

A CASE SERIES AND REVIEW OF SALVAGE SURGERY FOR REFRACTORY HUMERAL SHAFT NONUNION FOLLOWING TWO OR MORE PRIOR SURGICAL PROCEDURES

Todd A. Borus, M.D.¹, Edward H. Yian, M.D.¹ and Madhav A. Karunakar, M.D.¹

ABSTRACT

The orthopedic surgery literature is replete with techniques for managing primary humeral shaft nonunions, with success rates upwards of 90 percent with plate fixation and autogenous bone grafting. Despite this success, persistent nonunion following one or more initial failed nonunion interventions can occur, imposing a significant clinical and surgical challenge. We report the application of a standard treatment protocol for refractory humeral shaft nonunions including optimization of patient co-morbidities in the peri-operative period, rigid 4.5mm compression plating with a minimum of eight cortices of fixation proximal and distal to the nonunion site, and utilization of autogenous bone grafting. This study, a retrospective review of seven patients, all managed based on this standard treatment protocol, revealed that all achieved fracture nonunion within six months of revision surgery. Six of seven patients were clinically satisfied with the outcome of surgery; one remained dissatisfied secondary to a chronic neuropathic pain syndrome. Although more complex surgical options such as Ilizarov external fixation and allograft cortical strut augmentation have been reported, and are available in the salvage situation of refractory humeral nonunions, we conclude strict application of basic nonunion principles can result in successful salvage of humerus nonunions in patients who have failed two or more prior surgical interventions.

INTRODUCTION

The incidence of nonunion after operative treatment of humeral shaft fractures has been reported to range between 2.5 and 13 percent.^{1,2,3,4} Nonunions can result in significant patient morbidity by limiting activities of daily living secondary to pain and loss of function. Revision surgical management is indicated for treatment of nonunions following an initial failed surgical procedure. The literature is replete with studies outlining the various methods of treating humeral shaft nonunions following primary operative management^{1,3,5,6,7,8,9,10,11,12,13,14,15,16,17} with success rates approaching 100 percent in achieving nonunion healing. Despite this success, no studies have focused specifically on the salvage of refractory nonunions after failure of one or more nonunion surgical interventions. The purpose of this study was to review a standard treatment protocol, including optimization of associated patient co-morbidities, rigid 4.5mm compression plating with at least eight cortices of fixation, and utilization of autologous bone grafting, in a select group of patients who had failed two or more operative procedures for a humeral shaft fracture (an index surgery and at least one additional nonunion intervention).

METHODS

Patient Selection

Following Institutional Review Board approval, eight consecutive patients who were referred to our institution between 1992-2001 with refractory humeral nonunions following failure of at least two prior surgical procedures, were retrospectively reviewed. One patient was excluded from the study because of incomplete/missing medical records. Seven patients fulfilled criteria to be entered in the study group.

All charts were reviewed from initial presentation to final follow-up for history and physical examination, operative reports, and all radiographs. Laboratory studies including complete blood count with differential, erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) were obtained to rule out infection. All patients presented with complaints of functional loss of the involved extremity due to pain and weakness and demonstrated radiographic evidence of humeral nonunion.

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¹Department of Orthopedic Surgery
University of Michigan
1500 E. Medical Center Drive
TC 2912 G
Ann Arbor, MI 48109-0328

Correspondence:

Madhav A. Karunakar, M.D.
1500 E. Medical Center Drive
TC 2912 G
Ann Arbor, MI 48109-0328
(734) 936-5690
e-mail: mkarun@med.umich.edu

TABLE 1
Patient Demographics

Case No.	Sex	Age	Mechanism	Fracture Location	Co-morbidities	Time From Injury Until Definitive Procedure
1	F	69	Fall	Mid-shaft, closed	Diabetes, ipsilateral rotator cuff tear	31 months
2	M	36	MVA, polytrauma	Mid-shaft, closed	Smoker, ipsilateral above-knee amputation, ETOH	23 months
3	M	48	Fall	Mid-shaft, closed	Obesity	18 months
4	M	42	MVA, polytrauma	Mid-shaft, closed	Smoker, obesity	25 months
5	F	64	Fall	Mid-shaft, closed	Positive intra-operative cultures	54 months
6	F	42	Fall	Distal third	Mental retardation, smoker	22 months
7	F	61	Fall	Distal third	Diabetes, obesity	35 months

MVA—motor vehicle accident

The subjects (Tables 1 and 2) included four females and three males. Co-morbidities included smoking (2), polytrauma (2), obesity (3), diabetes mellitus (2), ipsilateral above-knee amputation (1) and mental retardation (1). The average age of the patients was 52 years (range 36-69). The average time interval between the initial procedure and definitive procedure was 29 months (range 18-54). An average of 2.3 (range 2-3) procedures had been performed on each patient prior to the final procedure. Fracture types included two transverse, four short oblique, and two long oblique. Two fractures were comminuted. All fractures were closed. There were five middle-third, and two extra-articular distal-third humeral fractures. The original mechanism of injury was a fall in five patients, and motor vehicle accident in two patients.

The initial operative indication was failure of closed treatment in four patients, polytrauma in two patients, and obesity in one patient. Initial operative procedures included open reduction and internal fixation with plate-and-screw fixation in four patients and intramedullary (IM) fixation in three patients. Secondary procedures consisted of revision open reduction and internal fixation (3), exchange intramedullary nailing (2), removal of intramedullary nail with open reduction and internal fixation (2), removal of internal fixation with external fixator placement (1) and internal bone stimulator implantation (1). Two patients received external bone stimulators.

All seven patients had persistent nonunions classified as atrophic. Four of the seven patients underwent autogenous bone grafting to the fracture site during at least one prior surgical procedure. Complications from prior management reported at presentation included radial nerve palsy in two patients, one of which was resolving and the other requiring a dynamic glove for support.

Surgical Management

Prior to undertaking revision surgery, patient co-morbidities were addressed. Within this study population, this included mandating smoking cessation (two patients) and optimizing medical management of diabetes mellitus (two patients). The operative approach selected for the revision procedure was based on prior skin incisions and the surgical approach necessary to remove hardware and expose the nonunion site. Four patients had undergone a prior posterior approach and three an anterolateral approach. The previously implanted hardware was removed in all patients, including an antegrade intramedullary nail in one patient and an external fixator in one patient. The radial nerve was identified and protected for the duration of the procedure. The intramedullary canal was reconstituted with a drill and bone ends were contoured to provide adequate diaphyseal contact. Tissue samples were sent to the microbiology lab for routine cultures. Compressive plating techniques with 4.5mm DCP plates were utilized and autogenous iliac crest bone graft was placed at the nonunion site. A minimum of eight cortices of fixation above and below the fracture site were obtained in all cases. If adequate cortical fixation could not be achieved, additional methods of fixation were utilized. Dual plating techniques were performed in (short-segment) distal fractures to obtain eight cortices of fixation of the distal fragment. Dual plating was also performed if any residual motion was detected at the nonunion site after primary plate fixation, to provide enhanced stability. With dual plating, one plate was positioned posteriorly, while the other was positioned either on the medial or lateral surface to create an orthogonal construct. In one patient with osteoporotic bone, methylmethacrylate was used to augment fixation.

TABLE 2
Surgical Information

Case Number	Number of Surgical Procedures Prior to Definitive Procedure	Initial Surgical Procedure, subsequent failed procedures	Implant Prior To Definitive Surgical Procedure	Bone Graft Utilized on prior procedures	Final Implant
1	2	ORIF, revision ORIF	8 hole narrow 4.5 DCP	Autograft	10-hole narrow 4.5 DCP
2	2	ORIF, revision ORIF	9 hole broad 4.5 DCP, 7 hole 3.5 LCDCP	Autograft	9-hole broad 4.5 DCP, 1 interfrag screw
3	2	ORIF, revision ORIF	6 hole narrow 4.5 DCP, 5 hole 3.5 LCDCP	Autograft	12-hole broad 4.5 DCP
4	2	IMN, exchange IMN	Antegrade Locked IMN,	None	8-hole narrow 4.5 DCP
5	3	IMN, exchange IMN, ORIF	7 hole 4.5 DCP .	None	8-hole 4.5 DCP, 7-hole 3.5 LCDCP with methylmethacrylate screw augmentation
6	2	ORIF, HWR with External Fixator Placement	External Fixator	Autograft	8-hole 4.5 DCP, 7 hole 3.5 LCDCP
7	3	Rush Rod, HWR and ORIF, placement of internal bone stimulator	12 hole narrow peri-articular distal humerus plate	None	8-hole 4.5 DCP

ORIF—open reduction and internal fixation; IMN—intramedullary nail; HWR—hardware removal; DCP—dynamic compression plate; LCDCP—limited contact dynamic compression plate

Postoperatively, patients were placed in a sling for comfort for two weeks. Early gentle pendulum and active assisted shoulder and elbow range of motion were started within two weeks of surgery. Progression to strengthening and passive range of motion exercises was instituted after radiographic evidence of union.

At final follow-up, clinical outcome was assessed by active range of motion of the shoulder and elbow and the presence or absence of pain in the extremity when conducting activities of daily living. Patients were asked if they were satisfied with the outcome of the final surgical intervention and the level of their satisfaction. Union was determined by radiographic evidence of cortical bone bridging at the nonunion, stable hardware position on radiographs, as well as absence of pain with manual palpation of the nonunion site.

RESULTS

All patients had normal preoperative laboratory studies. All patients had negative intraoperative tissue gram stains. Operative cultures revealed rare amounts of coagulase-negative Staphylococcus in one patient, who was treated with six weeks of intravenous vancomycin resulting in uneventful healing. The average number of cortices with screw fixation was 8.5 following the definitive surgical procedure. Six of seven patients showed evidence of complete healing as defined by radiographic evidence of at least three out of four bridging cortices within three months of the revision procedure. One patient demonstrated clear bridging of two of four cortices with stable hardware position over a period of over

nine months at final follow-up. Additionally, he was nontender over the fracture site with manual stress applied to the humerus, and therefore he was considered clinically healed. No new radial nerve palsies resulted from revision open reduction and internal fixation.

At final follow-up (Table 3), shoulder and elbow function was full (symmetric to the contralateral side) in five of seven patients. One patient who only regained 90 degrees of active shoulder forward flexion had an ipsilateral rotator cuff tear at the time of her initial surgical procedure at an outside institution that was repaired during that procedure. Despite the repair and active physical therapy, she never regained full shoulder motion. Another patient presented with 130 degrees of active forward flexion of the shoulder and a ten-degree elbow flexion contracture prior to definitive surgical intervention. Range of motion was not regained after surgery.

Six of seven patients reported that they were either very satisfied or satisfied with the outcome the revision nonunion surgery. One patient was dissatisfied. His initial humerus fracture resulted from a polytrauma motor vehicle accident in which he sustained a closed head injury and multiple other long bone injuries. He also had a history of a contralateral traumatic above-knee amputation from a previous trauma. Despite meeting criteria for humeral union after his revision procedure, he continued to complain of a vague, ill-defined pain in his upper arm that was not localized to a specific location or nerve distribution. He was diagnosed with a neuropathic pain syndrome and is currently being managed by a multidisciplinary pain clinic.

TABLE 3
Patient Outcomes

Case Number	Clinically and radiographically healed at 6 months?	Shoulder Function/ AROM	Elbow Function/ AROM	Patient Satisfaction
1	Yes	90 forward flexion	Full	Very Satisfied
2	Yes	Full	Full	Not Satisfied
3	Yes	Full	Full	Very Satisfied
4	Yes	Full	Full	Very Satisfied
5	Yes	Full	Full	Very Satisfied
6	Yes	Full	Full	Satisfied
7	Yes	130 forward flexion	10 flexion contracture	Satisfied

AROM – active range of motion

DISCUSSION

The surgical techniques required to successfully treat humeral shaft nonunions following initial operative management have been well described. The most commonly described techniques include exchange nailing following failed primary IM nailing^{11,17} and open reduction and internal fixation with a dynamic compression plate and autogenous bone graft.^{1,3,4,5,10,14,15} Considered the gold standard, the success rate reported using compression plating with a 4.5mm plate and autogenous bone grafting has been reported to be greater than 90 percent.^{3,4,5,10,14,15} The most commonly reported cause of failure of operative treatment of primary humeral shaft fractures is inadequate internal fixation.^{1,3,5,10,18,19} However, the recommendations for optimal fixation in both the primary fracture and nonunion settings are varied, ranging from six to ten cortices.^{1,3,4,10,14,19,20,21}

Although various investigators have reported on the treatment of primary humeral diaphysis nonunions, few papers have focused exclusively on revision procedures for salvaging refractory nonunions following a failed initial nonunion intervention. Several papers have focused on complex surgical techniques for managing persistent nonunion following two or more surgical interventions. Hornicek et al described the successful use of cortical allograft bone plates or struts in conjunction with internal fixation by metal plates to achieve healing in six patients with diffuse osteopenia and refractory nonunion following two failed surgical procedures.⁸ Patel utilized an Ilizarov circular external fixator in 16 patients averaging 2.6 previous surgeries to achieve union in 15 of the 16 cases.¹³ Other authors have obtained successful results with an operative protocol similar to the present study. Marti recently reported a series of 51 patients with humeral diaphyseal nonunions, ten of which had undergone at least two prior surgical

procedures prior to authors' intervention.¹⁰ These patients underwent uniform surgical repair with decortication, 4.5mm compression plating (with a minimum of six cortices of fixation proximal and distal to the fracture site), and application of autogenous bone grafting. All nonunions demonstrated consolidation at one year with 96 percent excellent or good shoulder and elbow function. Although this series does include patients with multiple previous operative failures, it is a mixed population that includes failure of nonoperative management, or one or more previous procedures. The specifics of treatment in the multiple failure subset population are not discussed.

Within the present series, seven patients who failed at least two prior surgical interventions of a humeral shaft fracture underwent successful salvage of the persistent nonunion with a standard protocol that included rigid fixation with a 4.5mm DCP plate and a minimum of eight cortices of fixation on each side of the fracture, application of autogenous bone graft, and optimization of associated patient co-morbidities in the perioperative period. Adjunctive fixation techniques including dual plating (two cases) in distal fractures and methylmethacrylate screw augmentation (one case) were utilized. All seven patients achieved clinical and radiographic union within six months, although one patient remained clinically dissatisfied secondary to a designated chronic pain syndrome.

With regard to our treatment protocol, although some authors have achieved success in the treatment of primary humeral shaft nonunions with a guideline of six cortices of fixation at each side of the nonunion site, we believe that in the salvage situation of multiple failed previous procedures, a minimum of eight, and possibly ten, cortices of fixation should be obtained. There are likely several reasons that the amount of fixation required to stabilize a nonunion (and especially a persistent nonunion) differs from that required for stabilization of an acute fracture. The surgical technique for nonunion surgery requires more extensive dissection, debridement of the fibrous nonunion tissue and shortening to bleeding bone. This frequently results in contoured bone ends that do not provide the same contact and stability as seen in acute fractures. Longer healing times are also common, requiring the implants to tolerate more stress for a longer period of time. In order to achieve the minimum of eight cortices of fixation, adjunctive techniques including dual plating were employed if necessary.^{12,14,15,21}

Our standardized treatment protocol also re-emphasizes the importance of autogenous bone grafting during revision nonunion surgery, especially in the case of atrophic nonunions. The importance of autogenous

bone grafting has been reported previously and should be considered a standard adjunct to the surgical treatment of these nonunions.^{3,4,7,10,15,20}

In addition to surgical factors, standard treatment of refractory humeral shaft nonunions in this series included the assessment and management of patient comorbidities which may impair bone healing. Smoking has been implicated as a specific risk factor for humeral nonunion.⁹ Similarly, others have found alcohol to be a risk factor for humeral nonunion based on a proposed mechanism of both physiologic (malnutrition, peripheral vascular impairment) and behavioral (noncompliance) mechanisms.² Smoking and alcohol cessation were mandatory before the definitive procedure. Although diabetes mellitus has not been demonstrated to be a specific risk factor for humeral shaft nonunion, several studies have demonstrated its impact on bone healing.²² Before performing definitive surgery in diabetic patients, attention was given to medically optimizing blood glucose control and hemoglobin A1c levels. We believe that prior to undertaking a salvage procedure for refractory humeral nonunion, patient comorbidities should be addressed, when possible.

Because of the retrospective nature of this series, there are limitations regarding the analysis that can be made about the causes of the multiple failures prior to definitive management. Possible contributing factors include: a combination of inadequate fixation (lack of six cortices of fixation on each side of the fracture site or utilization of a plate with inadequate mechanical strength), fracture distraction (antegrade IM nail or external fixation), or lack of autogenous bone grafting at the initial nonunion procedure. Moreover, tobacco and alcohol abuse cessation, as well as diabetes control, had not been optimized in certain patients. One patient, however, did meet all criteria of our treatment protocol at the time of her initial nonunion surgery, yet failed to achieve union. More specifically, prior to revision surgery she had no readily identifiable comorbidities, and surgical data from an outside institution revealed eight cortices of screw fixation on both sides of the nonunion site with utilization of autograft. As the surgery did take place at an outside institution, however, we are unable to fully evaluate the intricacies of the surgical technique performed, such as whether adequate debridement, re-cannulization of the intramedullary canal, and decortication at the nonunion site were performed. At the definitive procedure, a longer plate with ten cortices of fixation was placed with repeat application of autograft. Nonunion healing ensued. Although more complex surgical procedures remained an option in this patient, revision surgery with application of standard nonunion principles proved successful.

In summary, although specialized techniques such as Ilizarov circular external fixators and utilization of cortical allograft strut augmentation provide additional surgical fixation options in the salvage of refractory humeral shaft nonunions following failure of two or more prior surgical interventions, a standard revision operative protocol of 4.5mm DCP plating with at least eight cortices of fixation and autogenous bone grafting, as well as optimization of patient comorbidities, led to a high rate of union and significant improvements in patient function and outcome. These techniques can lead to bone healing in the revision setting even after multiple fixation attempts, including previous intramedullary nailing, intramedullary nail exchange or plate and screw fixation.

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