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The Functional Outcome of Operative Treatment of Ununited Fractures of the Humeral Diaphysis in Older Patients*

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Investigation performed at Massachusetts General Hospital, Boston

ABSTRACT: Twenty-two elderly patients (average age, seventy-two years) who had an atrophic, unstable, ununited fracture of the humeral diaphysis were managed with plate-and-screw fixation and application of an autogenous bone graft from the iliac crest. Fifteen of the patients had had at least one previous operation in an attempt to obtain union of the fracture. One patient had an active infection and two had a quiescent infection, all with *Staphylococcus epidermidis*. The average duration of nonunion before the patients were first seen by us was two years and four months (range, five months to sixteen years). Fifteen of the nonunions were synovial. In each patient, at least one modification of the standard technique of plate-and-screw fixation was needed as a result of osteopenia. In order to enhance fixation, the standard protocol incorporated the use of a long plate (with an average of eleven holes and an average length that was 76 percent of that of the bone), a plate with a blade (used in thirteen patients), and replacement of loose, 4.5-millimeter cortical-bone screws with 6.5-millimeter cancellous-bone screws (twelve patients). Spiked nuts (Schuhli nut; Synthes, Paoli, Pennsylvania) that lock the screws to the plate, creating a solid point of fixation analogous to a blade, were incorporated into the protocol when they became available (used in six patients). In five limbs, the nonunion was associated with an osseous defect that could not be addressed by shortening of the bone alone. Three of these limbs were stabilized with a bridge plate that had been contoured to stand away from the bone at the site of nonunion (so-called wave-plate osteosynthesis), and the remaining two limbs were stabilized with a combination of intramedullary and extramedullary plates. In one of these two limbs, the extramedullary plate was contoured (that is, a wave plate).

The fracture united in twenty (91 percent) of the

patients. There was no progressive loosening or breakage of a fixation device, even in two patients who had radiographs that were suggestive of an incomplete union. Five of the patients were followed for a limited duration (average, one year and six months) as a result of death or illness. They had two excellent results, two good results, and one poor result according to a modification of the rating system of Constant and Murley. The remaining seventeen patients, including the two who had a persistent nonunion, were followed for an average of three years and one month (range, two years to five years and ten months). They had significant improvements in all of the functional scores at the most recent follow-up evaluation: the average score according to the modified system of Constant and Murley increased from 9 to 72 points ($p < 0.001$), the average score according to the Enforced Social Dependency Scale decreased from 39 to 9 points ($p < 0.001$), and the average score based on the Disabilities of the Arm, Shoulder, and Hand Questionnaire decreased from 77 to 24 points ($p < 0.001$). According to the scores based on the Disabilities of the Arm, Shoulder, and Hand Questionnaire, nine of the seventeen patients who had been followed for more than two years had an excellent result, four had a good result, two had a fair result, and the two who had a persistent nonunion had a poor result. Complications included postoperative delirium, a stitch abscess, transient radial nerve palsy, a fracture distal to the plate, and the need for a blood transfusion, in one patient each. Two patients had a fibrous union. There were no major medical complications.

An unstable, united fracture of the humeral diaphysis can be extremely disabling and may threaten the ability of an elderly patient to function independently. Operative treatment can be very successful when the techniques of plate-and-screw fixation are modified to address osteopenia and relative or absolute loss of bone. Healing of the fracture substantially improves function and the degree of independence.

The belief is prevalent that, unlike ununited diaphyseal fractures in the lower extremity, which are disabling, nonunions in the upper extremity are often compatible with acceptable function, particularly in elderly patients

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FIG. 1-A

FIG. 1-B

FIG. 1-C

Figs. 1-A through 1-E: Case 7. Radiographs showing the sequence of events and treatment in a seventy-seven-year-old woman who sustained fractures of both humeral shafts in a fall. Both fractures were fixed with a plate and screws.

Fig. 1-A: Radiograph of the left humerus, showing that the bone quality was poor. Many of the screws had to be reinforced with bolts.

Fig. 1-B: Radiograph of the left humerus, made after the patient fell a second time, a fracture was sustained through the most distal screw-hole, and a second plate-and-screw procedure was performed; the initial fracture had not healed. The second operation was complicated by a deep infection with *Staphylococcus epidermidis*. We removed all of the implants, the wound was debrided, and the patient was managed with six weeks of parenteral antibiotic therapy.

Fig. 1-C: Radiograph made one year and four months after the original injury, showing a segmental nonunion of the humeral diaphysis and an osseous defect at the proximal site of nonunion.

who have decreased functional demands^{11,39,41}. This belief should be questioned because elderly individuals are often less capable of adapting to musculoskeletal dysfunction^{6,24,44}. Elderly patients depend on an intact musculoskeletal system to maintain function and independence in activities of daily living⁴⁴.

Improvements in the ability to obtain stable fixation in poor-quality, osteopenic bone^{10,18,20,22,30,37,40,43} have reinforced our policy of offering operative treatment to elderly patients who have an unstable, ununited fracture of the upper extremity that affects the quality of life. This investigation represents our efforts, with the use of objective scoring systems and patient-oriented outcome instruments, to quantify improvements in function and the degree of independence after operative treatment of ununited fractures of the humerus in older patients.

Materials and Methods

The criteria for inclusion in the present study were a mobile, unstable nonunion of the humeral diaphysis that had been present for at least five months after the initial injury, an age of sixty years or older, and osteopenia that would jeopardize standard plate-and-

screw fixation. Between December 1990 and June 1996, twenty-five patients met the criteria in the referral practice of one of us (J. B. J.). Twenty-two of these patients requested operative intervention.

The average age of the twenty-two patients was seventy-two years (range, sixty to eighty-five years). Eleven patients had one or more major comorbid diseases: six had coronary artery disease; three, congestive heart failure; four, diabetes mellitus; two, chronic obstructive pulmonary disease; two, peripheral vascular disease; and one each, end-stage renal disease, rheumatoid arthritis, Parkinson disease, senile dementia, cirrhosis, cerebrovascular disease, and breast cancer. Four patients were employed outside of the home at the time of the injury, and eighteen either were retired or were homemakers.

The initial fracture resulted from a fall from a standing height (eighteen patients), a motor-vehicle accident (three), or a fall from a roof (one). The right arm was involved in thirteen patients and the left arm, in nine. The dominant arm was involved in fifteen patients. The proximal third of the humeral diaphysis was affected in fourteen patients; the middle third, in five; the distal third, in two; and both the proximal and the middle third

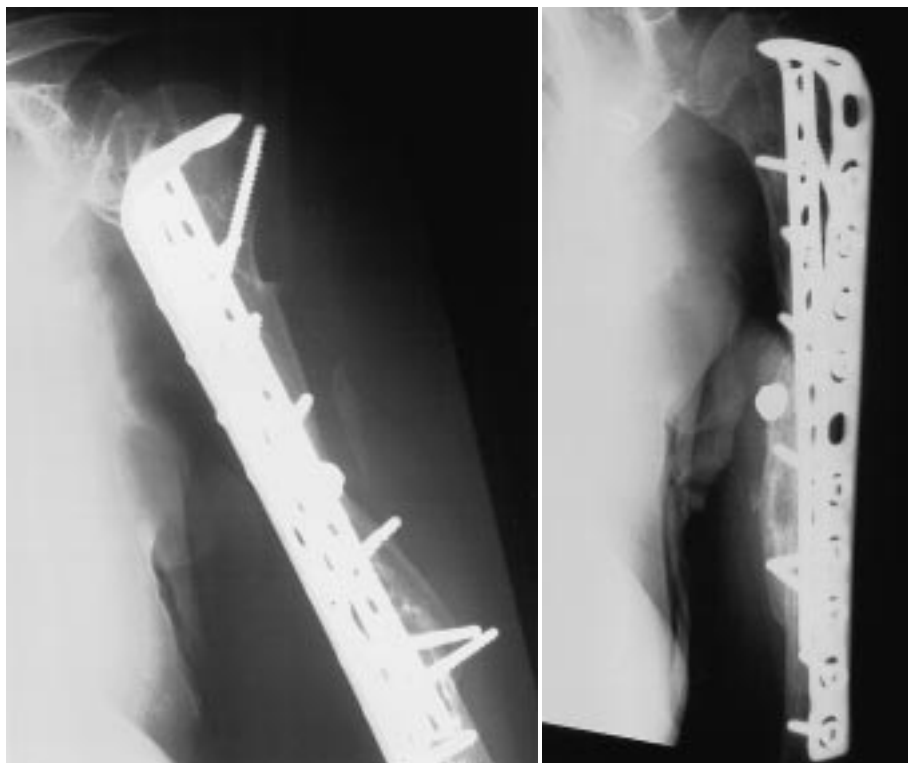


FIG. 1-D

FIG. 1-E

Fig. 1-D: Radiograph made two years and two months after autogenous cancellous bone-grafting and plate fixation, demonstrating healing of both fractures. A narrow, 4.5-millimeter limited-contact dynamic compression plate (Synthes) was modified into a blade-plate at its proximal extent, and a 3.5-millimeter dynamic compression plate was placed in the intramedullary space and was buttressed against the medial cortex by screws passing through the extramedullary plate. The plates spanned nearly the entire length of the humerus.

Fig. 1-E: Radiograph showing the 3.5-millimeter dynamic compression plate placed in the intramedullary space and buttressed against the medial cortex by screws passing through the extramedullary plate.

(a segmental fracture), in one. In one patient, the fracture occurred at the distal end of a shoulder prosthesis. The initial treatment was nonoperative for twelve patients: a hanging cast was used for five patients, a polypropylene brace was used for five, and a sling was used for two. In ten patients, the initial treatment was operative: plate-and-screw fixation was used in four patients, antegrade insertion of an intramedullary Rush rod was used in three, antegrade insertion of a locking intramedullary rod was used in two (with ancillary cerclage wiring in one), and a custom-made, extra-long stem was used to replace the humeral component of the total shoulder prosthesis in the patient who had a periprosthetic fracture.

Fifteen patients had one, two, or three operations after the initial treatment in an attempt to obtain union. The fixation device had either loosened or broken, or both, in all fifteen patients. At the time of the initial visit to our office, seven patients had an intramedullary device, six had a plate, and two had had the implant removed.

When first seen by us, one patient had an active infection and two had a quiescent infection, all with *Staphylococcus epidermidis*. The active infection was treated with serial débridement, temporary external fixation, and parenteral administration of antibiotics be-

fore definitive plate fixation. The patient who had had a fracture distal to the humeral component of a shoulder prosthesis had an infection after two subsequent operations: the first was a conversion of the humeral stem to a long-stem prosthesis that bridged the fracture site, and the second was the addition of bone graft obtained from the iliac crest. This patient came to our office after removal of the prosthesis and serial débridement with a resection arthroplasty of the shoulder and an antibiotic-impregnated polymethylmethacrylate spacer at the site of nonunion.

In each patient, the nonunion was unstable, had no sign of healing, and was defined as atrophic according to the criteria of Weber and Cech⁴⁹. In fifteen patients, the nonunion was defined as a synovial pseudarthrosis on the basis of the intraoperative finding of a fluid-filled, synovial-lined cavity at the site of nonunion. The average duration from the time of the injury to the index procedure was two years and four months (range, five months to sixteen years).

All twenty-two patients reported severe functional disability of the involved extremity due to pain and instability at the site of nonunion. At the time of the initial evaluation, most of the patients were wearing a sling or a brace, or both. Eight patients who had been advised by their surgeon that nothing additional could



FIG. 2-A



FIG. 2-B

Figs. 2-A through 2-E: Case 2. Radiographs and a photograph showing the sequence of events and treatment in a seventy-eight-year-old woman who fell and fractured the left, dominant humerus. Operative fixation with a plate and screws was complicated by a fracture at the distal limit of the plate.

Fig. 2-A: Radiograph showing the locking intramedullary rod that was inserted through the shoulder after removal of the plate and was fixed with cerclage wires at the site of the second fracture.

Fig. 2-B: Radiograph demonstrating that the fracture did not heal. The rod had been removed because of pain and dysfunction of the shoulder over the prominent proximal end of the rod.

be done to obtain an osseous union came to our office on their own.

Operative Technique

The operation was performed with the patient under general anesthesia and in the supine position. Twenty patients were managed with an anterolateral approach to the humerus, as described by Henry¹², extended proximally as needed into the deltopectoral interval. An extended lateral incision³² was used in one patient, and a medial incision was necessary in another patient to avoid the scarred previous lateral incision and sinus tract.

An attempt was made to limit dissection of the soft tissues to the area required for application of the plate and for débridement of the site of the synovial non-union. Every attempt was made to leave the periosteum in place. Circumferential reduction clamps were not used, and a distractor was employed to facilitate realignment of the bone segments²⁹. All inflammatory, fibrous, and synovial tissue and sclerotic and avascular bone were debrided. When the bone ends were sclerotic, the intramedullary canal of each fragment was opened with the use of a power drill. Autogenous cancellous bone graft obtained from the iliac crest was used in all of the patients.

The specific method of skeletal fixation was chosen on the basis of the previous operative procedure, the quality of the bone, and the presence of relative or absolute bone loss. The operative technique was based



FIG. 2-C

One year and three months after the initial injury, the patient had operative fixation with a 4.5-millimeter titanium blade-plate (Synthes) that had been designed for the proximal aspect of the humerus. The quality of the bone was very poor, and Schuhli nuts were used to enhance fixation of the screws. This clinical photograph, made fourteen days after the operation, shows that the patient was able to mobilize the involved extremity and touch the back of her head.

on the principle that every effort should be made to counteract the effects of osteopenia, either due to osteoporosis or secondary to the fracture, that would jeopardize the stability and rigidity of the plate-and-screw fixation. A long plate was used to increase the number of sites of fixation and to decrease the possibility of a fracture distal to the plate. The recommendation for the longer plate is based on the principle that an intramedullary rod should span the length of the humerus in order to enhance the stability of fixation and to decrease the risk of a fracture proximal and distal to the implant²³. We elected not to use an intramedullary rod because all of the patients had an atrophic or synovial nonunion and needed débridement and bone-grafting.

A broad, 4.5-millimeter dynamic compression plate was used in eight patients, six of whom were managed with a titanium limited-contact design (Synthes, Paoli, Pennsylvania). Six patients were managed with a narrow, 4.5-millimeter titanium limited-contact dynamic compression plate (Synthes), which had been modified into a blade-plate for five of them. A titanium blade-plate (Synthes) designed specifically for the proximal aspect of the humerus was used in eight patients. The plates had an average of eleven holes (range, nine to fourteen holes), and the average ratio of the length of the plate to the length of the entire bone was 76 percent (range, 55 to 90 percent). In one of the patients who had a nonunion of the distal aspect of the humerus, an additional eight-hole, 3.5-millimeter limited-contact dynamic compression plate (Synthes) was placed over the posterior surface of the humerus.

Another principle was to use, when necessary, a

blade-plate to enhance fixation (Figs. 1-A through 3-F). Of the thirteen patients in whom a blade-plate was used, nine had a nonunion in the proximal third of the humeral diaphysis (fourteen patients had a fracture at this level in the series as a whole); two, in the middle third of the diaphysis (five patients had a fracture at this level in the series as a whole); one, in the distal third of the diaphysis (two patients had a fracture at this level in the series as a whole); and one, in the proximal and middle thirds of the diaphysis. The blade acts as a broad, stable point of fixation in metaphyseal bone, which is not dependent on thread-bone purchase. Of the eight patients in whom a blade-plate designed specifically for internal fixation of the humerus was used¹⁸, one had insertion of the blade into the distal metaphysis and seven had insertion into the proximal metaphysis. In the five patients who had a modification of a narrow, 4.5-millimeter limited-contact dynamic compression plate, the proximal end of the plate was bent to a 90-degree angle and was impacted into the proximal humeral metaphysis.

The final principle was related to the enhancement of screw-bone purchase. It is necessary to be aware that the holding power of a screw is directly proportional to the density of the bone in which it is placed⁴⁶ and that, if the screw loosens, it will no longer stabilize the fracture²³. Initially, 4.5-millimeter cortical-bone screws that loosened immediately after insertion either were reinforced with polymethylmethacrylate^{35,42} (two patients) or were replaced with 6.5-millimeter cancellous-bone screws (twelve patients). In one of the first patients in the series, an allograft strut was placed on the me-



FIG. 2-D

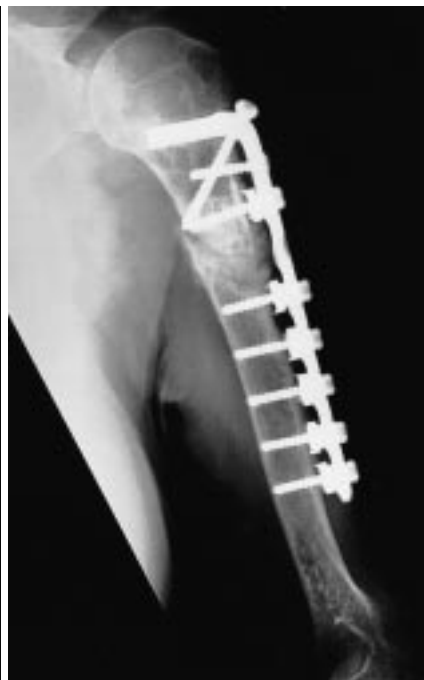


FIG. 2-E

Anteroposterior and lateral radiographs, made one year after the operation, demonstrating healing of the fracture.



FIG. 3-A

FIG. 3-B

FIG. 3-C

Figs. 3-A through 3-F: Case 11. Radiographs and clinical photographs showing the sequence of events and treatment in a sixty-eight-year-old woman who was seen eight months after a fall.

Fig. 3-A: Anteroposterior radiograph showing an ununited fracture of the proximal third of the humeral diaphysis of the right, dominant extremity.

Figs. 3-B and 3-C: Radiographs made two years and seven months after bone-grafting and fixation of the fracture with a long blade-plate, demonstrating healing of the fracture.

dial surface of the humerus to enhance fixation of the screws^{5,8,9}. However, this technique was later abandoned because of concerns regarding the extent of muscle elevation and the resulting devascularization of bone. When Schuhli nuts (Synthes) became available, we used them (in six patients) to enhance the stability of screw fixation in osteopenic bone^{20,22,23,30,31}. The Schuhli nut fits into a standard screw-hole from the underside of the plate. A standard screw inserted over a washer is then threaded into the Schuhli washer and is tightened so that the screw, washer, and Schuhli nut are attached rigidly to the plate, creating a rigid point of fixation analogous to the blade of a blade-plate. Screws that are fixed rigidly to the plate depend less on thread-bone purchase for stability²². Schuhli nuts have two-millimeter-long spikes on the undersurface that further enhance fixation of the screw-plate-nut construct in the bone. In addition, these spiked nuts increase the space between the plate and bone and further limit the area of bone that is covered by the internal fixation device, thereby increasing the area of contact between the vascularized soft tissues and bone^{20,30}.

After removal of loose hardware and débridement of avascular bone, five patients had an osseous defect that could not be corrected by skeletal shortening. The average length of the defect was three centimeters

(range, two to six centimeters). The osseous defect was treated with a bridge plate that was contoured to stand away from the bone at the site of the defect (so-called wave-plate osteosynthesis) in four patients^{2,3,35,37,38,50}. One of these patients as well as another patient had a combination of intramedullary and extramedullary plates^{10,29,30}. The latter technique enhances the stability of internal fixation by substituting an intramedullary plate for the absent cortex opposite the extramedullary plate. Some screws pass through the holes in both plates, whereas others serve to buttress the plate against the far cortex. Compared with standard plates, this construct may enhance the ability of the bone to resist a variety of forces that are present at the site of the segmental defect^{10,30}. A small-fragment (3.5-millimeter) dynamic compression plate, equal in length to an eight or fourteen-hole plate, was used in the intramedullary space in the two patients who were managed with this technique. Screw fixation was enhanced by the application of an intramedullary fibular allograft strut in one of the patients who had so-called wave-plate osteosynthesis.

Postoperative Management

After the operation, the extremity was placed in a sling, primarily for comfort, until the sutures were removed between ten and fourteen days after the proce-



FIG. 3-D

Clinical photograph showing the range of external rotation to be functional but decreased in comparison with that of the contralateral extremity.



FIG. 3-E

Clinical photograph showing that internal rotation was considerably restricted.

dure. The patients were then encouraged to actively mobilize the shoulder and elbow.

Evaluation of Preoperative and Postoperative Status

Two outcome instruments — the Enforced Social Dependency Scale¹ and the Disabilities of the Arm, Shoulder, and Hand Questionnaire¹⁵ — were used in an attempt to better define and quantify the disability associated with an unstable nonunion of the humeral diaphysis. A modification of the scale of Constant and Murley⁷ was used to evaluate the patients preoperatively and at the most recent follow-up visit. In addition, the patients were asked to rate their satisfaction with the outcome of the operative procedure on a scale of 0 to 10 points, with 0 representing total dissatisfaction and 10 representing extreme satisfaction.

Enforced Social Dependency Scale

The Enforced Social Dependency Scale is based on the results of a clinical trial of home nursing care for patients who had lung cancer²⁷. This scale was used to measure enforced social dependency, which is defined as the need for help from other people to perform activities and tasks that, under premorbid circum-

stances, the patients would have been able to perform independently¹⁷.

Enforced social dependency is essentially equivalent to functional status. It is a response to the current situation, not an inherent characteristic of the patient. There are two components in this scale. The first component, personal competence, is the ability to perform activities that are central to functioning as a normal adult; these include eating, dressing, bathing, toileting, walking, and traveling. The level of dependency in each activity is rated on a 6-point scale, with higher ratings reflecting greater dependency. The second component, social competence, is the ability to perform tasks related to a job, housework, and recreation. The level of dependency in each activity is rated on a 4-point scale. In addition, the coherence of the patient's responses is rated on a 3-point scale. Each item is assessed with the use of an interview-based questionnaire, which has been used most commonly to evaluate patients who have cancer or other medical illnesses^{38,51}.

According to the Enforced Social Dependency Scale, 10 points indicates no dependence on others and 54 points indicates complete dependence. In order to facilitate interpretation of this rating system, we standardized the score to fit on a scale of 0 to 100. With this scale, it is possible to stratify a wide variety of patients, ranging from those who require only a few minor modifications in their daily routine (such as changing the type of clothes that they wear in order to facilitate independent dressing) to those who are entirely dependent on others. The average preoperative score was 39 points (range, 25 to 48 points). These scores reflect the substantial dependence of our patients on the



FIG. 3-F

Clinical photograph showing that forward elevation was symmetrical with that of the contralateral extremity.

TABLE I
PREOPERATIVE DATA ON TWENTY-TWO ELDERLY PATIENTS WHO HAD
AN UNSTABLE, UNUNITED FRACTURE OF THE HUMERAL DIAPHYSIS

Case	Gender, Age (yrs.)	Involved Limb*	No. of Previous Ops.	Implant in Place at Initial Visit	Previous Infection	Location of Fracture	Interval from Injury to Index Op. (mos.)
1	F, 65	L	2	Intramedullary rod	—	Proximal third	34
2	F, 78	(L)	2	Intramedullary rod	—	Proximal third	15
3	M, 72	(R)	2	Rush rod	—	Middle third	18
4	F, 76	L	2	Intramedullary rod	—	Middle third	192
5	F, 60	(R)	1	Rush rod	—	Proximal third	11
6	F, 79	(L)	2	Plate	—	Distal third	5
7	F, 77	L	2	Plate	<i>S. epidermidis</i>	Segmental (proximal and middle thirds)	16
8	F, 84	(R)	2	Plate	<i>S. epidermidis</i>	Distal third	27
9	F, 80	(R)	1	Plate	—	Proximal third	29
10	F, 60	R	1	Plate	—	Proximal third	25
11	F, 68	(R)	0	—	—	Proximal third	8
12	F, 74	(R)	0	—	—	Proximal third	8
13	F, 70	L	0	—	—	Proximal third	36
14	F, 68	(R)	0	—	—	Proximal third	5
15	F, 71	L	0	—	—	Proximal third	6
16	F, 61	(R)	0	—	—	Middle third	12
17	F, 62	(R)	0	—	—	Proximal third	5
18	F, 72	(R)	2	—	—	Middle third	30
19	F, 70	(R)	1	Intramedullary rod	—	Proximal third	31
20	M, 72	L	1	Intramedullary rod	—	Proximal third	11
21	F, 85	(R)	1	Plate	—	Proximal third	36
22	F, 80	(L)	3	—	<i>S. epidermidis</i>	Middle third	58

*Parentheses indicate that the limb was dominant.

help of others for self-care activities, travel, and basic homemaking needs. Our patients had little difficulty with walking or communication.

Disabilities of the Arm, Shoulder, and Hand Questionnaire

The Disabilities of the Arm, Shoulder, and Hand Questionnaire was developed by the American Academy of Orthopaedic Surgeons (in collaboration with the Council of Musculoskeletal Specialty Societies and the Institute for Work and Health, Toronto, Ontario) as an outcome instrument specific to the upper extremity and applicable to a wide variety of problems. The current version of the questionnaire, which was not available to us at the time of the initial evaluation of our patients, includes twenty-one questions to evaluate difficulty with specific tasks, five questions to evaluate symptoms, and one question each to evaluate social function, work function, sleep, and confidence. We used the Disabilities of the Arm, Shoulder, and Hand Questionnaire to retrospectively determine the preoperative functional

level of the patients. We were well aware of the potential for bias when patients recall situations and its effect on the reliability and validity of the responses. In addition, the outcome measure itself, at the time of the initial publication in 1996, had yet to be field-tested to determine its reliability and validity. We believe that the accuracy of the responses increased with the severity of the disability because it is less likely for a patient who has severe difficulty or who is unable to perform a task to be inaccurate about the level of function. In spite of the limitations of this approach, useful information was obtained. At the time of the most recent follow-up, seventeen patients completed one copy of the Disabilities of the Arm, Shoulder, and Hand Questionnaire to describe their current status and another copy to describe their preoperative status. Questionnaire data were not available for four patients who had died and for one patient who had become severely demented.

All seventeen respondents noted severe difficulty with, or an inability to perform, nine selected activities before the index procedure; these included the ability to

place an object on a shelf above their head, perform strenuous household chores, perform tasks related to gardening or yard work, carry an object weighing more than ten pounds (4.5 kilograms), change a lightbulb overhead, wash or blow-dry their hair, wash their back, participate in recreational activities requiring some strength, and participate in recreational activities requiring repetitive motion. Twelve of the seventeen respondents noted severe difficulty with, or an inability to perform, seven other activities: opening a new jar or one with a tight lid, preparing a meal, pushing open a heavy door, making a bed, carrying a shopping bag or briefcase, putting on a pullover sweater, and participating in light recreational activities. Eight of the eleven patients who had involvement of the dominant extremity had severe difficulty with, or were incapable of, writing, turning a key, or using a knife to cut food. All seventeen patients had moderate-to-severe pain that was fairly constant, and all had severe or extreme pain with specific activities. Eight patients had severe difficulty sleeping, and four had moderate difficulty. All seventeen patients felt less capable, confident, or useful during the period that the humerus remained ununited. The average preoperative score based on these questionnaires was 77 points (range, 53 to 94 points) on a scale in which 0 points indicates no disability and 100 points indicates extreme disability.

Modified Scale of Constant and Murley⁷

The patients were evaluated preoperatively and at the most recent follow-up visit with the use of a modification of the scale of Constant and Murley⁷. With this method, the maximum score is 100 points: 15 points for pain, 20 points for activities of daily living, 40 points for range of motion, and 25 points for power. The patients subjectively graded pain as severe (0 points), moderate (5 points), mild (10 points), or none (15 points). They also graded their ability to perform all of their desired activities (work and recreational) and to sleep (maximum score, 10 points) and their ability to position the hand to perform various activities (maximum score, 10 points).

The patients were asked to demonstrate the ability to bring the hand to the waist, to the xiphoid, to the neck, to the top of the head, and above the head. Forward elevation and lateral elevation, as measured with a goniometer, were given a maximum of 10 points each. Internal rotation and external rotation were also given a maximum of 10 points each, on the basis of the patients' ability to perform composite movements. Rotation is usually combined with forward elevation and abduction to perform activities of daily living. We measured the strength of the involved upper extremity by comparing it with that of the contralateral upper extremity rather than using the method of Moseley³⁴, which involves a spring balance. We placed the shoulder in 90 degrees of abduction (or the maximum abduction

possible) and compared the degree of isometric resistance to forced adduction with that of the contralateral extremity. The strength of the involved limb was expressed as a percentage of that of the uninvolved limb, and the point value for strength was determined by dividing the percentage by four. The average preoperative score according to the modified scale of Constant and Murley was 8 points (range, 0 to 27 points) of a possible 100 points.

Radiographic Evaluation

Biplanar radiographs made at the time of the most recent follow-up evaluation were assessed to determine the presence of bridging osseous trabeculae, which is suggestive of healing, as well as any loosening or failure of the fixation.

Rating of Results

The objective result was assigned a discrete rating according to the modified scoring system of Constant and Murley. Between 80 and 100 points was considered excellent; between 60 and 79 points, good; between 40 and 59 points, fair; and between 0 and 39 points, poor. The subjective result was assigned a discrete rating according to the score derived from the Disabilities of the Arm, Shoulder, and Hand Questionnaire. Between 0 and 20 points was considered excellent; between 21 and 40 points, good; between 41 and 60 points, fair; and between 61 and 100 points, poor.

Statistical Analysis

The significance of differences between the preoperative and postoperative scores, according to the modified rating system of Constant and Murley, the Enforced Social Dependency Scale, and the Disabilities of the Arm, Shoulder, and Hand Questionnaire, was evaluated with a paired t test as performed with Microsoft Excel (Redmond, Washington). Linear correlation of the postoperative scores, according to the Disabilities of the Arm, Shoulder, and Hand Questionnaire and the modified scoring system of Constant and Murley, was also assessed with Microsoft Excel.

Results

Twenty of the twenty-two fractures united within six months of the index operation. In two patients, a fracture line was still visible on the radiographs; however, there was no evidence of progressive loosening of the plate or the screws at the time of the most recent follow-up evaluation (two years and seven months for one and three years and four months for the other). One of the two patients was a seventy-six-year-old woman who had had the nonunion for sixteen years before the index procedure. Two attempts at stabilizing the fracture with the use of an intramedullary rod had been unsuccessful. The patient had a loose implant, a four-centimeter-long absolute osseous defect, and nine cen-

TABLE
PREOPERATIVE AND POSTOPERATIVE DATA ON TWENTY-TWO ELDERLY PATIENTS

Case	Type of Plate	Blade-Plate	Schuhli Nuts	6.5-mm Cancellous-Bone Screws	Other	Duration of Follow-up (mos)
1	Blade-plate*	+	-	+	—	40
2	Blade-plate*	+	+	-	—	24
3	Narrow, 4.5-mm limited-contact dynamic compression plate	+	+	-	Wave plate	36
4	Broad, 4.5-mm limited-contact dynamic compression plate	-	-	+	Wave plate	31
5	Broad, 4.5-mm limited-contact dynamic compression plate	-	-	+	—	66
6	Blade-plate*	+	-	+	Second, 3.5-mm plate	30
7	Narrow, 4.5-mm limited-contact dynamic compression plate	+	-	-	Intramedullary plate	32
8	Broad, 4.5-mm limited-contact dynamic compression plate	-	-	-	—	40
9	Narrow, 4.5-mm limited-contact dynamic compression plate	+	+	-	Fibular allograft; wave plate	24
10	Broad, 4.5-mm limited-contact dynamic compression plate	-	-	+	Cortical strut allograft	50
11	Blade-plate*	+	-	-	—	33
12	Blade-plate*	+	-	+	—	36
13	Blade-plate*	+	-	+	—	70
14	Narrow, 4.5-mm limited-contact dynamic compression plate	+	+	-	—	24
15	Narrow, 4.5-mm limited-contact dynamic compression plate	+	+	-	—	24
16	Broad, 4.5-mm limited-contact dynamic compression plate	-	-	+	—	33
17	Broad, 4.5-mm limited-contact dynamic compression plate	-	-	-	—	36
18	Blade-plate*	+	-	+	Cement	Died
19	Blade-plate*	+	-	-	—	Dementia
20	Broad, 4.5-mm dynamic compression plate	-	-	+	—	Died
21	Broad, 4.5-mm dynamic compression plate	-	-	+	Cement	Died
22	Narrow, 4.5-mm limited-contact dynamic compression plate	-	+	+	Intramedullary plate; wave plate	Died

*A titanium blade-plate designed specifically for the proximal aspect of the humerus.

timeters of relative bone loss. Fixation with a bridge plate that extended over 90 percent of the length of the humerus and that had been contoured to stand away from the bone at the site of nonunion (so-called wave-plate osteosynthesis), together with an autogenous cancellous bone graft, led to substantial formation of bone. Six months after the procedure, there was radiographic evidence of lucency around some of the screws. At the most recent follow-up evaluation, there were no signs of breakage of the implant but a fracture line was still visible on radiographs. The second patient who had an incomplete union was an eighty-four-year-old woman who had had two previous operations. At the time of the initial evaluation, she had an infection at the site

of nonunion in the distal third of the diaphysis; it had been present for two years and three months. Three years and four months after the index procedure, the fixation devices had not loosened or broken but the fracture line remained visible on radiographs.

Five patients were followed for a limited duration (average, one year and six months; range, one year to one year and eleven months). Four of the five patients died, at an average of two years and eight months (range, one year and six months to three years and four months) after the procedure. The fifth patient had severe worsening of dementia, was unable to care for herself, and moved to a skilled nursing facility two years and six months after the procedure. In all five patients,

II

WHO HAD AN UNSTABLE, UNUNITED FRACTURE OF THE HUMERAL DIAPHYSIS

Modified Scoring System of Constant and Murley ⁷		Enforced Social Dependency Scale ¹		Disabilities of the Arm, Shoulder, and Hand Questionnaire ¹⁵		Complications
Preop.	Postop.	Preop.	Postop.	Preop.	Postop.	
6	95	48	0	80	4	
4	74	45	5	94	30	
16	89	34	2	74	17	
12	46	39	23	82	62	Fibrous union
4	91	34	0	66	2	Stitch abscess
2	53	41	23	80	55	Transient radial nerve palsy
0	66	48	18	76	32	Blood transfusion
4	34	48	36	91	78	Fibrous union
18	95	43	0	81	2	
15	67	34	11	73	25	
13	72	32	0	83	2	
18	77	32	2	66	2	
0	49	39	25	78	53	Fracture distal to plate (cast-brace)
6	64	45	9	78	22	
27	82	25	0	53	7	
4	81	32	2	72	7	
6	93	48	0	81	1	
0	62	—	—	—	—	
21	91	—	—	—	—	Postoperative delirium
4	88	—	—	—	—	
0	67	—	—	—	—	
0	37	—	—	—	—	

the nonunion healed and there was no evidence of loosening of the fixation devices. The average postoperative score according to the modified rating system of Constant and Murley was 69 points (range, 37 to 91 points) for these five patients. The average preoperative score had been 0 points for three of these patients, 4 points for one, and 21 points for one. The discrete rating according to the modified system of Constant and Murley was excellent for two patients, good for two, and poor for one. The poor result was for the patient who had had a resection arthroplasty of the glenohumeral joint after removal of a total shoulder prosthesis because of infection.

The remaining seventeen patients were followed for an average of three years and one month (range, two

years to five years and ten months). The average score according to the modified rating system of Constant and Murley increased from 9 points (range, 0 to 27 points) preoperatively to 72 points (range, 34 to 95 points) at the time of the most recent follow-up ($p < 0.001$). The average standardized score according to the Enforced Social Dependency Scale decreased from 39 points (range, 25 to 48 points) preoperatively to 9 points (range, 0 to 36 points) at the time of the most recent follow-up ($p < 0.001$). The average score with use of the Disabilities of the Arm, Shoulder, and Hand Questionnaire decreased from 77 points (range, 53 to 91 points) preoperatively to 24 points (range, 1 to 78 points) at the time of the most recent follow-up ($p < 0.001$). (It is necessary to keep in mind the limitations of preopera-

tive scoring with that questionnaire, which relies on retrospective assessment of the preoperative status.) There was a very strong linear correlation between the postoperative scores according to the modified rating system of Constant and Murley and those according to the Disabilities of the Arm, Shoulder, and Hand Questionnaire at the time of the most recent follow-up ($r^2 = 0.869$, $p < 0.001$).

The discrete ratings according to the Disabilities of the Arm, Shoulder, and Hand Questionnaire were excellent for nine of the seventeen patients, good for four, fair for two, and poor for the two who had a persistent nonunion. The discrete ratings according to the modified system of Constant and Murley were excellent for nine of the twenty-two patients, good for eight, fair for three, and poor for two. These discrete ratings reflected the high correlation between the two scales. The average score for the twenty-two patients according to the modified Constant and Murley rating system was 72 points (range, 34 to 95 points) postoperatively compared with 8 points (range, 0 to 27 points) preoperatively.

Complications included postoperative delirium, the need for a postoperative blood transfusion, and a stitch abscess in one patient each. Two patients had a fibrous union. There were no deep infections or breakage of the hardware. One patient had transient radial nerve palsy but had complete recovery in six weeks. Another patient fell out of bed six weeks after the index procedure and sustained a minimally displaced spiral fracture of the supracondylar region distal to the plate. The fracture healed after it was treated with a functional brace.

Discussion

Management of an older patient who has an ununited fracture of the upper extremity is challenging because of the hazards posed by osteopenic bone and the potential for medical complications due to associated comorbidities. The possible risks and problems of operative intervention in this population may dampen interest in operative treatment. Alternative treatment, such as support of the limb in a functional brace, is often considered^{19,39-41}. It is a viable option for hypertrophic or fibrous nonunions that are relatively stable, but it is less likely to have a satisfactory result when a patient has a painful, unstable, atrophic, or synovial nonunion. The patients in the present series had a painful, unstable, and nearly functionally useless upper extremity. The extremity was typically maintained in a dependent position against the trunk, often in a sling or brace, or both. The disability that ensues from such a position, particularly if the dominant extremity is involved, is considerable. Simple activities of daily living, such as eating, bathing, and dressing, were very difficult for these patients. This difficulty was retrospectively reflected by the relatively high preoperative score according to the Enforced Social Dependency Scale and by the extreme difficulty

that patients had performing many functional tasks as documented with the Disabilities of the Arm, Shoulder, and Hand Questionnaire. Elderly patients seem to be less capable of adapting to musculoskeletal disabilities and may become dependent on others for the accomplishment of simple daily activities^{6,24,44}.

If it is assumed that obtaining union of these ununited humeri to alleviate the accompanying disability is beneficial, Rosen's question regarding whether fixation is feasible⁴⁰ must be answered. The challenge of providing stable fixation in the presence of substantial osteopenia is formidable. The osteopenia in our patients not only was the result of advanced age and postmenopausal changes but also reflected the rapid loss of bone associated with disuse after an injury^{14,16,26,28,48}. Factors that contribute to the decrease in bone density in an injured extremity have been postulated to include immobilization, diminished muscle tone, impaired function of the limb, and limitation of weight-bearing. In addition, bone loss is more severe and bone density is less readily recovered in elderly patients¹⁶. A direct linear correlation has been demonstrated between the density of bone and the security of screw fixation ($r = 0.89$ or more)⁴⁶.

A wide array of techniques have been recommended for enhancing plate-and-screw fixation in osteopenic bone^{4,8,9,13,18,21,25,33,40,43,47}, and new techniques continue to evolve^{10,18,20,29,30}. The index procedure was based on basic principles of fixation of osteopenic bone. These principles merit emphasis.

First, a long plate should be used. Biomechanical studies have demonstrated that the strength of fixation is enhanced more by the length of the plate, which affects the spacing of the screws, than by the number of screws⁴⁵. The plate for a mid-diaphyseal fracture should extend nearly the entire length of the bone (from one metaphysis to the other). Extensile exposure of nearly the entire humerus can be accomplished through the direct lateral³², the anterolateral¹², or the medial¹⁸ approach without substantial risk to muscle or neurovascular structures.

Second, a blade-plate is useful for providing secure fixation of the osteopenic, primarily metaphyseal bone of a smaller articular fragment^{4,9,18,21,25,33,40,43}. The broad, fixed-angle blade gains a more predictable hold than standard screws in osteopenic metaphyseal bone.

Third, if a standard 4.5-millimeter cortical-bone screw loosens, insertion of a 6.5-millimeter cancellous-bone screw into the track can be attempted. An alternative is to fill the screw-hole with polymethylmethacrylate, with care taken to limit extrusion of the cement, particularly near the fracture site. The screw is then placed into the hole. When the cement is nearly hard, a final one-half turn is applied^{35,39}.

Finally, a better alternative may be to anticipate that standard screws will not function adequately and to use Schuhli nuts to transform each screw into a fixed-angle

device that will not lose its function if the screw-threads loosen in the bone because of osteopenia^{20,22,30}.

The use of these principles, techniques, and implants led to a high rate of union in the patients in the present series. The skeletal fixation was sufficiently secure to prevent progressive loosening or breakage of the implants, even in the two patients who did not have radiographic evidence of union. It is the functional results,

however, that are most striking. The disability associated with an ununited fracture of the humeral diaphysis can be substantial and, particularly in an elderly patient, should be a major factor in the decision-making process regarding management. Dramatic functional gains were the rule, and even the patients who had a fair or poor overall result were very satisfied with the outcome of the procedure.

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