Severely Impacted Valgus Proximal Humeral Fractures

Results of Operative Treatment

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Background: The functional results associated with nonoperative treatment of severely impacted valgus fractures of the proximal part of the humerus are poor, and these injuries are difficult to treat with minimally invasive percutaneous fixation techniques. The aim of this study was to review the functional and radiographic results and complications of a new operative technique in a series of twenty-five patients.

Methods: Over a two-year period, we treated twenty-nine patients with a severely impacted valgus fracture of the proximal part of the humerus. Three patients were lost to follow-up and one died, leaving twenty-five patients who were available for the study. In all of the fractures, the head-shaft angle had been tilted into ≥160° of valgus and the greater tuberosity was displaced by >1 cm. All patients were treated with open reduction of the fracture, and the space created behind the humeral head was filled with Norian Skeletal Repair System (SRS) bone substitute. The fractures were stabilized with either screws or buttress plate fixation. Associated rotator cuff tears were repaired. All patients underwent functional outcome assessment with use of the Constant, DASH (Disabilities of the Arm, Shoulder and Hand), and SF-36 (Short Form-36) scores at one year, and twelve patients were followed for two years.

Results: All fractures united within the first year, all reductions were maintained, and no patient had signs of osteonecrosis of the humeral head on the latest follow-up radiographs. At one year, the median Constant score was 80 points and the median DASH score was 22 points. The functional results continued to be satisfactory in the twelve patients who were followed for two years. The results in our series were better than those achieved in studies of nonoperative treatment of similar fracture configurations. There were six clinically relevant complications, although none required a reoperation and all six patients had a satisfactory short-term functional outcome.

Conclusions: Internal fixation of severely impacted valgus fractures of the proximal part of the humerus, supplemented by Norian SRS bone substitute to fill the proximal humeral metaphyseal defect, produces good early functional and radiographic outcomes. Additional follow-up will be required to assess whether these initially satisfactory outcomes are maintained over the longer term.

Level of Evidence: Therapeutic study, Level IV (case series [no, or historical, control group]). See Instructions to Authors for a complete description of levels of evidence.

The impacted valgus fracture is a relatively uncommon but well-recognized subtype of proximal humeral fracture[1-3]. The injury is considered to have a favorable prognosis compared with that of other complex multipart proximal humeral fractures, and the risk of osteonecrosis is low because the medial capsular blood supply is preserved[4,5].

Treatment of the less severely displaced forms of this injury, both with nonoperative methods[6] and with minimally invasive internal fixation techniques[1-3], has been reported to yield satisfactory results. However, when the head fragment is severely impacted and rotated and there is more severe displacement of one or both of the tuberosities, the functional results of nonoperative treatment are suboptimal[6]. Minimally invasive techniques may also be less successful in the treatment of these more severe injuries because they fail to address concomitant tears of the rotator cuff. In addition, secondary displacement may occur, despite percutaneous fixation, as a result of instability caused by the metaphyseal defect created behind the humeral head after it is reduced[3].

We developed an operative technique to treat these more severely angulated fractures. It involves open repair of any coexisting rotator cuff tear, restoration of stability by filling the metaphyseal defect with a bone-graft substitute, and internal fixation of the fracture with screw or buttress plate-fixation techniques. The aim of this study was to review the functional and radiographic results and complications of this

Fig. 1-A

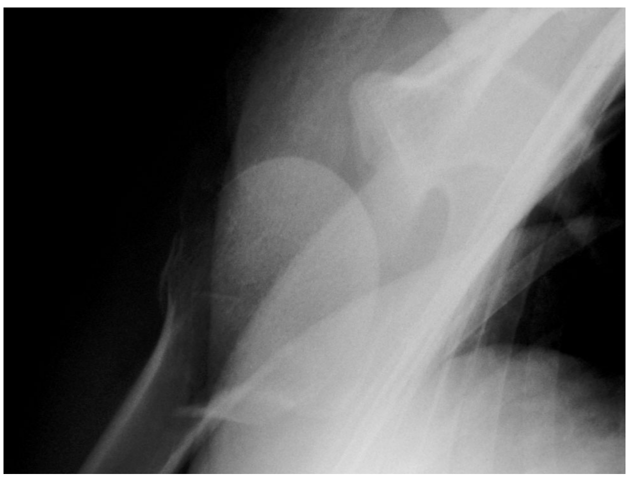

Fig. 1-B

Figs. 1-A and 1-B Anteroposterior and modified axial radiographs of a forty-three-year-old woman who sustained a proximal humeral fracture in 168° of valgus angulation, as a result of a fall from a horse. A tear in the rotator cuff was repaired anatomically with number-2 Ethibond sutures.

treatment in twenty-five patients who were followed prospectively for at least one year.

Materials and Methods

During a two-year period, we operatively treated a consecutive series of twenty-nine patients with a severely impacted valgus fracture of the proximal part of the humerus. To be considered eligible for the procedure, a patient had to be medically fit for anesthesia, younger than eighty-five years old, and mentally alert and orientated (with a mini-mental test score[7] of >8 of 10) and had to have a history of normal shoulder function prior to the injury. All patients had sustained an impacted valgus fracture in which the inclination angle (the angle between the intramedullary axis and the perpendicular to the articular surface margin) had been tilted into ≥160°[8,9]. All patients also had a fracture of the greater tuberosity that was displaced by >1 cm, and twenty of the twenty-five patients had a displaced fracture of the lesser tuberosity as well. Medically frail, demented, or uncooperative patients and those eighty-five years of age or older were treated nonoperatively. Three patients were lost to follow-up and could not be traced, and one patient died at six months after the injury, from unrelated causes, leaving twenty-five patients for follow-up evaluation.

There were six men and nineteen women, with an average age of 67.2 years (range, thirty-five to eighty-four years). Only two patients were less than fifty years of age, three patients were between fifty and fifty-nine, nine were between sixty and sixty-nine, eight were between seventy and seventy-nine, and three

Fig. 1-C

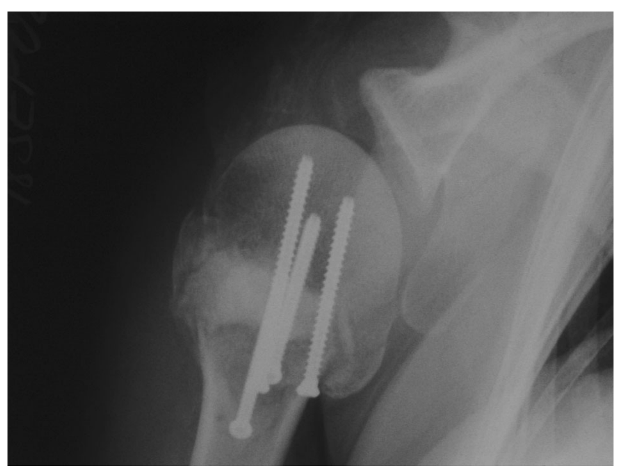

Fig. 1-D

Figs. 1-C and 1-D Following elevation of the humeral head, 7 mL of Norian SRS cement was used to fill the resulting metaphyseal defect. The fracture reduction was stabilized with four cancellous screws. At one year, the Constant score was 91 points and the DASH score was 16 points.

Fig. 2-A

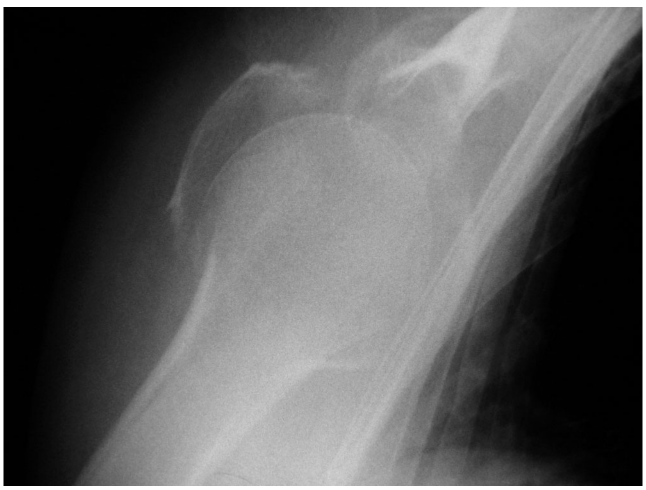

Fig. 2-B

Figs. 2-A and 2-B Anteroposterior and modified axial radiographs of an eighty-two-year-old woman who sustained a proximal humeral fracture in 205° of valgus angulation, as a result of a fall downstairs.

were between eighty and eighty-four. Twelve patients had been regularly employed prior to the injury: seven had a sedentary job, and five performed manual work. A simple fall (from a standing or lower height) was the cause of eighteen fractures, and the remainder were sustained in falls from heights of >2 m, including falls downstairs. Two patients had an initial anterior fracture-subluxation of the humeral head, and another two patients had an initial anterior fracture-dislocation of the humeral head. None of the patients had another substantial injury of the musculoskeletal or other systems. Three patients had a transient axillary nerve neurapraxia, which fully resolved during the first week after injury. There were no other clinically detectable neurovascular deficits preoperatively.

Operative Technique

All operative procedures were performed within seven days after the injury (average, three days; range, one to seven days). After induction of general anesthesia, the patient was positioned supine in the so-called beach-chair position, with a shoulder operating table "cut-away" to facilitate access for the image intensifier from the opposite side of the table. Routine antibiotic and antithrombotic prophylaxis was used. The superior subacromial approach[10] with a "bra-strap" skin incision was employed in all patients, as this provided the best access to

Fig. 2-C

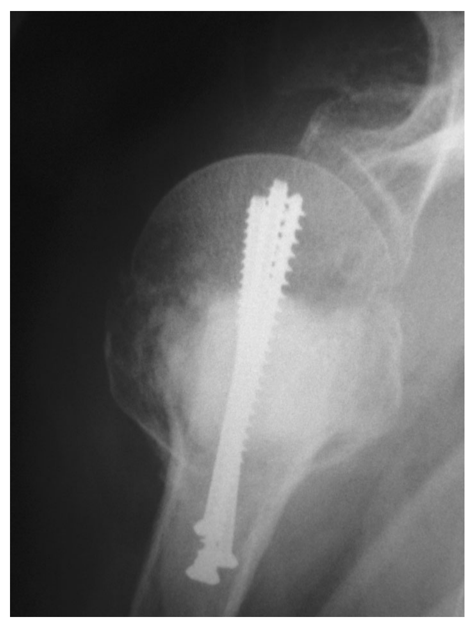

Fig. 2-D

Figs. 2-C and 2-D Following elevation of the humeral head, 10 mL of Norian SRS cement was used to fill the resulting metaphyseal defect. The fracture reduction was stabilized with three cancellous screws. At one year, the Constant score was 85 points and the DASH score was 23 points.

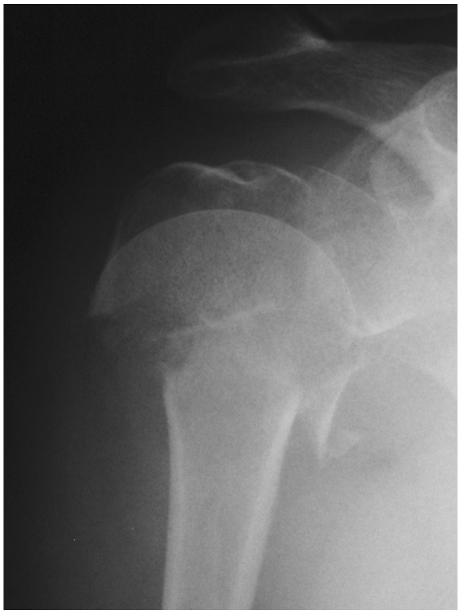
Fig. 3-A


Fig. 3-B

Figs. 3-A and 3-B Anteroposterior and modified axial radiographs of a sixty-three-year-old man who sustained a proximal humeral fracture in 175° of valgus angulation as a result of a simple fall.

the humeral head and tuberosities. A standard anterior acromioplasty was performed in all patients, to reduce the risk of later rotator cuff impingement. The split in the tuberosities was identified to allow access to the humeral head. This was usually readily apparent, as the humeral head was facing superiorly or superolaterally with the tuberosities splayed on either side of it. In all patients, the greater tuberosity was displaced by >1 cm; in five patients, the lesser tuberosity was displaced by <1 cm (the three-part fracture described by Neer[11,12]); and in twenty cases, both tuberosities were displaced by >1 cm (the four-part fracture described by Neer[11,12]).

Eleven patients had a substantial tear (>2.5 cm in length) in the rotator cuff, which propagated through the rotator interval and was repaired with number-2 nonabsorbable Ethibond sutures (Ethicon, Edinburgh, United Kingdom). The rotator cuff tears all occurred in association with a fracture in which the greater and lesser tuberosities were both displaced by >1 cm. Three or four number-5 nonabsorbable Ethibond interosseous sutures were initially inserted through each tuberosity as stay sutures. The humeral head was elevated and reduced with use of a blunt dissector, under image-intensifier control. The head was fixed temporarily with threaded Kirschner wires inserted through the proximal part of the humerus and into the head.

The metaphyseal cavity created behind the humeral head after the head was reduced was irrigated to clear it of blood and debris and then was filled with Norian Skeletal Repair System (SRS) bone substitute (Norian, Cupertino, California). As with ordinary bone cement, the material is injected in a semiliquid form, although the curing time is slower (fifteen minutes). A specially designed cement gun with a narrow cannula is used to deliver the cement to the deepest recesses of the cavity, after which it is gradually withdrawn to fill the more superficial areas in a retrograde fashion. Careful monitoring with an image-intensifier is required throughout the injection process to ensure that there is no extravasation of the cement into the soft tissues. An average of 8 mL (range, 5 to 10 mL) of SRS was injected. The greater and lesser tuberosities were sutured together by tying the interosseous stay sutures together to create a closed cavity behind the humeral head to contain the SRS during setting.

The fracture reduction was then stabilized by internal fixation with "positional screws," without any attempt at compression of the osteoporotic metaphyseal bone. In fourteen patients who had a single greater tuberosity fragment, stabilization was achieved with two, three, or four 3.5-mm partially threaded cannulated screws fixing the greater tuberosity to the humeral head and/or proximal humeral metaphysis (Figs. 1-A through 2-D). The remaining eleven patients had substantial comminution (more than two separate fragments) of the greater tuberosity, and fixation with screws alone was not possible. In these patients, a buttress plate and screws were used

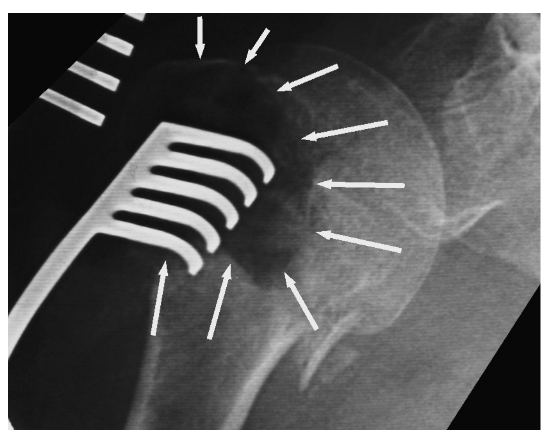
Fig. 3-C

Following elevation of the humeral head, 8 mL of cement was used to fill the resultant metaphyseal defect (arrows).

to maintain the reduction (Figs. 3-A through 3-E).

All patients wore a shoulder immobilizer sling with the shoulder in the so-called safe position (the shoulder held in internal rotation, neutral flexion, and neutral abduction, and the elbow flexed 90°) for six weeks after the operation. Active-assisted range-of-motion exercises were begun at two weeks after the operation, with avoidance of abduction of the shoulder beyond 90° or external rotation beyond the neutral position. Isometric rotator cuff exercises and graduated active range-of-motion exercises supervised by a physiotherapist were commenced after removal of the sling and were continued for at least six months after the operation.

Fig. 3-D

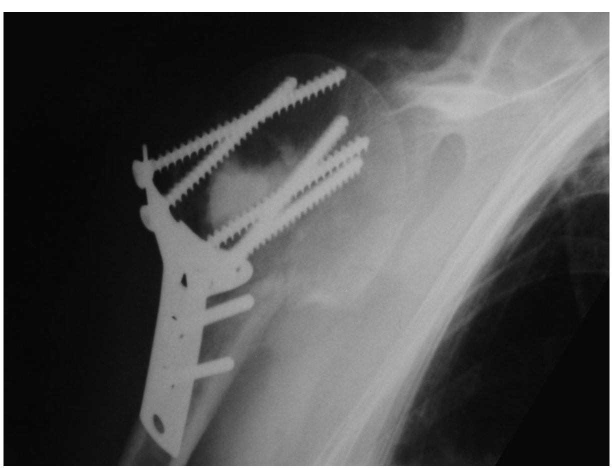

Fig. 3-E

Figs. 3-D and 3-E Because of excessive comminution of the greater tuberosity, the fracture was stabilized with a buttress plate and screws. At one year, the Constant score was 89 points and the DASH score was 21 points.

Outcome Assessment

The primary outcome measures for the study included the functional outcome at one year as assessed with three scoring systems, the prevalence of complications and side effects of the treatment protocol, and the radiographic outcomes. A subgroup of twelve individuals had been followed for two years, and the results in this group are also presented.

All patients were prospectively monitored for intraoperative and postoperative complications. The duration of the surgery, the type of implants that had been used, and the duration of the hospital stay were also recorded. Independent functional shoulder assessments were carried out at three months (twenty-four patients), six months (twenty-one patients), one year (twenty-five patients), and two years (twelve patients) with use of the score of Constant and Murley[13], the Disabilities of the Arm, Shoulder and Hand (DASH) limb-specific questionnaire[14] and the Short Form-36 (SF-36) general health status questionnaire[15,16]. The SF-36 scores were compared with those in an age and sex-matched population of healthy volunteers[16].

Some patients missed one or more follow-up appointments (Figs. 4 and 5), but all returned for the one-year follow-up visit, at which time we recorded the work status of the twelve patients who had been regularly employed prior to the injury.

Standardized anteroposterior and so-called modified axial[17] radiographs of the shoulder were made at presentation and at each of the follow-up appointments. We measured the head-shaft angle[8,9] postinjury, immediately after the operation (twenty-five patients), at three months (twenty-four patients), at six months (twenty-one patients), at one year (twenty-five patients), and at two years (twelve patients). We also measured the degree of residual displacement of the tuberosities in millimeters, adjusting for magnification artifact, and all radiographs were assessed for signs of osteonecrosis of the humeral head. In addition, we assessed whether the Norian SRS showed evidence of resorption by measuring the dimensions of the radiopaque cement on all postoperative radiographs. All radiographs were measured by the senior one of us and by a research assistant who was independent of the project. Intraobserver error (to within 2 mm) was assessed with use of the Cohen kappa statistic and found to be 0.95 and 0.89 for neck-shaft angle and tuberosity displacement, respectively. When there was a difference in the measurements between the two observers, the average value was used.

Assessment of fracture union proved difficult, as the nearly anatomic reduction and the presence of the radiopaque bone cement made it difficult to assess internal callus formation and none of the fractures produced external callus. We therefore arbitrarily defined a fracture to be united when the patient reported no shoulder pain or only mild activity-related discomfort and had no loss of the initial fracture reduction or evidence of implant loosening or breakage on the most recent radiographs.

Results

The average duration of the surgery was sixty-eight minutes (range, fifty to 120 minutes). There were no intraopera-

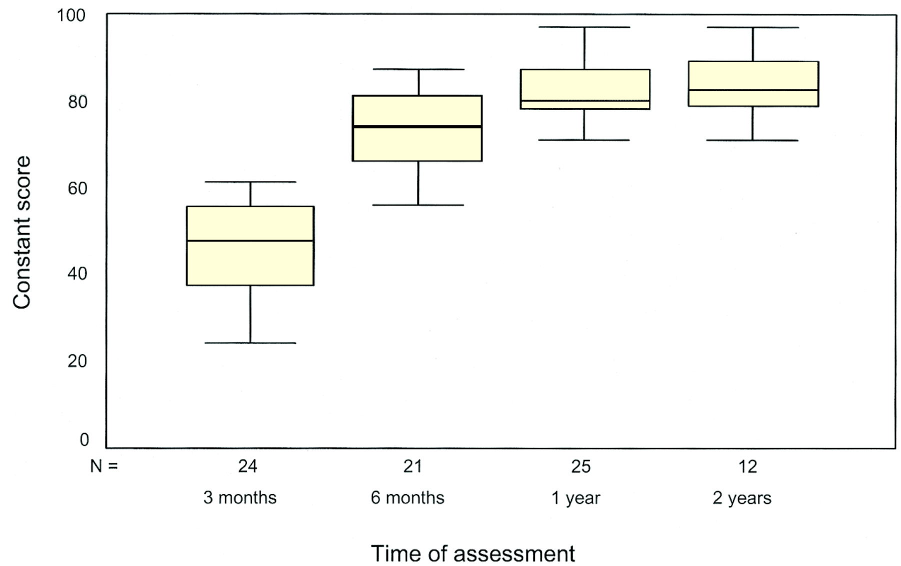

Fig. 4
Box-and-whisker plot of the change in the Constant score with time.

tive hypotensive episodes at the time of the injection of the bone substitute or other intraoperative complications.

Postoperatively, a superficial wound infection developed in two patients. Both infections resolved with a one-week course of oral broad-spectrum antibiotic therapy. There were no deep infections. No new neurological deficits developed after the surgery.

Symptoms of subacromial impingement developed in three patients between three and six months after surgery; all of these symptoms resolved following one subacromial injection of a corticosteroid and local anesthetic, and there were no recurrences of these symptoms at two years postoperatively. Substantial shoulder pain and stiffness, consistent with a diagnosis of adhesive capsulitis, developed in one patient. These symptoms were treated with an intensive course of physiotherapy, and they had resolved by the time of the one-year assessment.

The average duration of the hospital stay was two days (range, one to ten days). Patients who were sixty years of age or older had a significantly longer hospital stay than those who were younger than sixty (Mann-Whitney U test, $p < 0.05$). According to our definition of fracture union, all fractures had united by the time of the six-month follow-up assessment, except for the fracture in the patient with signs of adhesive capsulitis. Despite satisfactory radiographic evidence of healing (maintenance of reduction and no implant breakage), that patient was not free of shoulder pain until one year after the sur-

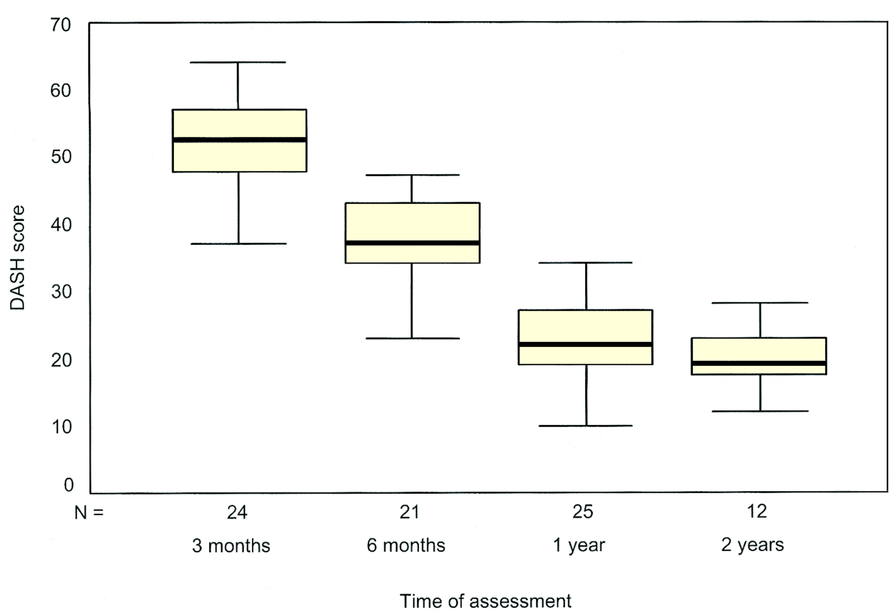

Fig. 5
Box-and-whisker plot of the change in the DASH score with time.

gery. There were no late postoperative complications, and no patient required implant removal.

Radiographic Outcome

The average head-neck inclination angle was 171° (range, 162° to 205°) preoperatively and 134° (range, 125° to 148°) postoperatively. No loss of reduction or failure of fixation was seen on follow-up radiographs. At the time of follow-up, twenty patients had <5 mm of displacement of the tuberosities, and the remaining five had between 5 and 10 mm of displacement of one or both tuberosities. No patient had signs of osteonecrosis on the one-year or two-year radiographs. There was no radiographic evidence of resorption of the bone cement within the first year; the cement appeared relatively inert, with no evidence of progressive lucencies at the bone-cement interface.

Functional Outcome

The median Constant and DASH scores for the group as a whole improved significantly between three months and six months (Wilcoxon matched-pairs test, $p < 0.001$, Figs. 4 and 5). However, with the numbers available, the scores did not improve significantly between six months and one year or between one year and two years (Wilcoxon matched-pairs test, Figs. 4 and 5). At one year, the median Constant score was 80 points (interquartile range, 78 to 87.5 points) and the median DASH score was 22 points (interquartile range, 19 to 27 points).

At one year, twenty-one patients reported no pain in the shoulder, three patients reported mild pain, and one patient reported moderate pain. The average forward flexion of the shoulder was 164° (range, 108° to 180°) and the average abduction was 159° (range, 104° to 180°). Twenty-two patients had regained full external rotation of the shoulder (with the shoulder in neutral flexion and abduction) compared with the range for the contralateral, uninjured shoulder; the other three patients had lost between 10° and 18° of external rotation. Nineteen patients had regained full internal rotation at the shoulder (with the shoulder in neutral flexion and abduction) compared with the range for the contralateral, uninjured shoulder; the remaining six patients had lost between 10° and 30° of internal rotation.

On linear regression analysis, only age was independently predictive of both the Constant and the DASH functional score at one year ($p < 0.05$); the results were poorer with advancing age, and the majority of the functional loss was attributable to loss of internal rotation of the shoulder. With the numbers available, there was no significant difference in outcome between dominant and nondominant injured shoulders. No patient had evidence of rotator cuff weakness or impingement or signs of glenohumeral joint instability on formal clinical testing at the latest follow-up assessment.

The SF-36 scores are presented in the Appendix. The role physical and physical functioning components were significantly lower than those for the age and sex-matched controls at three and six months ($p < 0.05$), but the scores for the six other subcategories were not significantly different at those times-points. None of the SF-36 scores in the eight subcategories were significantly different from the scores for the age and sex-matched controls at one or two years.

All seven patients who had been regularly employed preoperatively in a sedentary job returned to their full work duties by one year. Of the five patients who had been regularly employed in a manual job prior to the injury, three returned to their previous work duties. The remaining two patients, who were sixty-two and sixty-four years of age, had planned to retire from active employment within six months after the injury; neither of those patients had returned to work before their retirement.

Discussion

Most impacted valgus fractures of the proximal part of the humerus can be treated satisfactorily with nonoperative or minimally invasive, percutaneous fixation techniques[3,6]. However, when the impaction is severe, this fracture configuration becomes more difficult to treat adequately with those means. Court-Brown et al.[6] evaluated the results of nonoperative treatment of impacted valgus fractures, which they classified into four subtypes. At one year following nonoperative treatment, the patients with the most severely impacted valgus fractures had a mean Constant score of 65.6 points, which was lower than the scores in the three subgroups with less severe fractures, perhaps as a result of rotator cuff dysfunction or subacromial impingement caused by malunion of the tuberosities.

Minimally invasive techniques have been used to treat impacted valgus injuries with a wide range of severity[1-3]. However, authors of previous reports have not quantified the initial degree of valgus angulation or attempted to relate the functional results to the initial severity of the displacement of the key fracture fragments. It has been our experience that the more severely displaced fractures of this type are difficult to treat with percutaneous techniques, which do not allow assessment of the severity of any concomitant injury of the rotator cuff. The prevalence of fixation failure is also higher as a result of the instability produced by the severe metaphyseal comminution created behind the humeral head, which is apparent only after the head fragment has been reduced to its anatomical position. This more severe injury is analogous to the displaced extra-articular comminuted dorsally tilted distal radial fracture, in which metaphyseal comminution leads to a high risk of redisplacement following primary reduction[18,19].

The fractures in this series correspond with the more severely displaced fractures of the greater tuberosity and humeral neck in the series reported by Court-Brown et al.[6]. The demographic distribution in their study was similar to that in ours, and the humeral head was rotated into extreme valgus angulation in all of their patients. In addition, all of their patients had a concomitant displaced fracture of the greater tuberosity, the majority had a displaced fracture of the lesser tuberosity, and there was a high prevalence of concomitant tears of the rotator cuff. Metaphyseal bone deficiency due to the impaction of the humeral head in a valgus position was also severe, as evidenced by the size of the defect (average, 8 mL in our study) created behind the humeral head following its reduction.

To treat this difficult fracture, we developed a new technique, in which the rotator cuff lesion is repaired through an open surgical approach, followed by reduction and internal fixation of the fracture and filling of the metaphyseal bone defect with a bone substitute. Comparison of our results with those in historical controls reveals that, despite the severity of the initial injury pattern, our technique produced satisfactory functional results comparable with or superior to those achieved with nonoperative treatment[6] or with percutaneous fixation techniques[1-3]. The procedure was well tolerated by all patients, and the hospital stay was relatively short. The prevalence of complications was low, and all fractures united without evidence of osteonecrosis, although at the time of the review thirteen patients had not yet been followed for two years and were therefore still at risk for the development of this complication. As seen radiographically, the average head-neck inclination angle was restored to within the normal ranges reported in previous series[8,9]. Anatomic reduction or <5 mm of displacement of the tuberosities was achieved in the majority of patients, with only five patients having between 5 and 10 mm of displacement of one or both tuberosities.

It could be argued that it would have been more appropriate to have used autogenous bone graft instead of bone cement to fill the metaphyseal defect created behind the humeral head following its reduction. However, the use of bone cement has a number of advantages over the use of autograft: with the patient supine in the beach-chair position to facilitate image-intensifier access, the surgical approach to the preferred site of bone-graft harvest from the iliac crest is difficult and relatively large quantities of autograft would be required. Before bone cement became available, we harvested iliac crest autograft as a separate procedure, with the patient in the supine position, and then redraped to perform the shoulder surgery, adding approximately forty minutes to the total duration of the surgery. Also, harvesting of autograft from the iliac crest is associated with well-recognized morbidity[20,21], and bone cement has been shown to be more effective than bone graft in maintaining articular reduction in response to axial loads[22-25]. Finally, as this particular bone cement cures by means of a non-exothermic reaction, the risk of further damage to the already compromised blood supply to the humeral head is not increased.

There are theoretical concerns that the cement may act as an impediment to healing of these fractures. Assessing union of metaphyseal fractures is difficult, as production of external callus is often minimal, and in our study assessing the amount of endosteal callus produced was difficult as it was obscured by the radiopaque bone cement. However, according to our relatively stringent clinical criteria for assessing union, all fractures in this series healed. Furthermore, there were no implant failures or progressive lucencies to suggest nonunion.

Although the theoretical advantages of the use of bone cement to augment fixation of proximal humeral fractures have been described in an experimental model[26], we believe that this is the first clinical study to evaluate the clinical efficacy of this material in the treatment of proximal humeral fractures. The material has been successfully used in the treatment of metaphyseal bone defects following fractures of the wrist, calcaneus, and tibial plateau[27-30]. As in those sites, careful intraoperative technique is required to ensure adequate filling of the cavity, although the material appears to be relatively inert, with little tendency to resorb.

The main weakness of our study lies in the lack of a contemporaneous control group of patients treated either nonoperatively or with a minimally invasive technique, or treated with autogenous bone graft instead of cement, with whom to compare our results. However, our inclusion and exclusion criteria dictated that we were treating a relatively small subgroup of younger, active, and mentally alert patients with a more severe fracture configuration. We thought that it would have been unethical to randomize those patients to receive nonoperative treatment, and our previous experience had been that the use of percutaneous techniques for these fractures has a high failure rate due to secondary displacement. Objective comparison, in the form of a clinical trial, of the results of the use of bone-graft substitute with the results of conventional bone-grafting to fill the metaphyseal defect would be appropriate. However, there are a number of issues determining the relative efficacy of the two techniques, including autograft donor-site morbidity, relative costs, and speed of rehabilitation, which would be difficult to compare objectively in this type of study. The relative rarity of these fractures dictates that such a study would have to be carried out over a prolonged period or in the form of a large multicenter trial.

We believe that the treatment approach that we describe provides a good solution to a challenging problem. Longer follow-up of our patients is required to assess whether late osteonecrosis and/or degenerative joint disease develops within the glenohumeral joint, although the relatively high five and ten-year mortality rates in the population with proximal humeral fracture may dictate that many will not survive long enough for this to become clinically relevant.

Appendix

eA A graphic depiction of the SF-36 scores after surgery is available with the electronic versions of this article, on our web site at www.jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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