Treatment of Atrophic Diaphyseal Humeral Nonunions With Compressive Locked Plating and Augmented With an Intramedullary Strut Allograft

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Objective: The aim of this study was to evaluate the effectiveness of thorough debridement and locked compression plating augmented with an intramedullary fibular allograft for the treatment of atrophic diaphyseal humeral nonunions.

Design: The study involved a level 4 retrospective case series.

Setting: This study was conducted at a level 1 university trauma center.

Patients: Twenty patients with painful atrophic nonunions of the humeral diaphysis were examined.

Intervention: This involved a thorough debridement and locked compression plating augmented with an intramedullary fibular allograft.

Main Outcome Measures: These were union rate, shoulder range of motion, visual analog scale (VAS) pain, VAS function, patient satisfaction, and American Shoulder and Elbow Surgeons score at latest follow-up.

Methods: Clinical and radiographic examinations were performed preoperatively and postoperatively. VAS pain and function scores were collected preoperatively and postoperatively. Patient satisfaction and ASES scores were recorded at the time of the most recent follow-up.

Results: Bony union was achieved in 19 of 20 patients (95%). The patients demonstrated an average improvement in forward elevation from 65 to 144° ($P = 0.001$), abduction from 48 to 133° ($P < 0.001$), external rotation from 34 to 70° ($P = 0.05$), and internal rotation from S1 to T12 ($P = 0.025$). VAS pain scores improved from 6.05 to 1.88 ($P = 0.032$). VAS function scores improved from 2.06 to 7.75 ($P = 0.003$). The average postoperative ASES score was 76, and the average patient satisfaction was rated 9.3/10.

Conclusions: Atrophic nonunions of the humerus can be successfully treated with debridement of the nonunion, coupled with the use of a fibular allograft and locked compression plating. This technique leads to predictable healing without the morbidity associated with autograft.

Key Words: humeral nonunion, compressive plating, locked plate, intramedullary allograft

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

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INTRODUCTION

Despite conventional bracing and surgical intervention, a relatively high percentage of humeral shaft fractures may progress to nonunion. Nonoperatively managed humeral shaft fractures present with nonunion rates of 2%–10%, with proximal third or those with a proximal butterfly fragment most likely to progress to nonunion.[1–4] In a review by Volgas et al,[5] surgically managed fractures fared even worse with nonunion rates as high as 30% based on fracture pattern and mode of fixation. Although a variety of surgical strategies have been proposed, other authors have had obtained similar results.[4,6–12]

Weber and Cech[13] provided the original classification of nonunions in 1976. Variations have been described, but this basic classification has not changed substantially in the subsequent literature. Hypertrophic nonunions are due to excess motion and as a result exhibit prolific callus formation. These nonunions are vascular and have excellent healing potential when adequately stabilized. Atrophic nonunions have an absence of callus coupled with atrophic bone ends, which may be tapered, osteopenic, or sclerotic. Treatment of these latter nonunions can be more difficult due to nonviable bone, questionable vascularity, fibrous tissue interposition, and instability.

The purpose of this study is to report the results of our treatment of humeral diaphyseal atrophic nonunions using locked compression plating coupled with and an intramedullary fibular allograft, a technique originally described by Wright et al.[14] Our hypothesis was that diaphyseal atrophic nonunions can be successfully treated by adequate debridement including removal of all nonviable bone and use of this technique.

PATIENTS AND METHODS

Between January 1999 and September 2008, 26 patients with a painful, diaphyseal humeral atrophic nonunion presented to our institution, were subsequently treated with

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surgical intervention, and were included for consideration in this Institutional Review Board approved study. Confirmation of the nonunion was made by both clinical and radiographic examination and was defined as no evidence of bone healing after 6 months or no evidence of progression of healing radiographically for 3 consecutive months. All nonunions were classified as atrophic, according to the criteria of Weber and Cech.[13] Atrophic nonunions were excluded if they (1) had an active infection that was documented at the time of operative intervention, (2) were secondary to a pathologic fracture, (3) were in patients that had severe osteoarthritis of the ipsilateral shoulder, or (4) were too distal to allow for placement of the intramedullary graft.

All the patients were managed with a similar surgical technique by 3 surgeons fellowship trained in trauma or shoulder and elbow. The incision and approach were chosen based on the location of the nonunion and/or preexisting surgical scars. Seventeen patients had an anterolateral approach (85%), whereas a posterior triceps splitting approach was used for 3 (15%). Important neurovascular structures were initially identified (radial nerve posteriorly, musculocutaneous nerve anteriorly) and protected throughout the surgical dissection. Implant removal, when needed, preceded takedown of the nonunion. The fracture ends were debrided of fibrous tissue until bleeding bone ends were seen. The medullary cavity was opened either with a rongeur or a drill and then "reamed" using large drill bits under fluoroscopy until medullary bleeding occurred from both the proximal and distal segments. In cases of angulation or shortening, the nonunion was stripped of fibrous tissue so that alignment could be restored and the bone ends could be compressed. Shortening of the bone of up to 3 cm, when necessary, was used to obtain contact between segments.

A circumferentially intact allograft fibula graft was then shaped into a dowel with a high-speed burr and shortened to a length 2–4 times the diameter of the humeral shaft. This length allowed an intramedullary fit proximal and distal to the nonunion site. The graft was further fashioned until it could slide within the intramedullary canal and then inserted almost fully into one canal. The nonunion was reduced over the small amount of dowel that protruded, and using a small bone clamp, the graft was advanced fully into the other side of the nonunion so that it was centered within the nonunion. Once secure, the fracture ends were manually impacted into a stable position. Verification of the position of the graft with fluoroscopy was performed, and a locked compression plating was performed according to standard techniques.[13] When possible, additional compression was achieved using a push-pull screw technique as described by Mast et al[15] (Fig. 1). At least 1 screw was placed proximally and 1 screw distal to the nonunion site through the plate so that these screws crossed both humeral cortices and the graft (4 cortices).

Postoperatively, the patients were placed in a sling for comfort only. Range of motion of the upper extremity and activities of daily living such as combing hair, brushing teeth, and feeding were permitted. The patients were not permitted to lift, carry, push, or pull until complete union was demonstrated clinically and radiographically. The patients were seen at routine postoperative intervals at which time x-rays were obtained until clinical and radiographic union was achieved.

FIGURE 1. Virtual simulation of compression across the nonunion site with the fibular strut in place using a push–pull screw and a Verbrugge clamp.

At each follow-up visit, an independent clinician conducted patient interviews, physical examinations, and a patient survey assessed outcome. A review of the medical charts and radiographs was then performed to obtain the data for the current series. Healing of the nonunion was demonstrated by clinical stability, and 3 of 4 cortices found to have bridging bone on orthogonal radiographic views. Patients' active range of motion and VAS pain and function were examined preoperatively and postoperatively. Patient satisfaction, rated on a scale of 1–10 with 10 being most satisfied, and ASES scores were obtained at the most recent follow-up.

Statistical Methods

The paired samples *t* test was employed to compare the patient-reported preoperative and postoperative pain and function and range of motion measures. Significance was set at $P < 0.05$.

Source of Funding

There was no external funding for this study and funding did not play a role in this investigation.

RESULTS

Of the 26 patients identified, 6 patients were excluded from this study. Three patients had fractures too distal for dowel placement, one was infected, one had ipsilateral arthritis, and one was secondary to a pathologic fracture. There were 10 women and 10 men with a mean age of 61 years (range 44–81 years). According to the Orthopaedic Trauma Association fracture classification system,[16] the original fracture pattern was oblique in 5 patients (25%), spiral in 5 (25%), spiral complex in 3 (15%), transverse in 2 (10%), spiral wedge in 2 (10%), irregular complex in 2 (10%), and segmental complex in 1 (5%). Two fractures were reported as originally open (10%). Ten (50%) fractures were initially treated with surgical intervention, whereas 10 (50%) were treated nonoperatively. Ten (50%) nonunions were located at midshaft, whereas 10 (50%) were at the diaphyseal junction of the proximal/middle one-third. Significant comorbidities included 10 patients (50%) who smoked at least one half-pack of cigarettes per day, 5 patients (25%) with diabetes, 3 patients (15%) who were obese and 2 (10%) with confirmed osteoporosis. One patient had a complete permanent preoperative radial nerve injury. In the previously surgically managed fractures, 5 were treated with intramedullary nails (25%), 4 had undergone plate fixation (20%), and 1 was treated with both methods (5%). For those patients, the number of surgical interventions before the current treatment varied between 1 and 2.

Minimum follow-up was 1 year, with an average follow-up of over 3 years (39 months; range 12–94 months). Union was achieved in 19 of 20 patients (95%) using the described technique (Fig. 2). On average, forward elevation improved from 65 to 144° ($P = 0.001$), abduction improved from 48 to 133° ($P < 0.001$), external rotation improved from 34 to 70° ($P = 0.05$) and internal rotation improved from the level of the S1 vertebra to the level of the T12 vertebra ($P = 0.025$).

VAS pain scores improved from 6.05 to 1.88 ($P = 0.032$). VAS function scores improved from 2.06 to 7.75 ($P = 0.003$). At the most recent follow-up, patient-reported ASES scores were 76, and patient satisfaction was 9.3/10. The lone failure occurred in a patient who had suffered a gunshot wound 9 years before our intervention and underwent 2 prior unsuccessful surgical attempts at fixation. The patient also smoked 5 cigars daily for 20 years and had a complete radial nerve palsy due to the original gunshot wound. At his 24-month follow-up visit, the nonunion was not radiographically healed, but the patient was clinically asymptomatic and refused further treatment; he rated his satisfaction with the procedure at 7/10.

Complications included 3 cases of adhesive capsulitis (15%). The 2 isolated cases of adhesive capsulitis were successfully managed conservatively, while a patient with concurrent impingement was managed successfully with an arthroscopic capsular release and subacromial decompression. There were no documented cases of infection, hematoma, or operative neurovascular injury in this series.

DISCUSSION

Fractures of the humeral diaphysis typically unite, however, those that progress to nonunion can be extremely debilitating for the patient and pose a challenge to the treating physician. These patients typically present with pain and may have comorbidities that contribute to the development of their nonunion including obesity, diabetes, smoking, alcoholism, and osteoporosis.[2,17–21] Management may be even further complicated by a history of prior surgery necessitating possible implant removal and a more extensive surgical dissection. Although several authors have proposed various techniques to manage humeral diaphyseal nonunions, the results have been mixed and no definitive treatment has been identified.[3–12,14,22–24]

Based on the currently available literature, the least effective treatment for midshaft humeral nonunions is exchange intramedullary nailing. Flinkkila et al[6] reported on a series of 24 patients with symptomatic midshaft humeral nonunions after intramedullary nailing. In their series, 13 of 24 patients were managed with exchange nailing and only 46%

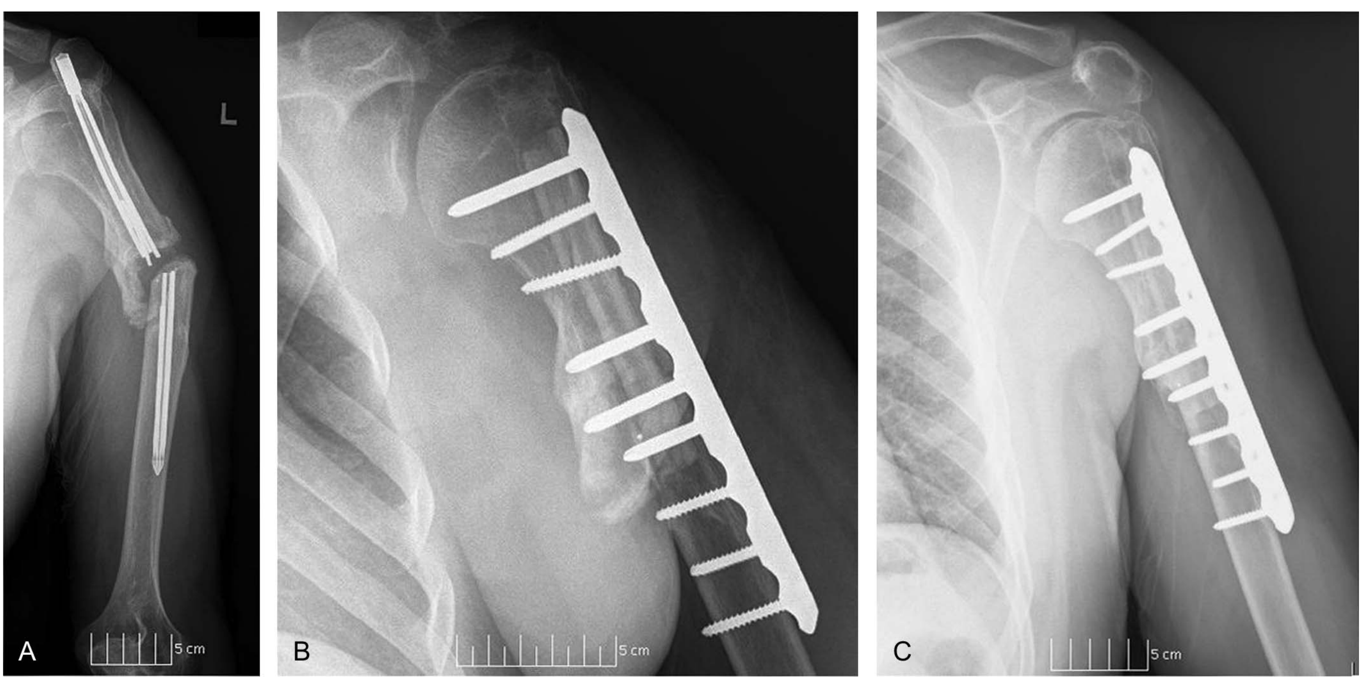

FIGURE 2. Radiographs of a proximal one-third atrophic nonunion with a healed butterfly fragment before and after revision fixation. A, Preoperative anteroposterior radiograph demonstrating an atrophic nonunion with failed intramedullary fixation. B, Anteroposterior radiograph 3 weeks after revision fixation to a compressive hybrid plating construct using an intramedullary fibular allograft strut. Proximal fracture of the allograft without apparent structural compromise is incidentally noted, likely due to screw placement. C, Anteroposterior radiograph 6 months after revision fixation demonstrating a healed nonunion.

(6 patients) achieved union. The unreliability of exchange nailing for the management of humeral nonunions treated initially by IM nailing was further documented by McKee et al.[25] In this series, the authors compared nonunions treated with compression plating with those treated with exchange nailing. In the 9 patients who were revised to a compression plate construct with autogenous bone graft, 100% healed; by comparison, only 4 of 10 patients (40%) treated with exchange nailing achieved bony union. They concluded that when considered alone, exchange nailing for nonunion of the humerus after failed intramedullary nailing is not an acceptable treatment.

In contrast, plate fixation alone or in combination with various bone grafting techniques has resulted in healing rates between 83 and 100%.[23] Further evidence suggests that the treatment of nonunions does not always require the addition of an osteoinductive agent, either autograft or bone morphogenetic protein. Lin et al[26] evaluated the effect of revision with dynamic compression plate and cancellous bone graft for aseptic nonunion after surgical treatments of humeral shaft fracture. Out of 86 patients, 31 were defined as atrophic nonunions. They had a 100% union rate. Ring et al[4] successfully treated 24 humeral nonunions with locked compression plating and either autogenous iliac crest graft or demineralized bone matrix. Based on their series, no difference in patient outcome was noted. Hierholzer et al[7] retrospectively reported on 45 atrophic delayed unions or nonunions treated with plate fixation and autogenous iliac crest bone grafting (ICBG) and compared this group with a cohort of 32 atrophic nonunions treated with plate fixation and demineralized bone matrix (DBM). They noted 100% healing of the ICBG group and 97% healing of the DBM group, although 44% of the ICBG group experienced donor site morbidity including prolonged pain or infection. The authors primarily used 4.5-mm compression plating in the ICBG group and locked plates in the DBM group. In fact, they concluded that adequate debridement and stabilization may be more important than the use of any type of bone graft although this was not clearly demonstrated in their study. Reed et al[27] obtained biopsies from the fracture gap of patients with healing fractures, hypertrophic nonunions, and atrophic nonunions and demonstrated no difference in median vessel count between these groups. In combination with our study in which we obtained a 95% healing rate, these results suggest that the biologic environment at the site of an atrophic nonunion is generally suitable for healing without the need for autograft. The majority of atrophic nonunions may be capable of healing after adequate preparation and mechanical stabilization with allograft as previously described.

The concept of quadricortical plating through an intramedullary allograft was first presented by Wright et al[14] and has been used with success by the senior authors (M.M. and R.S) for >10 years although we have expanded the use of this technique beyond patients with osteoporotic bone for several reasons. The addition of the intramedullary dowel graft has both biomechanical and biological advantages. The combined cortical thickness of the fibular dowel greatly increases the surface area for screw purchase. In the biomechanical arm of the study by Wright et al, the authors demonstrated that the construct strength of quadricortical fixation was similar to that of bicortical fixation augmented with cement and significantly stronger than bicortical fixation alone. This improved mechanical environment may reduce the risk of fibrous union or failed fixation that can occur as a result of excessive motion or osteoporotic bone. From a biological perspective, intramedullary placement of the allograft does not require the same amount of circumferential soft tissue stripping around the nonunion that extramedullary allograft struts may require.[11] The bone is only exposed enough to properly debride the atrophic nonunion, correct the deformity and allow adequate space for a plate. The periosteum is left intact whenever possible.

Some drawbacks to the technique exist. Caution should be exercised when using this technique in osteoporotic bone to avoid fracture of the humeral shaft with insertion of the graft. Although diaphyseal midshaft and proximal one-third fractures were amenable to the placement of an intramedullary dowel, more distal fractures precluded this technique due to the olecranon fossa. Furthermore, none of these fractures had substantial bone loss requiring the use of bone graft. More distal fractures or those with substantial bone loss would likely benefit from alternative techniques including shortening and compression, bridge plating with autografting, or the use of bone morphogenetic protein.[10]

Several weaknesses are also present in this study. First, this is a retrospective review with no comparison group available to evaluate union rates with adequate debridement and compression plating alone. We recognize it is possible that for some of these fractures, only thorough debridement and adequate stabilization may have been required. Second, preoperative ASES scores were not available for comparison to postoperative scores. Third, we were unable to define exactly which fractures should or should not be treated with this technique. Despite its merits, compression plating of atrophic humeral nonunions may not always be technically feasible. Some patients may have poor bone quality or limited bone stock due to unusual fracture patterns, open fractures with bone loss, or prior surgical intervention making the application of a compression plate technically challenging or not possible at all.

In summary, this technique has proven successful in our hands for treatment of humeral midshaft and proximal third atrophic nonunions with a union rate of 95%. It is both a reliable and reproducible means of treatment that avoids the need for iliac crest autograft. The use of an intramedullary allograft improves stability at the nonunion site while minimizing additional surgical dissection. The key, as with any nonunion surgery, is proper preparation of the fracture site and adequate debridement of the fibrous caps covering the bone ends in addition to intramedullary drilling/hand reaming to reintroduce bleeding into the nonunion site. Once this has been accomplished, the addition of an intramedullary fibula dowel graft coupled with locked compression plating offers the surgeon an additional option to achieve improved mechanical stabilization and promote bony union.

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