Additional treatment is therefore required. Most of our cases were managed late, with only four patients with less than 6 months between the initial fracture and treatment for delayed union.

The search for the causes of union failure is not without practical consequences in the initial management of humeral diaphysis fractures. The fractured ends of an off-loaded limb are subjected to traction forces, which tend to increase the interfragment space, as well as rotation forces, leading to stresses harmful to healing [9,10]. Classical factors leading to nonunions can be patient-related (advanced age, osteoporosis, malnutrition) or fracture-related (open fracture, loss of bone substance): union failures are also frequently related to therapeutic error (whether or not treatment is surgical) compromising the blood supply or promoting instability.

After orthopaedic treatment, the literature reports 2–10% nonunion of the humeral diaphysis [11–13]. These failures are most often secondary to a poor therapeutic indication or inadequate immobilization. Sarmiento et al. [12] reported union rates of 98% for closed and 94% for open fractures of the humeral shaft after functional bracing. In this therapeutic option, tolerance to micromovements allows union in that there is good alignment and/or sufficient fracture contact. Among the immobilization means available, a U-shaped brachial cast held in place by a Velpeau bandage is the most frequently used and the most effective. However, the use of a hanging cast is not satisfactory because it promotes distraction of the injured area and does not prevent rotatory stresses. Nevertheless, clinical experience has isolated certain circumstances requiring immediate surgical treatment, which would otherwise result in high rates of nonunion. These are reduction defects (spiral and transverse fracture with muscle interposition between the fragments) or errors in maintaining reduction (protruding chest, notably in obese patients). In our series, we noted a preponderance of nonunion in older subjects treated orthopaedically for a more or less complex spiral fracture. It seems that the presence of a long intermediary butterfly fragment may be a...
negative prognosis for union (Fig. 2A). The absence of union has often been noted on the diaphyseal extremity of the butterfly fragment, whereas union is more favourable on the extremity near the metaphysis. Retrospectively, five erroneous indications for orthopaedic treatment were found, caused by a substantial interfragmentary gap.

The cause of failures after surgical treatment of fractures, up to 15% nonunion of the humeral diaphysis [1,8,11,13,14], is very often secondary to technical error: the plate is too short, not strong enough, or without fracture compression; or the nail is too thin, insufficiently locked, or there is distraction leaving a fracture gap; the nail does not fill the medullary shaft; or the external fixator leaves too wide a fracture gap. The other cause that may make a humerus fracture progress toward nonunion during surgical management is fragment devascularization. In our series, there were three cases of nonfilling fasciculated nailing, one nail that was too short, one poorly locked nail that left a voluminous fracture gap, one plate that was too short, one plate that was not sufficiently resistant, two plates that left a large interfragmentary gap, and one external fixator leaving a fracture gap that was too wide.

Noninvasive treatment can be appropriate in the very elderly who have major osteoporosis or comorbidities that make anesthesia or surgical repair impossible. When there is little discomfort, a light orthosis can provide sufficient stability and an acceptable level of function. In rare cases (absence of infection, absence of bone loss, and stable and well-aligned nonunion), noninvasive treatment such as ultrasound or electrical stimulations can be proposed, but success is somewhat random (0–60% union) [8,15].

Surgical treatment remains widely indicated. The objective of surgery is to provide a stable assembly and to begin early mobilization. Stabilization of a nonunion provides the mechanical means necessary for calcification followed by ossification of the fibrous cartilage present in the fracture gap. Experimentally [16], when there is sufficient and good-quality bone stock, fixation by compression can alone guarantee union, without resection of the nonunion fibrous tissue.

Three types of fixation are used today: intramedullary, external and plate fixation.

**Intramedullary nail fixation**

Intramedullary nail fixation, when compared to open reduction or plate fixation, is less damaging. However, one must acknowledge that the results of nailing the humerus are not as favourable as in the lower limb. Even with locked implants, this option remains associated with considerable problems of axial and rotational instability that prevent any fracture compression and are a source of many union failures [17–19]. Although for Pietu et al. [20] and Beguin et al. [21] certain small series report 100% union after locked nailing in treating nonunion of the humerus, other authors found insufficiently high rates of union (40% failure for Dujardin et al. [22], 60% for McKee et al. [23], and 67% for Fattah et al. [24]) and pain syndromes of the rotator cuff (40% for McKee et al. [23]). In a retrospective multicenter study reported by McKee et al. [23] in 19 patients presenting nonunion after nailing of the humerus, only four out of 10 patients achieved union after re-sizing, whereas nine others achieved union after plate fixation and autologous grafting. Robinson et al. [18] reported only two successes out of five cases of nail replacement after failure of a Seidel nail.

**External fixator**

Fixation using an external fixator provides stable fixation, progressive reduction, and compression of the fracture [25–27]. This type of fixation does not come without complications: nerve damage due to poor pin placement, repeated fractures when the fixator is removed, stiffness, pin track infection, and septic arthritis of the elbow [26,27]. Patel et al. [27] described the use of the Ilizarov technique to treat nonunions of the humeral diaphysis. In 10 patients presenting nonunion after insertion of a large-diameter humerus nail, the authors left the nail in place after having removed the locking screws and applied a circular external fixator and compressed the nonunion area. They reported union in all patients, but encountered many complications. This technique has a union rate that is nearly identical to the rate reported in other series treated with a plate, but a high fixator time (mean, 6 months). However, this technique has a role to play in cases of poor-quality soft tissue and complex multiplanar deformations near the joints in which correction in a single phase seems difficult and risky.

**Plate fixation**

Plate fixation is probably the best material for stabilization of nonunion. It provides fracture compression [9,28], correction of axis malalignment, and stimulation of osteogenesis (shingling, graft) in a single procedure. The union rates reported using this technique are excellent (83–100%), with high subjective satisfaction [8,23,29,30]. This union rate is nearly identical to the rate found using external fixator treatment but is higher than treatment using nails [31]. Otsuka et al. [29] demonstrated 25 successes out of 25 nonunions of the humeral shaft treated by compression plate. Barquet et al. [32] reported 24 successes out of 25 cases treated with a wide DCP plate combined with shingling and an autologous bone graft. With 95% union obtained, these results are in agreement with the data reported in the literature.

In the presence of nonunion with reasonable bone loss (around 3 cm), Ring et al. [33] recommend using a wave plate associated with an autologous bone graft to bridge the fracture and respect the blood supply while restoring the length. They observed 14 successes out of 15. In elderly patients, using a LCP plate [34], a blade plate [35], a long assembly [36], or polymethyl-methacrylate [11] are technical tricks that can significantly increase fixation in mediocre-quality bones.

Classically, this treatment is criticized because of the risk of infection and radial nerve palsy. We found no sep sis in our series and only two cases of transitory paresis of the musculocutaneous and radial nerve that resolved spontaneously. This complication can be minimized by systematic identification of the musculocutaneous and radial nerve.
Stimulation of osteogenesis with shingling [4] is the simplest and most effective means to expose the nonunion without considerable devascularization. In cases of diaphyseal nonunion, the periosteum is intimately attached to the adjacent muscles and the superimposed bone, which receives its blood supply from the extraneous tissue. Circumferential shearing of the external diaphyseal periphery preserves the blood supply for the fragments that have detached in this way and that bridge the nonunion. This technique is used to reconstitute union by creating a well-irrigated bed to receive the bone graft.

Stimulating osteogenesis with an autologous bone graft is the surest means of bridging a limited loss of bone substance. It has the advantage of being osteogenic (a source of living bone cells), osteoinductive (local recruitment of mesenchymal cells), and osteoconductive (scaffolding for growth of bone tissue). Biologically, it is far superior to allograft or the bone substitutes available today. The disadvantages of cancellous autologous bone graft are morbidity (pain, hematomas) associated with the harvest sites. The most abundant harvest site is the anterior iliac crest. Recently [37], a comparative study of two types of bone grafts (autologous bone from the iliac crest versus allograft of demineralized bone matrix) demonstrated identical results in management of humeral nonunion, with the advantages of preventing morbidity at the harvest site when using demineralized bone matrix.

Conclusion

Invalidating in the young subject, nonunion of the humerus can seriously compromise autonomy in an elderly individual. Given its good results, surgical treatment should be widely indicated.

Our experience confirms the success of stable internal compression fixation and the wide use of autologous bone graft. In the management of nonunion of the humeral diaphysis, this technique ensures rapid union in 95% of cases with few complications.

Although controversial, the literature shows that the open reduction technique—plate fixation—is more reliable than intramedullary nailing or external fixation for treating nonunion of the humerus.

At a time when many pharmacological solutions, often extremely costly, are proposed, such as osteoinductive bone substitutes or diverse growth factors, it is reassuring to find that respecting a few simple principles allows one to obtain union in cases of nonunion of the humerus with excellent chances of success.

Conflict of interest statement

None.

References


