# Transosseous Suture Fixation of Proximal Humeral Fractures

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# Transosseous Suture Fixation of Proximal Humeral Fractures

By Panayiotis Dimakopoulos, MD, Andreas Panagopoulos, MD, PhD, and Georgios Kasimatis, MD

*Investigation performed at the Shoulder and Elbow Unit, Orthopaedic Department, Patras University Hospital, Patras, Greece*

**Background:** The optimal treatment of displaced fractures of the proximal part of the humerus remains controversial. We evaluated the long-term functional and radiographic results of transosseous suture fixation in a series of selected displaced fractures of the proximal part of the humerus.

**Methods:** Over an eleven-year period, a consecutive series of 188 patients with a specifically defined displaced fracture of the proximal part of the humerus underwent open reduction and internal fixation with transosseous sutures. Twenty patients were lost to follow-up and three died before the time of follow-up, leaving a cohort of 165 patients (ninety-four women and seventy-one men; mean age, fifty-four years) available for the study. Forty-five (27%) of the injuries were four-part fractures with valgus impaction; sixty-four (39%) were three-part fractures; and fifty-six (34%) were two-part fractures of the greater tuberosity, thirty-six (64%) of which were associated with anterior dislocation of the shoulder. All fractures were fixed with transosseous, nonabsorbable, number-5 Ethibond sutures. Associated rotator cuff tears detected in fifty-seven patients (35%) were also repaired. Over a mean follow-up period of 5.4 years, functional outcome was assessed with the Constant score. Follow-up radiographs were assessed for fracture consolidation, malunion, nonunion, heterotopic ossification, and signs of impingement, humeral head osteonecrosis, and degenerative osteoarthritis.

**Results:** All fractures, except for two three-part fractures of the greater tuberosity, united within four months. The quality of fracture reduction as seen on the first postoperative radiograph was regarded as excellent/very good in 155 patients (94%), good in seven (4%), and poor in three (2%). Malunion was present in nine patients (5%) at the time of the last follow-up; six of the nine had had good or poor initial reduction and three, excellent/very good reduction. Humeral head osteonecrosis was seen in eleven (7%) of the 165 patients; four demonstrated total and seven, partial collapse. Fifteen patients had heterotopic ossification, but none had functional impairment. Four patients had signs of impingement syndrome, and two had arthritis. At the time of the final evaluation, the mean Constant score was 91 points, and the mean Constant score as a percentage of the score for the unaffected shoulder, unadjusted for age and gender, was 94%.

**Conclusions:** The clinical and radiographic results of this transosseous suture technique were found to be satisfactory at an average of 5.4 years postoperatively. Advantages of this technique include less surgical soft-tissue dissection, a low rate of humeral head osteonecrosis, fixation sufficient to allow early passive joint motion, and the avoidance of bulky and expensive implants.

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

The management of displaced proximal humeral fractures is challenging and often reflects the personal experience of the physician treating the injury. Regardless of the treatment protocol that is employed, these fractures pose difficulties in terms of restoring humeral alignment, joint surface congruity, and rotator cuff function while maintaining humeral head vascularity.

Treatment options include nonoperative methods, open

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reduction and internal fixation, and hemiarthroplasty. However, each is associated with a high risk of complications. Nonoperative treatment is preferable for minimally displaced or impacted fractures, but the results may be poor as the fracture fragments can become displaced[1,2]. Hemiarthroplasty is most often considered for four-part fractures, fractures in which the head is split, or fracture-dislocations[3,4]. In most series, the outcomes of hemiarthroplasty have been unpredictable and at times disappointing[5,6]. Open reduction and internal fixation with standard or modified plates can provide favorable results[7-9]. However, hardware failure, infection, and osteonecrosis are risks, especially when the fracture is comminuted or associated with severely osteopenic bone[10]. Current trends in the operative treatment of proximal humeral fractures have been toward less invasive techniques of reconstruction, with limited soft-tissue dissection and minimal amounts of hardware to achieve stable internal fixation[11-18]. Lately, low-profile locking plates and intramedullary nails have been introduced, with promising early results[19-21].

Over the last fourteen years at our institution, we have used transosseous suture fixation for a large number of displaced proximal humeral fractures. Predominantly, these injuries have been four-part valgus impacted fractures, three-part fractures, and two-part fractures of the greater tuberosity with or without associated dislocation of the humeral head. The purpose of this study was to present the radiographic and clinical outcomes in a series of 165 consecutive patients who had been treated with this technique at our institution.

## Materials and Methods

Between 1993 and 2003, 443 patients with an acute, displaced fracture of the proximal part of the humerus were treated surgically in the Shoulder and Elbow Unit at Patras University Hospital, Greece. The indication for transosseous fixation was an isolated, displaced two-part fracture of the greater tuberosity with or without anterior dislocation of the humeral head, a three-part fracture, or a four-part valgus impacted fracture.

The contraindications for suture fixation included a two-part fracture of the surgical neck, a displaced four-part fracture (>7 mm of translation or an impaction angle of >45°), and a fracture associated with a dislocation of the humeral head or a head-splitting component.

One hundred and eighty-eight patients met these criteria and were treated with transosseous fixation with nonabsorbable number-5 Ethibond sutures (Ethicon, Edinburgh, United Kingdom). Of the remaining 255 patients, eighty-four had a displaced two-part surgical neck fracture, which was treated with plate-and-screw osteosynthesis, and 171 had a displaced four-part fracture, a three or four-part fracture-dislocation, or a head-splitting fracture. One hundred and thirty-six of those 171 patients underwent primary shoulder hemiarthroplasty and thirty-five young patients (an age of less than thirty-nine years) underwent transosseous suture fixation (a so-called head-preserving subgroup) to avoid the consequences of a primary hemiarthroplasty. Those thirty-five patients, however, were not included in this study.

Of the 188 patients who met the criteria for transosseous suture fixation, twenty were not evaluated because of inadequate follow-up and three died of unrelated causes before the time of follow-up. Thus, 165 patients were available for assessment. Ninety-four of the patients were women, and seventy-one were men. The mean age was fifty-four years (range, eighteen to seventy-five years). All fractures were classified according to the four-segment classification system of Neer[1]. Forty-five (27%) of the injuries were four-part valgus impacted fractures; sixty-four (39%) were three-part fractures; and fifty-six (34%) were isolated fractures of the greater tuberosity, thirty-six (64%) of which were associated with anterior dislocation of the shoulder.

Ninety-eight patients (59%) sustained the fracture as a result of a fall from a standing or low height. The remainder sustained a high-energy injury: forty-five were injured in a motor-vehicle accident; eight, in a fall from a height of >2 m; and fourteen, in a sports-related accident. One hundred (61%) of the fractures occurred in the dominant arm.

Five patients had a clinically detectable neurological deficit preoperatively. It was attributed to a brachial plexus injury in two of these patients, to an axillary nerve paresis in two others, and to an isolated radial nerve deficiency in one. Eighty (48%) of the patients had been regularly employed prior to the injury: thirty-five had had a sedentary job, and forty-five had performed manual work.

A standard radiographic trauma series of the shoulder (an anteroposterior radiograph in the scapular plane as well as lateral and axillary radiographs) was made for all patients as soon as there was clinical suspicion of a fracture. In order to reduce discomfort, the axillary radiograph was usually made with the patient in a supine position, under the supervision of the attending physician. Additional radiographic views (anteroposterior in external rotation or in internal rotation with 15° of cephalic tilt) and computed tomography scans were made for forty of the 165 patients for further evaluation of the degree of fracture displacement.

### *Surgical Technique*

One hundred and fifty-five (94%) of the operations were performed within five days after the injury; the remaining ten patients, who had been referred from other hospitals, underwent surgery within three weeks after the injury. The original technique was developed by the senior author (P.D.), who performed or supervised 145 of the 165 procedures.

After induction of general anesthesia, the patient was placed in the beach-chair position with at least 60° of flexion at the waist. Two folded sheets were placed behind the scapula to bring the shoulder girdle forward, facilitating access to the glenohumeral joint. A second-generation cephalosporin was administered preoperatively and for the first postoperative day. The entire upper extremity was prepared and draped in a manner that allowed full and unrestricted arm positioning during the procedure.

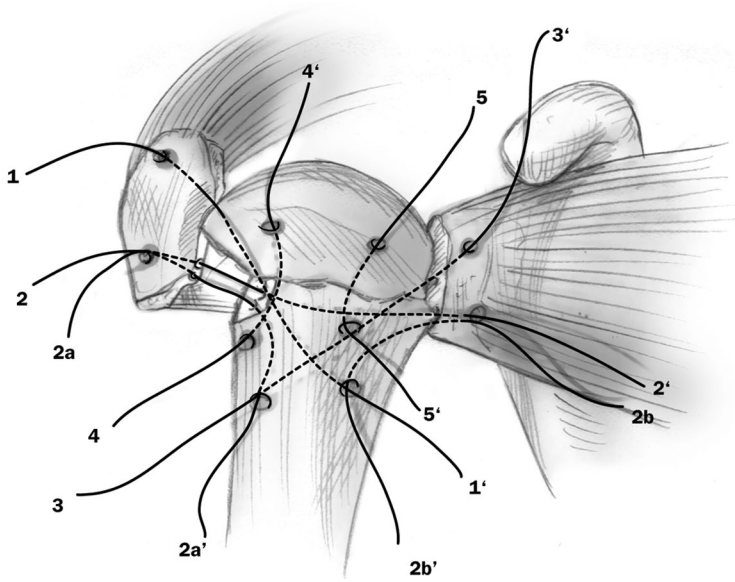


Fig. 1-A

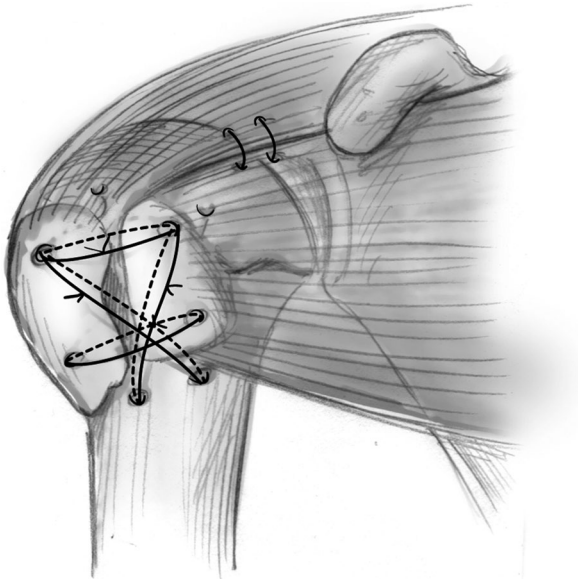

Fig. 1-B

Schematic representations of the suture technique for the treatment of a four-part valgus impacted fracture. The humeral head is maintained in the valgus position while both tuberosities are pulled down below the level of the head and secured not only to each other but also to the head fragment and to the medial and lateral sides of the diaphysis, in a cruciate fashion. The numbers and letters indicate the appropriate placement of the sutures in the treatment of this type of fracture.

**Fixation of Four-Part Valgus Impacted Fractures (Figs. 1-A and 1-B)**

The fracture area was exposed through a lateral transdeltoid approach, between the anterior and middle portions of the muscle. The skin incision was made from the anterolateral tip of the acromion and extended approximately 6 to 7 cm distally. With use of blunt dissection, the deltoid was split for 4 to 5 cm. Rotation and abduction of the proximal part of the humerus in this surgical window allowed adequate visualization of both tuberosities and of the metaphyseal area, thus minimizing the risk of iatrogenic injury to the axillary nerve. In cases with metaphyseal extension, the nerve was identified and protected by the surgeon's finger.

Soft-tissue attachments to the fracture fragments were carefully preserved to prevent devascularization of the humeral head. The fracture lines between the tuberosities were identified and gently separated, facilitating access to the humeral head. Invariably, the humeral head was facing superiorly with the tuberosities splayed on either side of it. In every case, both tuberosities were displaced by >1 cm. Initially, two stay sutures were passed through each tuberosity fragment (or near its site of tendon insertion in osteoporotic bone or when extensive comminution was present), and the rotator cuff tendons were mobilized. Without disimpacting the articular head fragment from its valgus position, two pairs of sutures were passed transosseously, 1 cm proximal to the fracture line at both the medial and the lateral border of the articular head fragment. Finally, another two pairs of sutures were inserted laterally and medially through 2.7-mm drill holes in the diaphysis. These sutures were directed into the opposite tuberosity, near the musculotendinous junction, and onto the neighboring area of the articular segment (i.e., through the medial aspect of the diaphysis toward the greater tuberosity and through the lateral aspect of the diaphysis toward the lesser tuberosity as well as onto the adjacent articular fragment). Once all sutures were in place, the tuberosities were approximated to the diaphysis, just below the top of the head fragment. Each suture was then tied individually, and then to each other, in a cruciate arrangement that allowed secure fixation of each part to the others. Further loosening of the sutures, due to fracture compression, was corrected by tying additional knots between the free sutures, once more in a cruciate manner. Ten patients (22%) had associated or coexisting tears of the rotator cuff tendons, which were also repaired with nonabsorbable sutures.

Once the fracture had been repaired, the adequacy of the fixation was verified by gentle mobilization of the shoulder through 90° of forward elevation and 30° of both external and internal rotation. Fixation was considered to be stable if the repaired humeral head and the diaphysis moved as a single unit. Intraoperative imaging was employed for the initial procedures. As the experience of the surgeon increased, he checked for abnormal motion by means of observation and palpation of the fracture site alone. The deltoid flaps were then reapproximated with use of absorbable sutures in a figure-of-eight manner. The subcutaneous tissue was closed with absorbable sutures, and the skin was closed with a subcuticular technique. A Velpeau dressing secured the arm to the chest wall; it was converted to a simple sling on the second postoperative day.

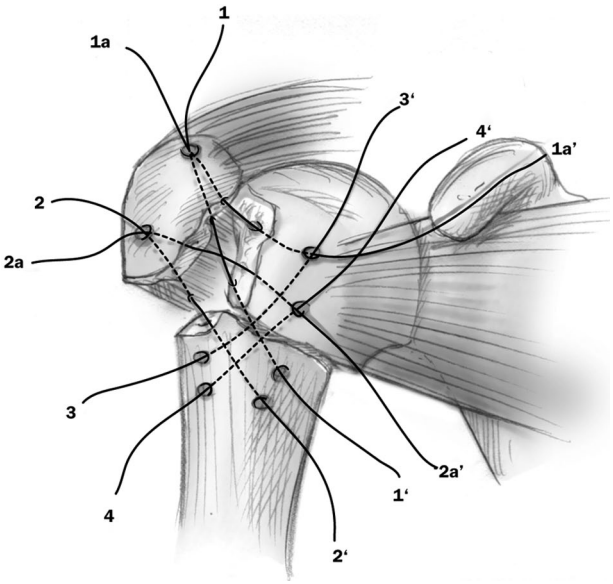


Fig. 2-A

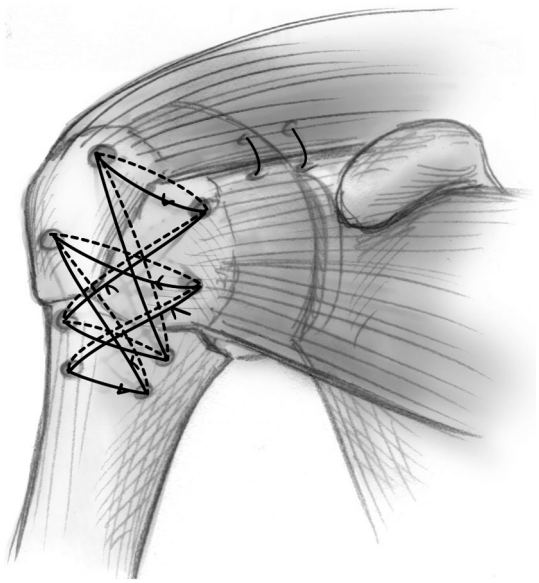

Fig. 2-B

Schematic representation of the suture technique for the treatment of a three-part fracture. The numbers and letters indicate the appropriate placement of the sutures in the treatment of this type of fracture.

**Fixation of Three-Part Fractures (Figs. 2-A and 2-B)**

The same principles of fixation were used for three-part fractures. Again, the sutures were placed through the displaced greater or lesser tuberosity, the humeral head with the intact lesser or greater tuberosity, and the diaphysis. In this type of fracture, the humeral head typically is rotated either internally or externally, and attention should be paid to achieving an adequate reduction in both the frontal and the sagittal plane. Eighteen patients (28%) with a three-part fracture had associated rotator cuff tears, which were repaired with nonabsorbable sutures.

**Fixation of Two-Part Fractures of the Greater Tuberosity (Figs. 3-A and 3-B)**

When the fracture of the greater tuberosity was associated with an anterior dislocation of the shoulder, the patient was lightly

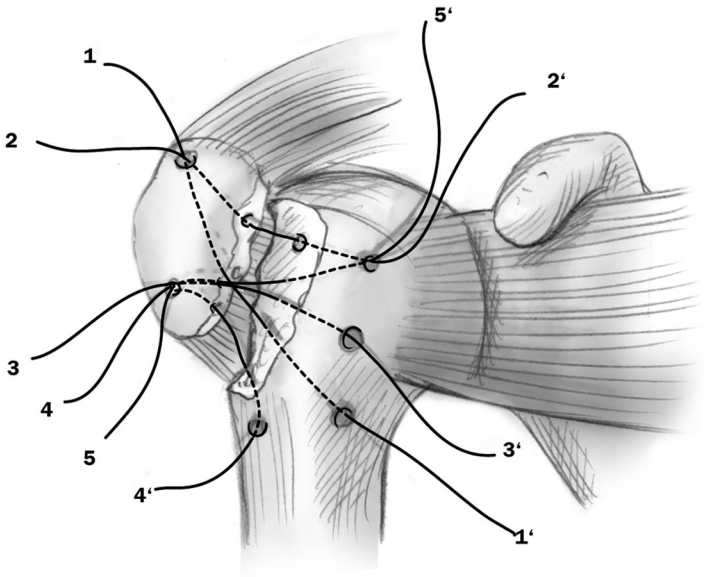


Fig. 3-A

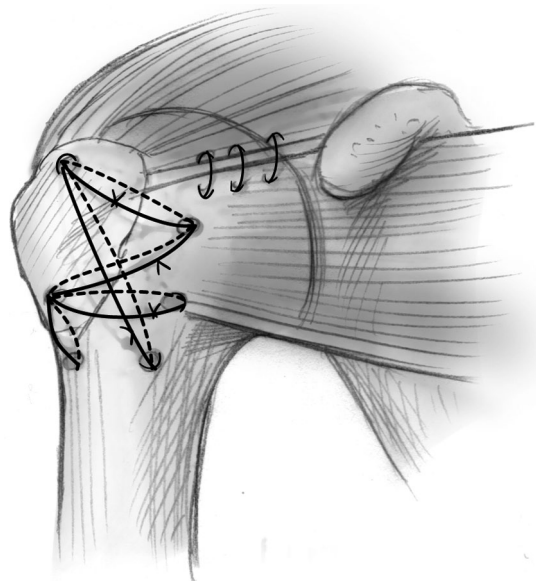

Fig. 3-B

Schematic representation of the suture technique for the treatment of a two-part fracture of the greater tuberosity. The greater tuberosity fragment is anatomically reduced and the longitudinal tear in the rotator cuff is repaired. The numbers and letters indicate the appropriate placement of the sutures in the treatment of this type of fracture.

**TABLE I Clinical Outcomes**

| Fracture Type | Total No./No. Lost to Follow-up/(No. with Complete Clinical and Radiographic Evaluation) | Constant Score | | No. Satisfied with Result |
|---|---|---|---|---|
| | | Mean (Range) *(points)* | % of Score on Unaffected Side | |
| Two-part greater tuberosity without dislocation | 24/4/(20) | 93 (65-100) | 95 | 18 |
| Two-part greater tuberosity with dislocation | 41/5/(36) | 94 (66-100) | 95 | 34 |
| Three-part | 72/8/(64) | 88 (54-100) | 93 | 53 |
| Four-part valgus impacted | 51/6/(45) | 89 (55-100) | 93 | 39 |
| Total series | 188/23/(165) | 91 (54-100) | 94 | 144 (87%) |

sedated in the emergency department to facilitate reduction. One or a maximum of two efforts were made to reduce the dislocation by closed means. If closed reduction failed, the patient was transferred to the operating theater for reduction under general anesthesia. Twenty-nine (52%) of the fifty-six patients with a two-part fracture of the greater tuberosity had a characteristic longitudinal tear in the rotator cuff, through the rotator interval. Five of these patients had a complete avulsion of the supraspinatus tendon, three had a complete avulsion of the infraspinatus tendon, and two had a combined avulsion of both tendons. The cortical edge of the tuberosity fragment was reduced to align with the edge of the fracture bed on the proximal part of the humerus. Two or three pairs of sutures were then passed through the bone, in the upper and lower portions of the tuberosity fragment, and then through corresponding drill holes in the humerus. The sutures were tied in a cruciate fashion with care taken to prevent overreduction or further comminution. The longitudinal tears in the rotator cuff were also repaired with nonabsorbable sutures.

### *Rehabilitation Protocol*

All patients participated in a closely monitored three-phase rehabilitation program. Pendulum exercises were started on the second postoperative day and continued until the third or fourth postoperative week. The second phase included active-assisted range-of-motion exercises for five to ten weeks. In the final phase, active dynamic shoulder motion and strengthening exercises were prescribed until the sixth postoperative month.

### *Outcome Assessment*

The functional outcome was assessed independently by two senior physiotherapists using the parameters of the Constant score. Pain, performance of daily activities, range of motion, and strength were scored on a scale of 1 to 100 points, with 100 points being an excellent score. The isometric power of the shoulder was assessed according to a scale that awarded a maximum of 25 points when a patient could hold a weight of 12 kg at 90° of shoulder abduction or if the maximum weight that he or she could hold in this position was <12 kg but was equal to the greatest weight that could be held on the contralateral, uninjured side.

Standardized anteroposterior and axillary radiographs of the shoulder were made postoperatively; at one, three, six, and twelve months; and at the last visit. These radiographs were assessed by an independent specialist registrar (G.K.) for the quality of the reduction, progression of healing, malunion, nonunion, heterotopic ossification, and signs of subacromial impingement, humeral head osteonecrosis, or posttraumatic osteoarthritis.

On the basis of two measures—varus or valgus deformity of the head with respect to the humeral shaft (in degrees) and residual displacement of the greater tuberosity (in millimeters)—the quality of the reduction on the first postoperative radiograph was classified as excellent/very good (mild deformity [a varus or valgus angle of <20° and displacement of the greater tuberosity of <3 mm]), good (moderate deformity [a varus or valgus angle of between 20° and 40° and displacement of the greater tuberosity of between 3 and 6 mm]), or poor (severe de-

**TABLE II Clinical and Radiographic Outcomes** ➤

| Fracture Type | Total No./No. Lost to Follow-up/(No. with Complete Clinical and Radiographic Evaluation | Reoperation | Malunion |
|---|---|---|---|
| Two-part greater tuberosity without dislocation | 24/4/(20) | 1 | — |
| Two-part greater tuberosity with dislocation | 41/5/(36) | — | 1 |
| Three-part | 72/8/(64) | 3 | 6 |
| Four-part valgus impacted | 51/6/(45) | 3 | 2 |
| Total series | 188/23/(165) | 7 (4%) | 9 (5%) |

formity [a varus or valgus angle of >40° and displacement of the greater tuberosity of >6 mm]). At the final radiographic assessment, persistent malunion was classified as mild, moderate, or severe with use of the same criteria as was used for the rating of the postoperative quality of the reduction. Fracture union was considered to have occurred when the patient reported no shoulder pain or activity-related discomfort and the fracture lines were no longer visible on the plain radiographs. Inherent to this definition was the absence of evidence of loss of reduction when compared with the reduction seen on previous postoperative images. Heterotopic bone formation was graded with a modification of the system of Brooker et al.[22]. Class I indicated islands of bone in the soft tissues; class II, at least 1 cm of space between apposing bone surfaces; class III, <1 cm of space between apposing bone surfaces; and class IV, complete bridging. Subacromial impingement was demonstrated radiographically by migration or flattening of the greater tuberosity, subacromial erosion, calcification, or malunion of the humeral head. However, the diagnosis of this condition depended largely on clinical parameters, such as a positive Neer test, a painful arc of abduction, or a drop arm sign. Posttraumatic osteoarthritis was graded according to the Kellgren-Lawrence scale[23] as 0 (no features of osteoarthritis), 1 (questionable osteophyte development), 2 (definite osteophyte observed with a minimal loss of joint space), 3 (moderate loss of joint space width), or 4 (severe loss of joint space width with subchondral bone sclerosis). Humeral head osteonecrosis was defined by destruction of the trabecular architecture with loss of osseous substance in an articular segment. It was considered to be complete if the entire humeral head segment had been reabsorbed and partial if only a portion of the humeral head had collapsed.

## Results

The average duration of the surgery was seventy minutes (range, fifty-two to 105 minutes), and the average duration of the hospital stay was 4.7 days (range, 3.5 to seven days). The average follow-up period was 5.4 years (range, three to eleven years). All neurological deficits accompanying the initial injury resolved within four to six months after the surgery, except for one brachial plexus injury that persisted after fracture consolidation. No iatrogenic injuries of the axillary nerve supply to the anterior deltoid were noted at the time of final follow-up. Three postoperative superficial infections were managed with oral antibiotics, and a deep infection developed five weeks after the operation in one patient. It was treated effectively with surgical débridement and drainage, and the fracture united uneventfully.

### *Functional Outcome (Table I)*

At the time of final follow-up, the mean Constant score was 91 points (range, 54 to 100 points) and the mean Constant score as a percentage of the score for the unaffected shoulder, unadjusted for age or gender, was 94% (range, 60% to 100%). The average amount of active elevation with the patient standing was 167° (range, 140° to 180°), and the average amount of external rotation was 75° (range, 50° to 90°). The mean amount of internal rotation, measured as the highest posterior spinal segment reached by the thumb with the arm in adduction, was T10 (range, L3 to C7).

Three patients reported stiffness and compromised shoulder motion, which was consistent with a diagnosis of adhesive capsulitis. Each of these patients had cooperated poorly with the rehabilitation protocol. Despite an intensive course of physiotherapy, the symptoms decreased in only one of these patients; the remaining two patients declined additional treatment.

One hundred and forty-four patients (87%) were satisfied with the result; they had no pain with vigorous activities and were able to resume previous levels of daily and recreational activities. Thirty of the thirty-five patients who had been regularly employed in a sedentary job prior to the injury returned to their full work duties within seven months. Of the forty-five patients who had been regularly employed in a manual job prior to the injury, thirty-nine returned to their previous work duties.

### *Radiographic Outcome (Table II and Fig. 4)*

The quality of the reduction as seen on the first postoperative radiograph was assessed as excellent/very good in 155 (94%) of the 165 patients, good in seven (4%), and poor in three (2%). In the group with an initial good reduction, partial osteonecrosis developed in one patient and nonunion developed in another. In the group with a poor reduction, partial osteonecrosis developed in one patient and one patient had complete collapse of the head. The remaining six patients with a good or poor reduction demonstrated a persistent malunion, which was moderate in five and severe in one, at the last radiographic assessment.

**TABLE II** ***(Continued)***

| | Osteonecrosis | | | | |
|---|---|---|---|---|---|
| Nonunion | Partial | Total | Subacromial Impingement | Heterotopic Ossification | Symptomatic Osteoarthritis |
| — | — | — | 1 | 2 | — |
| — | — | — | — | 3 | — |
| 2 | 5 | 1 | 2 | 6 | 1 |
| — | 2 | 3 | 1 | 4 | 1 |
| 2 (1%) | 7 (4%) | 4 (2%) | 4 (2%) | 15 (9%) | 2 (1%) |

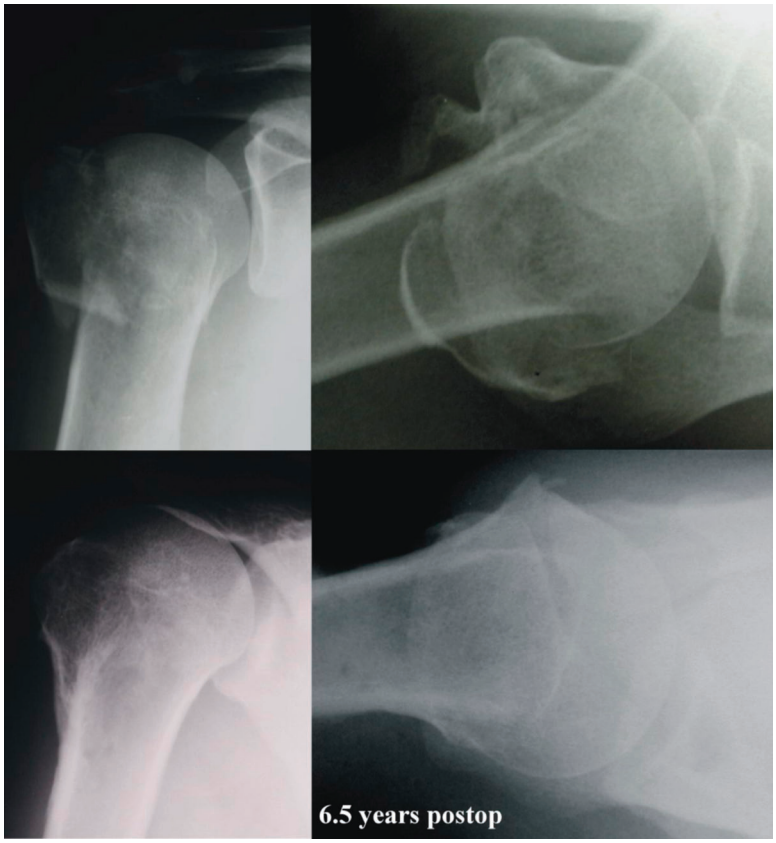


Fig. 4

Top: A four-part valgus impacted fracture in a thirty-nine-year-old woman. There is 40° of valgus angulation, >1 cm of displacement of both tuberosities, and no lateral translation of the humeral head with respect to the diaphysis. The fracture was fixed with transosseous sutures. Bottom: The reduction remained excellent 6.5 years postoperatively without evidence of arthritic changes, whereas the Constant score (indicating functional outcome) was 98 points.

During the follow-up period, a malunion also developed in three patients who had had an excellent/very good reduction; all three of these malunions were mild. Overall, nine (5%) of the 165 patients had a malunion; six of these patients had sustained a three-part fracture of the greater tuberosity.

According to the definition of fracture union described previously, all fractures had united within two to three months, with the exception of two three-part fractures of the greater tuberosity that showed no signs of healing at four and six months. One of those fractures had had a good postoperative reduction. Revision osteosynthesis with use of a plate and screws, supplemented with bone graft, led to union of both of these fractures within four months.

Heterotopic ossification was detected in fifteen (9%) of the 165 patients and was classified as class I in twelve patients and class II in three. Ten of these patients had been involved in road traffic accidents and had sustained other skeletal injuries.

### *Complications*

Overall, osteonecrosis of the humeral head developed in eleven patients (7%) and total collapse was detected in four (2%). Three of these cases were attributed to the nature of the fracture; the other patient had a poor postoperative reduction. Each of these four patients with total collapse was treated with conversion to a hemiarthroplasty, at a mean of sixteen months postoperatively. Partial osteonecrosis, present in seven patients (4%), was most often located at the anterolateral portion of the head. None of these seven patients had severe pain or clinically relevant restriction of shoulder motion.

Symptoms of impingement were detected in four patients (2%) between six months and one year after the surgery. Three patients were treated successfully with one, two, or three subacromial injections of corticosteroid and local anesthetic. The other patient, a seventy-two-year-old woman, remained symptomatic eighteen months postoperatively. She did not wish to undergo subacromial decompression as she was satisfied with the outcome of the fracture fixation and experienced only moderate pain with forward elevation of >150°. At the time of the last follow-up, two patients (1%) had symptomatic posttraumatic osteoarthritis that was seen radiographically and was classified as grade 2 and 3.

The overall reoperation rate was 4% during the average 5.4-year follow-up period. One deep infection required surgical drainage, there were two conversions to plate osteo-

synthesis as described, and there were four conversions to a hemiarthroplasty.

## Discussion

The ideal treatment of a displaced proximal humeral fracture remains controversial and is still a matter of debate in the literature. Misra et al.[24] conducted a meta-analysis in 2001 and concluded that, although the quality of reports seems to be improving, the current published literature is inadequate to allow evidence-based clinical decision-making.

With the exceptions of minimally displaced fractures, which can be successfully managed by nonoperative means, and of four-part fractures, head-splitting fractures, and fracture-dislocations, which are usually treated with hemiarthroplasty, open reduction and internal fixation is usually indicated for displaced two, three, and four-part valgus impacted fractures[3,25-27].

In contrast to conventional plate methods, there is a growing trend toward less invasive surgical exposures and osteosynthesis techniques involving screws, wires, sutures, and tubular or locking plates, in an endeavor to minimize soft-tissue detachments, periarticular scarring, and vascular insult to the articular humeral head segment. Percutaneous pin, cannulated screw, and intramedullary wire and nail fixation techniques are reasonable alternatives, but there is always the risk of breakage, migration, joint or neurovascular penetration, and superficial infection with the use of these implants[11,28,29].

McLaughlin[30] first suggested the use of sutures for fixation of avulsed tuberosity fractures. Neer[31] advocated the use of wires and silk or nylon sutures for the fixation of three-part fractures and reported excellent or satisfactory results in 86% of patients so treated. Cuomo et al.32 reported good to excellent results in eighteen of twenty-two patients in whom a two-part or three-part fracture had been treated with wire or suture fixation. Flatow et al.[33] reported that twelve patients with a displaced fracture of the greater tuberosity had a good or excellent result at a mean of five years after suture fixation.

To date, there have been few reports of large series of patients treated with suture fixation. One of the most recent studies is that by Park et al.[15], who reported on twenty-seven patients in whom a total of twenty-eight fractures of the proximal part of the humerus had been treated with nonabsorbable sutures. Thirteen fractures were of the greater tuberosity, nine were two-part surgical neck fractures, and six were three-part fractures. Overall, there were twenty-five excellent or satisfactory results and few complications. Hockings and Haines[13] reported only one case of osteonecrosis and a mean Constant score of 86% in a study of eleven patients in whom a four-part valgus impacted fracture had been treated exclusively with transosseous sutures. Finally, Banco et al.[34] and Iannotti et al.[25] described the parachute and figure-of-eight techniques of transosseous fixation with use of Dacron tapes and number-2 FiberWire sutures, respectively.

To our knowledge, the current study involved one of the largest reported series of displaced proximal humeral fractures managed solely with nonabsorbable sutures. However, our treatment regimen has several critical differences when compared with the suture-fixation techniques described in similar reports. First, we prefer the lateral transdeltoid approach as it provides adequate exposure of the fracture while reducing soft-tissue trauma. The axillary nerve, which is the major anatomical structure in danger, is located approximately 5 to 6 cm below the tip of the acromion. With the exposure that we used, the split in the deltoid ends far more proximally, as only 1 to 2 cm of metaphyseal exposure is required for the drill holes. In a cadaveric study, Gardner et al.[35] investigated an extended anterolateral acromial approach to the proximal part of the humerus. The axillary nerve typically was found deep to the anterior deltoid raphe, approximately 6.3 cm from the undersurface of the acromion. Subsequently, they used this approach in sixteen patients with a proximal humeral fracture, and none had complications related to the surgical approach. In our series, we found no cases of axillary neurapraxia that could be attributed to the surgical approach. We believe that the main advantage of the lateral approach when compared with the more standard deltopectoral approach is the preservation of the remaining blood supply of the humeral head, especially in patients with a four-part valgus impacted fracture.

Second, with our technique, the displaced tuberosities in four-part valgus impacted fractures always are pulled down below the level of the head in an attempt to avoid subacromial impingement, and they are sutured not only to each other but also to the articular fragment and to the medial and lateral aspects of the diaphysis in a manner that we believe neutralizes the deforming muscular forces. Similarly, in the treatment of three-part fractures of the greater tuberosity, the sutures are also passed through the intact lesser tuberosity. This provides a stable construct and restores the normal functional balance of the involved tendons, thus allowing early motion of the shoulder joint. In the treatment of isolated two-part fractures of the greater tuberosity, the displaced tuberosity also is reduced to its anatomical position, thus avoiding mechanical blockage to abduction of the shoulder, or obstruction of external rotation due to posterior displacement of the greater tuberosity.

Third, we avoid reducing the impacted articular component of the four-part valgus impacted fracture to its anatomical position, thus minimizing the risk of further disruption of the posteromedial hinge (Figs. 1-A and 1-B). The overall prevalence of total osteonecrosis of the head in this subgroup of patients was only three (7%) of forty-five, one of the lowest rates that has been reported[13,17,36,37]. Despite incomplete fracture reduction with our technique, it seems that the disruption of normal anatomy does not affect shoulder joint biomechanics. The moment arm of the rotator cuff muscles remains normal as we suture the tuberosities below the level of the impacted head. Use of this technique is supported further by the very low rate of early degenerative arthritis seen in this series.

Partial head osteonecrosis and malunion were well tolerated by most of our patients, especially the younger ones. Severe complications developed in only four of the ten patients with good or poor postoperative reduction (one had total necrosis, two had partial osteonecrosis, and one had nonunion). Two of these patients required a reoperation. In

addition, three patients who had had an excellent/very good reduction had a malunion. However, all of these patients with a malunion had a good Constant score at the last clinical assessment. McLaughlin[30] emphasized that normal anatomy is not crucial for normal function of the shoulder joint, and some authors have suggested that some residual deformity may be acceptable in the setting of percutaneous fixation[11].

Careful patient selection and adherence to the defined indications are important for the success of our therapeutic regimen. The final decision regarding which intervention is undertaken should be made at the time of the surgery, when the true nature of each fracture can be fully recognized. Should the humeral head be found to be completely dislocated or to have undergone substantial translation (>1 cm) or comminution, a primary hemiarthroplasty should be performed. Furthermore, we believe that most two-part surgical neck fractures should be treated with plate-and-screw osteosynthesis. We do not recommend transosseous suture fixation for this type of fracture as rotational instability and unstable fixation between the large proximal fragment and the narrow diaphysis often can cause problems.

Finally, completion of the full rehabilitation program is integral to obtaining the optimum outcome. A major variation from previous protocols that was employed in our patient cohort was the institution of pendulum exercises on the second postoperative day and the use of such exercises for the first three to four weeks. A full range of motion could be established in this fashion without exerting undue stress on the fixation. Neer[31] emphasized the importance of early rehabilitation in the management of proximal humeral fractures, and its value was demonstrated in the studies by Koval et al.[38] and Kristiansen et al.[39]. We believe that a good functional outcome can be achieved only with individualized and supervised monitoring of the patient's progress.

The strength of this study lies in the large number of patients as well as the strict criteria for assessment of long-term clinical and radiographic outcomes, but there were also limitations. While we attribute our good outcomes to precise surgical technique and a rigorous rehabilitation protocol, refined assessment of these parameters is difficult. Furthermore, reproducibility of the radiographic measurements is difficult to obtain. Often the humeral head is either internally or externally oriented, depending on the position of the radiographic plate and the orientation of the beam. Efforts were made in all cases to obtain a good-quality radiographic trauma series and to define strict criteria for inclusion of patients in the treatment protocol. The lack of a control group is also an important weakness of our study. In the future, a multicenter study should be conducted to compare our technique with other stabilization techniques, such as fixation with the new locking plates. Despite these limitations, we recommend open reduction and suture fixation for acute four-part valgus impacted, three-part, and two-part greater tuberosity fractures of the proximal part of the humerus with the intention of achieving stable osteosynthesis, an adequate rotator cuff repair, and early mobilization of the shoulder joint. ■

Panayiotis Dimakopoulos, MD
Georgios Kasimatis, MD
Shoulder and Elbow Unit, Orthopaedic Department, Patras University Hospital, Rio-Patras 26504, Greece. E-mail address for P. Dimakopoulos: pa.dimakopoulos@gmail.com

Andreas Panagopoulos, MD, PhD
Ipapantis and 25 Martiou 1, 26504 Kato Kastritsi, Patras, Greece

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