# Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus

Pascal Boileau, MD,[a] Christophe Trojani, MD,[a] Gilles Walch, MD,[b] Sumant G. Krishnan, MD,[a] Anthony Romeo, MD,[c] and Richard Sinnerton, MD, FRCS,[d] *Nice and Lyon, France, Chicago, Ill, and Berks, England*

*The purpose of this multicenter study was to analyze the results of shoulder arthroplasty for the treatment of the sequelae of proximal humerus fractures and establish an updated classification system and treatment guidelines for these complex situations. Seventy-one sequelae of proximal humerus fractures were treated with shoulder replacement with the use of the same nonconstrained, modular, and adaptable prosthesis: the Aequalis prosthesis (Tornier Inc, St Ismier, France). The average time between initial fracture and shoulder arthroplasty was 5 years and 5 months. On the basis of anatomic classification schemes, sequelae were divided into 4 types: type 1, humeral head collapse or necrosis with minimal tuberosity malunion (40 cases); type 2, locked dislocations or fracture-dislocations (9 cases); type 3, nonunions of the surgical neck (6 cases); and type 4, severe malunions of the tuberosities (16 cases). The mean postoperative follow-up was 19 months (range, 12 to 48 months). Overall, the postoperative Constant score was excellent in 11 cases (16%), good in 19 cases (26%), fair in 18 cases (25%), and poor in 23 cases (33%). There were 18 complications (27%). Fifty-nine of 70 patients (81%) stated that they were satisfied with the result. The most significant factor affecting functional outcome was greater tuberosity osteotomy ($P < .005$). Regarding both surgical treatment and postoperative prognosis, we identify 2 categories of proximal humerus fracture sequelae: category 1, intracapsular/impacted fractures sequelae (associated with both cephalic collapse or necrosis [type 1] and chronic dislocation or fracture-dislocation [type 2]), in which an articulating joint can be reconstructed without a greater tuberosity osteotomy; and category 2, extracapsular/disimpacted fractures sequelae (associated with both surgical neck nonunions [type 3] and severe tuberosity malunions [type 4]) where the proximal humerus cannot be reconstructed without a greater tuberosity osteotomy. All of the excellent and good postoperative Constant scores were obtained in type 1 and 2, in which osteotomy of the greater tuberosity was not required. All patients in type 3 and 4, who underwent a greater tuberosity osteotomy, had either fair or poor results and did not regain active elevation above 90°. We conclude that a greater tuberosity osteotomy is the most likely reason for poor and unpredictable results after shoulder replacement arthroplasty for the treatment of the complex sequelae of proximal humerus fractures. Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus should be performed without an osteotomy of the greater tuberosity when possible. If prosthetic replacement is possible without an osteotomy, surgeons should accept the distorted anatomy of the proximal humerus and adapt the prosthesis and their technique to the modified anatomy. A modular and adaptable prosthesis with both adjustable offsets and inclination may allow surgeons to adapt to a large number of malunions and may help to avoid the troublesome greater tuberosity osteotomy in a higher proportion of cases. (J Shoulder Elbow Surg 2001;10:299-308.)*

From the Department of Orthopaedic Surgery, Medical University of Nice, Hôpital de L'Archet, Nice,[a] and the Department of Orthopaedic Surgery, Clinique St Anne Lumière, Lyon,[b] France; the Rush Presbyterian Hospital, Chicago, Ill[c]; and the Princess Margaret Hospital, Osborne Road Windsor, Berks, England.[d]

Reprint requests: Pascal Boileau, MD, Department of Orthopaedic Surgery, Medical University of Nice, Hôpital de L'Archet, 151, Route de Saint Antoine de Ginestière, 06202, Nice, France (E-mail: *boileau.p@chu-nice.fr*).



1058-2746/2001/$35.00 + 0 **32/1/115985**
doi:10.1067/mse.2001.115985

## INTRODUCTION

Fractures of the proximal humerus, which have received either conservative treatment or surgical treatment, may result in pain and disability of the shoulder. Among these fracture sequelae, some cases of avascular

**iTable I** The 4 pathophysiologic types of sequelae of fractures of proximal humerus

| Fracture sequelae | Initial fracture | No. | Initial treatment | | Delay before prosthesis | Prosthesis type | | Osteotomy | | Status of rotator cuff | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Nonop | Op | | Humeral | Total | GT | LT | Normal | Thin | Torn |
| Type 1: Cephalic collapse or necrosis (n = 40) | 3- or 4-part valgus impacted | 20 | 35 | 5 | 8 y, 2 mo | 19 | 21 | 2 | 0 | 19 | 17 | 4 |
| | 3- or 4-part varus impacted | 12 | | | | | | | | | | |
| | 4-part displaced | 1 | | | | | | | | | | |
| | 2-part anatomic neck | 3 | | | | | | | | | | |
| | 2-part surgical neck | 4 | | | | | | | | | | |
| Type 2: Locked dislocations and fracture-dislocations (n = 9) | Posterior locked dislocation | 7 | 9 | 0 | 1 y, 7 mo | 8 | 1 | 1 | 0 | 2 | 2 | 2 |
| | Posterior fracture-dislocation | 1 | | | | | | | | | | |
| | Anterior fracture-dislocation | 1 | | | | | | | | | | |
| Type 3: Nonunion of the surgical neck (n = 6) | 2-part surgical neck displaced | 2 | 2 | 4 (1 reoperation) | 3 y | 6 | 0 | 6 | 2 | 4 | 0 | 2 |
| | 3-part greater tuberosity | 2 | | | | | | | | | | |
| | 4-part, already operated on | 2 | | | | | | | | | | |
| Type 4: Severe tuberosity malunion (n = 16) | 4-part displaced or dislocated fractures | 16 | 6 | 10 (2 reoperations) | 2 y | 13 | 3 | 11 | 6 | 4 | 7 | 5 |
| Entire series (n = 71) | | | 52 | 19 | 5 y, 5 mo | 46 | 25 | 20 | 8 | 29 | 29 | 13 |

*Nonop,* Nonoperative procedure; *Op,* operative procedure; *GT,* greater osteotomy; *LT,* lesser osteotomy.

necrosis with subchondral bone collapse, certain locked dislocations and fracture-dislocations, some nonunions of the surgical neck with a small osteoporotic head fragment, and some malunions of the tuberosities with incongruity of the humeral articular surface may be indications for the insertion of a shoulder prosthesis.[5,26,37] However, indications for shoulder arthroplasty in old trauma remain controversial because the possible functional benefit after arthroplasty has not yet been clearly established and the prognosis remains unpredictable.*

Neer was the first author to describe the technical difficulties, the high complication rate, and the poor and inconsistent functional results of shoulder arthroplasty in old trauma.[24-26] However, there is disappointingly little in the literature on this subject because the number of cases in each series is limited.† Moreover, there is some confusion between these heterogeneous groups of old trauma of the proximal humerus and the therapeutic results achieved by shoulder replacement within each group. The lack of an updated classification of the sequelae of proximal humerus fractures may be instrumental in preventing communication and comparison of treatments between different centers.

These post-traumatic sequelae usually occur in relatively young and active patients, making it even more crucial to predict prognosis preoperatively when decid-

*References 1, 8, 11, 14, 16, 18, 20, 21, 26, 29-32, 37, 40.

†References 8, 11, 14, 16, 26, 30, 33, 38.

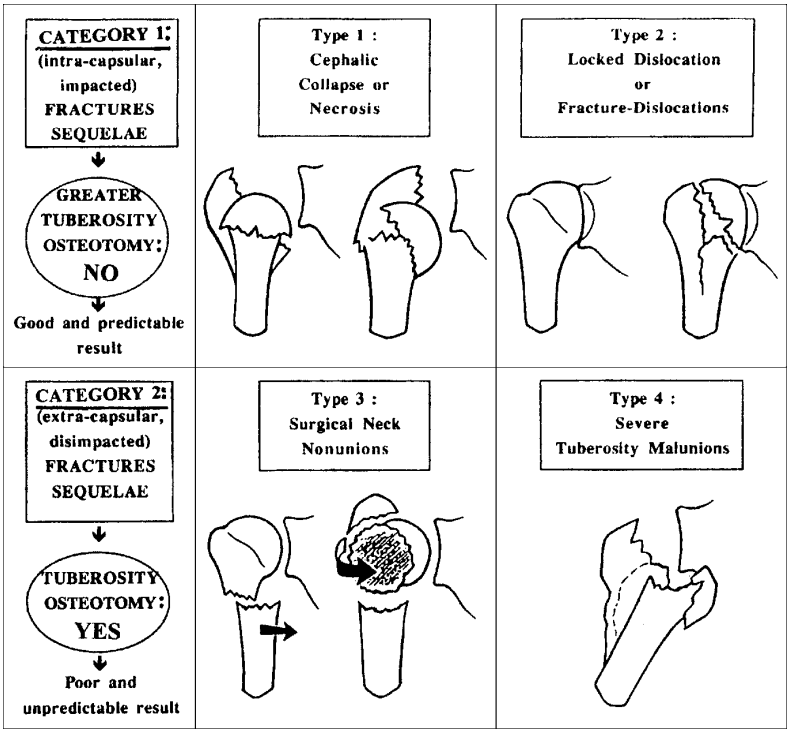


**Figure 1** Surgical classification of sequelae of proximal humerus fracture: 4 types of sequelae.

ing on shoulder joint arthroplasty.[19,40] The purpose of this study was to evaluate the results achieved with the use of a nonconstrained shoulder prosthesis for the treatment of the sequelae of proximal humerus fractures and establish an updated classification system and treatment guidelines in these complex situations.

## MATERIALS AND METHODS

Between 1991 and 1995, 70 patients (71 shoulders) were operatively managed in a multicenter study with the same nonconstrained shoulder prosthesis for the sequelae of fractures of the proximal humerus. Only the sequelae of fractures of the proximal humerus treated with a shoulder replacement were included in this series. Patients who underwent operative treatment for isolated arthrolysis, subacromial decompression, or isolated correction of malunions or nonunions were excluded from this series. The indication for shoulder arthroplasty was pain and loss of function that were unresponsive to nonoperative treatment and physical therapy. There were 40 male and 30 female patients. One patient underwent bilateral shoulder replacements. The average age of the patients at the time of shoulder arthroplasty was 59 years (range, 30 to 87 years). The right side was involved in 44 cases (62%), and the dominant side was involved in 42 cases (59%).

The initial fracture was classified according to the Neer[22,23] and AO[17,18] classifications of fractures of the proximal humerus. The initial lesions and initial treatments are summarized in Table I. The cause of the initial fracture was a fall in 31 cases, a car accident in 12 cases, a seizure in 4 cases, and unknown in 24 cases. No vascular injuries occurred with the initial fractures. Two transient axillary nerve lesions, which were present at the time of fracture and resolved spontaneously, were documented. There was one associated glenoid fracture in a patient with a posterior fracture-dislocation.

Fifty-two patients (73%) underwent nonoperative treatment of the original fracture, and 19 (27%) underwent a previous operative procedure to fix the initial fracture. Of these 19 patients, 3 had also undergone a subsequent revision surgery before the shoulder arthroplasty. The average time between the initial fracture and the insertion of the shoulder prosthesis was 5 years and 5 months (range, 7 months to 26 years).

The clinical charts, operative reports, and preoperative and postoperative radiographs were retrospectively reviewed for all patients at a mean postoperative follow-up evaluation of 19 months (range, 12-48 months). Patients were clinically evaluated, both preoperatively and at the latest follow-up evaluation, with the scoring system described by Constant and Murley,[7] which covers pain, activity, mobility, and force. Strength was measured with a spring balance with the patient sitting straight in a chair to avoid spinal compensation. The arm was held horizontal to the scapula, and a dynamometer scaled in 0.5-kg increments was attached to the wrist. The patient was asked to resist the downward pressure exerted by the assessor and to keep his or her arm in the horizontal position for 5 seconds. This test was repeated 5 times, and the force registered. The score was adjusted for age and sex. Radio-

**Table II** Functional results of shoulder arthroplasty

| Fracture sequelae | Pain (Constant score) | Pain anterior elevation Preop → review (gain) | Active external rotation Preop → review (gain) |
|---|---|---|---|
| Intracapsular/impacted | | | |
| Type 1: Cephalic collapse or necrosis (n = 40) | 12/15 | 87° → 133° (+46°) | 0° → 40° (+40°) |
| Type 2: Locked dislocations or fracture-dislocations (n = 9) | 11.5/15 | 57° → 114° (+57°) | –2° → 42° (+44°) |
| Extracapsular/disimpacted fracture sequelae | | | |
| Type 3: Surgical neck nonunions (n = 6) | 7/15 | 50° → 63° (+13°) | 10° → 26° (+16°) |
| Type 4: Severe tuberosity malunions (n = 16) | 9.5/15 | 58° → 91° (+32°) | –5° → 20° (+25°) |
| Entire series (n = 71) | 10.7 | 74° → 102° (+28°) | 0° → 34° (+34°) |

graphic evaluation for each patient consisted of preoperative and postoperative follow-up anteroposterior views of the shoulder in neutral, internal, and external rotation. A scapular profile view (58 cases) and an axillary view (50 cases) were often available both preoperatively and postoperatively. Two observers (P.B. and C.T.) performed the radiographic evaluations first independently and then concurrently. They definitively classified difficult or controversial cases after discussion to reduce misinterpretation.[35,36] Statistical analysis was performed with the Student *t* test for numeric data, with $\chi^2$ analysis for nonparametric data. The level of significance was set at $P < .05$.

*Pathophysiologic classification*

Faced with the enormous variability of the lesions seen late and their many possible combinations, we were initially confronted with a problem of terminology and classification of the different sequelae of fractures of the proximal humerus. Originally, the fracture sequelae were grouped as a heterogeneous series within which various different lesions coexisted, such as malunion with avascular necrosis of the humeral head, nonunion, or a locked fracture-dislocation. A literature review of published series demonstrated the same confusion, making any comparison between results impossible.* Most authors studied limited, heterogeneous groups of old fractures and combined the results obtained for various different lesions. Some authors included nonunions of the surgical neck and locked fracture-dislocations in their series,† whereas others studied them separately or excluded them entirely.[12,13,28,30,34,38] Therefore it seemed that the inconsistent results reported with the use of shoulder prostheses to treat fracture sequelae were partly due to this enormous variability in the anatomic lesions and the resulting comparisons between very heterogeneous groups of sequelae. Starting from this basis, we determined that the first logical step was to try to categorize the sequelae of fractures of the proximal humerus. A study of the natural history of the different fractures and how they developed into their sequelae allowed us to understand the lesions that clinically presented later. By studying the initial radiographs and those at later stages, and by reviewing the operative notes, we were able to distinguish 4 basic pathophysiologic types of lesions that, when present, dominated the clinical picture and allowed the fracture sequelae to be grouped as follows (Table I).

*References 1, 8, 10, 11, 14, 26, 29, 31, 33, 34, 37.
†References 1, 8, 10, 11, 14, 16, 27, 29, 31, 38.

*Type 1: Humeral head collapse or necrosis with minimal tuberosity malunion (40 cases).* With the use of the Ficat staging system for osteonecrosis,[9] necrosis was classified as stage III in 19 cases and stage IV in 21 cases. The initial fractures in this group were dominated by 3- and 4-part fractures impacted either in valgus (20 cases) or in varus (12 cases), leading to slight malunion of the tuberosities. The initial treatment had been nonoperative in 35 cases and operative in only 5. Overall, the time between the initial fracture and the prosthetic replacement averaged 8 years and 2 months, and 6 of the patients underwent surgery more than 20 years after their fracture. Greater tuberosity osteotomy was required in only 2 cases.

*Type 2: Locked dislocations or fracture-dislocations (9 cases).* This group consisted of 7 locked posterior dislocations with greater than 50% head collapse, one posteriorly locked 2-part fracture-dislocation, and one anteriorly locked fracture-dislocation. In all cases the lesion had gone unrecognized and received no treatment. The time between the initial trauma and prosthetic replacement was 1 year and 7 months on average. In this group only one partial osteotomy (with incomplete detachment) of the greater tuberosity (in the anterior dislocation case) was required.

*Type 3: Nonunion of the surgical neck (6 cases).* Nonunions of the surgical neck followed either nonoperated 3-part fractures, with rotation of the humeral head fragment and significant displacement of the greater tuberosity, or 2- and 4-part fractures that had undergone primary surgery. The time between the initial fracture and the prosthesis was, on average, 3 years. A greater tuberosity osteotomy was necessary in all cases, and 2 cases also required a lesser tuberosity osteotomy.

*Type 4: Severe malunion of the tuberosities (16 cases).* The initial fracture was a displaced or dislocated 4-part fracture with disimpaction of the head. In 6 cases the initial treatment had been nonoperative. The other 10 cases had undergone a total of 12 interventions (10 primary surgeries and 2 revisions). The operations included one open reduction combined with a posterior bone block, one open reduction revised after 2 years to debride the joint of periarticular ossification, and 8 open reductions with internal fixation, in which various materials (screws, plates, staples, and/or intramedullary nails) were used. The average time between

**Table III** Complications

| Complications | n |
|---|---|
| Perioperative fractures (4 diaphysis, 1 metaphysis) | 5 |
| Greater tuberosity early loss of fixation | 1 |
| Greater tuberosity nonunion | 4 |
| Greater tuberosity osteolysis | 4 |
| Anterior dislocation | 1 |
| Transitory neurologic lesions (radial nerve) | 1 |
| Late infection | 2 |
| Total | 18 |

the initial trauma and shoulder replacement was 2 years. In 11 cases it was impossible to implant a shoulder prosthesis without performing a greater tuberosity osteotomy, and in 6 cases a lesser tuberosity osteotomy was also required.

*Surgical technique*

In this series all patients underwent operative treatment by senior shoulder surgeons who used the same criteria for operative selection, the same operative technique, the same prosthetic implant, and a uniform postoperative rehabilitation protocol. These parameters were controlled in a prospective manner. An extended deltopectoral approach was used in 70 cases. A superior transacromial approach was used in 1 case. Table I illustrates the type of prosthesis (hemiarthroplasty or total arthroplasty), the associated bone procedures (tuberosity osteotomy), and the status of the rotator cuff at the time of surgery. On 8 occasions the joint was approached by means of an osteotomy of the lesser tuberosity with subscapularis attached to improve mobilization. Whenever possible, the greater tuberosity was not osteotomized, and the prosthesis was implanted by attempting to adapt the implant to the modified anatomy. A greater tuberosity osteotomy was indicated in 20 cases, because the excessive displacement of the bone fragments made it otherwise impossible to reconstruct the anatomy of the proximal humerus with a prosthesis. Great care was taken to leave enough bone attached to the rotator cuff to allow solid fixation of the tuberosities to the diaphysis. After the osteotomy had been performed, the rotator cuff was released medially on its deep and superficial surfaces. Any capsular retraction was released at the glenoid edge to allow the tendon to be advanced laterally. At the end of the procedure, the tuberosities were fixed both to the implant and to the humeral shaft with heavy nonabsorbable sutures. An autologous bone graft, taken either from the residual humeral head or from the iliac crest, was added in 8 of the cases of tuberosity osteotomy. A rotator cuff tear was reported and repaired in 13 cases; in 7 of these, the rupture involved 2 tendons (supraspinatus and infraspinatus), and in 6, there was a single tendon rupture (4 supraspinatus and 2 infraspinatus tears). The biceps tendon was tenodesed 9 times (13%). Fifteen acromioplasties were performed with the goal of improving the space for the tuberosities under the coracoacromial arch or to protect the cuff repair. The head was carefully dislocated with adduction, external rotation, and extension to minimize the risk of a humeral shaft fracture. Despite this attention, there were 4 diaphyseal fractures and one metaphyseal fracture in the series. The humeral head osteotomy was usually minimal and was not even

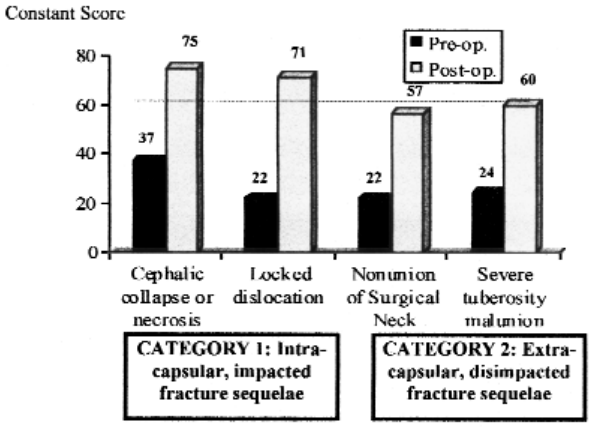


**Figure 2** Preoperative *(Pre-op)* and postoperative *(Post-op)* Constant score: functional result is significantly better in category 1, intracapsular/impacted sequelae of proximal humerus fractures.

required in some cases of collapse or necrosis after impacted fractures. Because of bony distortion, reaming the intramedullary canal was often difficult. All humeral stems were cemented in place after a cement restrictor was inserted. The implant used was the Aequalis shoulder prosthesis (Tornier Inc, St Ismier, France), the concept of which is based on anatomic studies that have demonstrated variations in the dimension and especially the shape of each individual proximal humerus.[2,3,15] The possibility of changing the position of the articular surface by changing inclination and offsets was used in this series to adapt the prosthesis to the potential distorted anatomy of the proximal humerus. Forty-six hemiarthroplasties (65%) and 25 total shoulder arthroplasties (35%) were carried out. A cemented polyethylene glenoid component was used in 23 of the total shoulder replacements. In the other 2 cases a metal-backed glenoid component, whose primary bone fixation comes from 2 expansion screws, was used.

Postoperative passive mobility was begun the day after surgery, and the rehabilitation program followed Neer's recommendations.[23,24,26] No active muscular activity was started until a complete range of passive movement had been achieved and until bony healing of the tuberosity osteotomies was observed on the radiographs (6-8 weeks). All patients had a home physiotherapy program, and 45 patients benefitted from a stay in a specialist rehabilitation center for an average of 35 days.

## RESULTS

The overall functional results, calculated with the Constant score, were excellent in 11 cases (16%), good in 19 cases (26%), fair in 18 cases (25%), and poor in 23 cases (33%). The preoperative and final follow-up results for pain and active mobility are detailed in Table II.

Results differed depending on the pathophysiologic type of lesion (Figure 1). In types 1 and 2 (cephalic collapse or necrosis and locked dislocations or fracture-dislocations, respectively), results demonstrated pain reduction (11.7 points out of 15), recovery of active

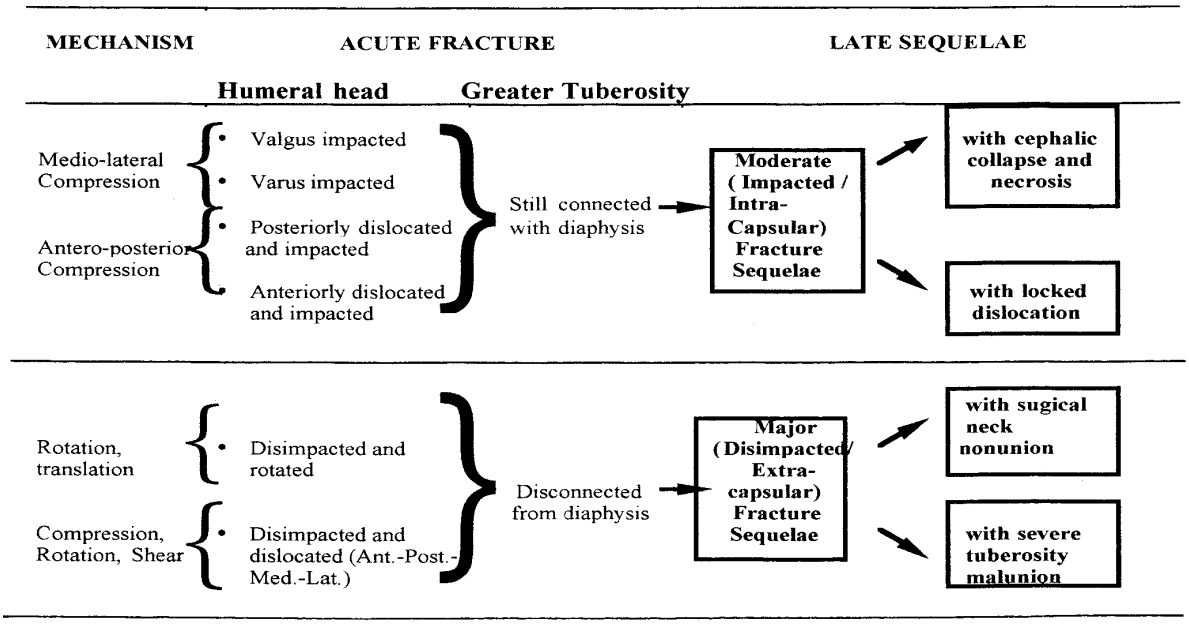


**Figure 3** Relationship between mechanism of initial fracture and final sequelae. *Ant,* Anteriorly; *Post,* posteriorly; *Med,* medially; *Lat,* laterally.

anterior elevation beyond the horizontal (average 123°, gain +51°), and recovery of active external rotation (average 41°, gain +42°). In types 3 and 4 (nonunion of the surgical neck and severe tuberosity malunion, respectively), results demonstrated slight reduction in pain (8.2 points out of 15), no recovery of anterior elevation beyond the horizontal (average 77°, gain +22°), and slight recovery of active external rotation (average 23°, gain +20°). Adjusted for age and sex, the Constant score achieved after shoulder arthroplasty averaged 73% in types 1 and 2 (cephalic collapse or necrosis with slight malunion and locked dislocation or fracture-dislocations, respectively). It was only 58.5% in types 3 and 4 (nonunions of the surgical neck of the humerus and severe tuberosity malunions, respectively).

Fifty-nine of the 70 patients in the series (81%) declared themselves as being satisfied or very satisfied with the result. The 10 patients who were disappointed with the operation and the 2 patients who were unhappy all had type 3 or type 4 sequelae. The Constant score significantly correlated with the subjective result ($P = .001$).

Osteotomy with complete detachment of the greater tuberosity was performed in 20 cases. This procedure was necessary in the most severe tuberosity malunions (11 cases). Greater tuberosity osteotomy was also performed in all 6 cases of nonunion of the surgical neck in order to separate the 2 tuberosities and remove the remaining fibrous tissue between the tuberosity and the diaphysis. Only 2 cases of cephalic collapse with tuberosity malunion and 1 case of locked anterior fracture-dislocation required a greater tuberosity osteotomy (one of them being partial). There was a significant difference with regard to functional result between the patients who required an osteotomy of the greater tuberosity and those who did not ($P < .005$). Patients who required osteotomy of the greater tuberosity demonstrated significantly less recovery of active anterior elevation (mean, 82°; range, 15° to 130°) compared with patients who did not have an osteotomy of the greater tuberosity (mean, 123°; range, 75° to 175°). In contrast, patients who underwent isolated lesser tuberosity osteotomy demonstrated no significant change in active anterior elevation when compared with patients who required no lesser tuberosity osteotomy (mean, 132°; $P = .6$)

We did not find any statistical correlation, either overall or in any specific group, between the functional results and the following parameters: age at the time of shoulder arthroplasty, sex, time between initial fracture and prosthesis, initial treatment of the fracture (nonoperative or operative), type of initial surgical treatment (closed or open), type of prosthesis (hemiarthroplasty or total arthroplasty), or type of rehabilitation (home therapy or rehabilitation center).

In this series there were 18 recorded complications (27%), 6 of which occurred perioperatively. These complications demonstrate the technical difficulties of these surgeries and are summarized in Table III. Complications were significantly more frequent in patients who required greater tuberosity osteotomy than in those patients in whom greater tuberosity osteotomy was not necessary ($P = .005$). All complications concerning the greater tuberosity (nonunion, bone resorption, tuberos-

ity migration) occurred after osteotomy, leading to a significantly worse functional result measured by the Constant score compared with that in patients who did not have a greater tuberosity osteotomy ($P < .005$).

Four patients required revision surgery, and of these, 3 had lesions classified as either type 3 or type 4. In 2 of the cases, the prosthesis was removed because of late infection. Both of these patients had undergone a previous surgical attempt to reduce and fix the initial fracture before prosthetic replacement. Surgical debridement and antibiotics were used to eradicate the infections. No attempt was made to reimplant a shoulder prosthesis, and the functional result was poor in both cases. One patient underwent an acromioplasty 9 months after the shoulder replacement because of anterosuperior impingement due to low placement of the prosthesis; radiographs demonstrated that the top of the greater tuberosity was 6 mm higher than the level of the prosthetic head. Results in this patient were improved for pain but not for function. Finally, one patient presented with failure of fixation of the greater tuberosity osteotomy 3 weeks postoperatively when, having already achieved complete passive elevation, she complained of pain and sudden loss of function. Radiographs revealed posterior and superior migration of the greater tuberosity, and this was surgically reattached with metal sutures. Her functional result was fair, with elevation of only 90° and episodic pain.

## DISCUSSION

Sequelae of fractures of the proximal humerus are one of the most difficult situations to treat in shoulder reconstruction. An anticipated and reliable functional result is usually difficult to establish because of the complexity of the bone loss and resultant deformity. For these reasons, shoulder arthroplasty is considered by many authors to be an unpredictable treatment for fracture sequelae of the proximal humerus.* Moreover, because these patients are usually younger and more active than those treated for osteoarthritis or rheumatoid arthritis, a preoperative prognosis is even more crucial when deciding on shoulder joint replacement.[4,26,40]

Analysis and grouping of the 4 pathophysiologic types of lesions and specific correlations in our series have allowed us to propose a new surgical and prognostic classification system for the sequelae of fractures of the proximal humerus. Two categories of fracture sequelae can be distinguished (Figure 1): category 1, intracapsular/impacted fracture sequelae, associated with both cephalic collapse or necrosis (type 1) and chronic dislocation or fracture-dislocation (type 2), in which an osteotomy of the greater tuberosity for prosthetic replacement is not required; and category 2, extracapsular/disimpacted fracture sequelae, associated with both surgical neck nonunions (type 3) and severe tuberosity malunions (type 4), in which an implant usually cannot be inserted without osteotomy and repositioning of the greater tuberosity. The type of initial fracture, the technical difficulties, the complications, and the functional outcomes are clearly different for these 2 categories of fracture sequelae (Figure 2, Tables I and II). In this study, statistically significant differences were seen in prosthetic replacement between those fracture sequelae in which a greater tuberosity osteotomy was performed and those in which this procedure was not performed. All of the excellent and good functional results were obtained in the intracapsular/impacted sequelae category, in which a greater tuberosity osteotomy was not required. With the extracapsular/disimpacted category, in which prosthetic arthroplasty required greater tuberosity osteotomy and repositioning, results were poor and no patient regained active anterior elevation above 90°.

In extracapsular sequelae of fractures of the proximal humerus, there is often a disimpaction and/or a rotation of the humeral head. This displacement of the humeral head, which remains outside the capsule, leads to a

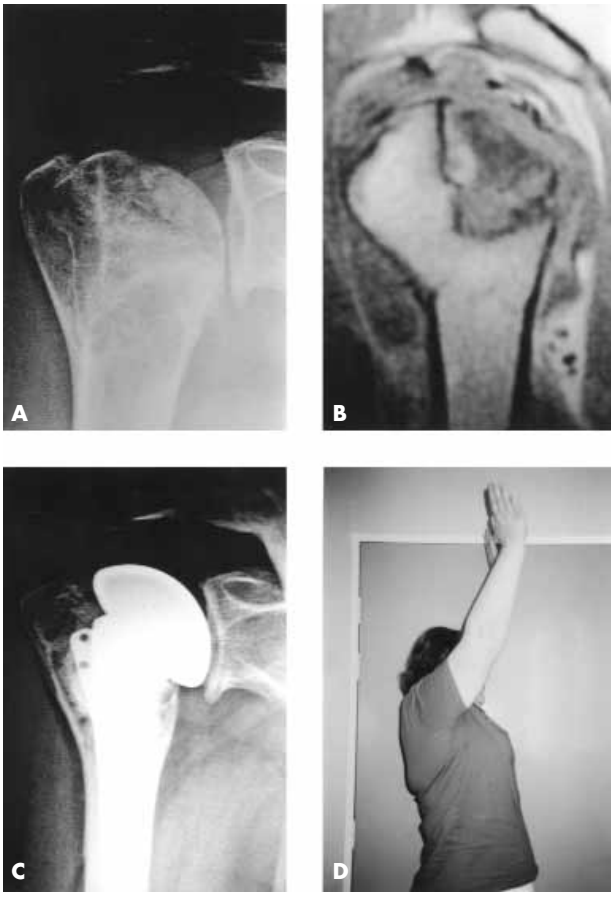


**Figure 4** Radiograph (**A**) and MRI (**B**) of type 1 sequela of a proximal humerus fracture, with minimal displacement of greater tuberosity and impaction of head fragment (type 1). After shoulder arthroplasty (**C**), there was an excellent functional result (**D**), despite the slight distortion of the anatomy of the proximal humerus.

*References 1, 8, 11, 14, 16, 18, 21, 26, 29, 31, 37, 40.

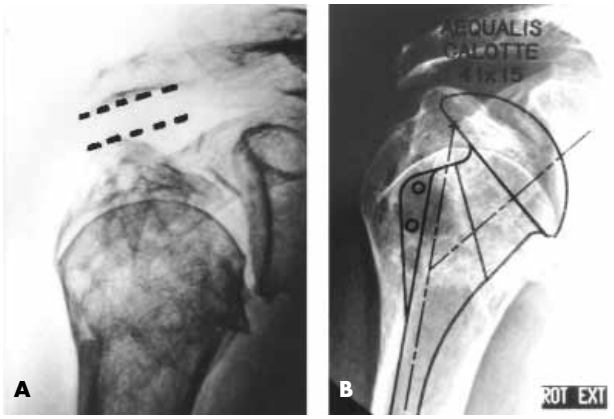


**Figure 5** Radiograph demonstrating the false impression of greater tuberosity upward migration in type 1 fracture sequela, due to valgus impaction of the head fragment: measurement of greater tuberosity to acromion distance is normal (**A**). The radiographic preoperative planning helps to anticipate adaptation of prosthesis to modified anatomy (**B**).

major and intolerable displacement of the tuberosities. Figure 3 summarizes the relationship between the mechanism of the initial fracture and the final sequelae. As evidenced in our series, when a greater tuberosity osteotomy is necessary for tuberosity repositioning accompanying prosthetic implantation, the greater tuberosity does not seem to tolerate this second "fracture." Devascularization of the greater tuberosity, leading to tuberosity nonunion, migration, and resorption, is probably the reason for these poor results.[6,8,10,26] We believe that this new classification system provides a coherent pathophysiologic basis for the sequelae of proximal humerus fractures and allows the operative indications, the potential technical problems, and the postoperative prognosis to be more clearly and predictably defined during the important preoperative planning stages.

The negative prejudicial effect of a greater tuberosity osteotomy in prosthetic replacement of the shoulder has been suggested by many authors.[5,6,16,26,37,40] Neer[26] himself has already suggested "cheating" in the borderline malunions by using a prosthesis with a small stem and a small head, in a varus position, to avoid having to perform a greater tuberosity osteotomy. As Neer[23,25] further emphasized, greater tuberosity nonunion is responsible for weakness of the infraspinatus, one of the key muscles in active elevation. He suggested that by maintaining continuity of the tuberosity and the cuff with the diaphysis, there is no need to slow down rehabilitation until there is bony consolidation. The greater tuberosity is often only slightly displaced in type 1 and 2 sequelae, following those fractures that are intracapsular/impacted (Figure 4). Hence, it is often possible to remove enough bone from the deep surface of the greater tuberosity to allow implantation of the humeral component and still maintain continuity of the tuberosity and the rotator cuff. Retrospectively, we feel that the 3 osteotomies performed


**Figure 6** Radiograph of type 3 sequela of proximal humerus fracture, with severe displacement of the greater tuberosity and nonunion of the surgical neck (**A**). Despite the accurate reconstruction of the anatomy of the proximal humerus (**B**), functional result is poor, with active elevation below the horizontal level (**C**) and painful shoulder, but good rotation (**D**). Greater tuberosity osteotomy is the reason for this poor functional result because of persistent nonunion and bone resorption.

in type 1 and 2 sequelae in this series could have been avoided and were not indicated. In our radiographic review we observed that there is often a false impression of superior migration of the greater tuberosity in these intracapsular/impacted fractures because of varus or valgus impaction of the humeral head fragment: measurement of the greater tuberosity to acromion distance demonstrates only slight narrowing or even a normal space (Figure 5). Superior malposition of the greater tuberosity in these cases usually remains limited: the bone fragment remains hooked on the diaphysis because of the neutralizing forces between the supraspinatus (pulling superiorly) and the infraspinatus and teres minor (pulling inferiorly). This explains why greater tuberosity osteotomy can often be avoided in type 1 and 2 sequelae at the time of shoulder arthroplasty.

In contrast, isolated osteotomy of the lesser tuberosity

was not detrimental to the functional results of shoulder replacement in this series and possibly even augmented restoration of active elevation beyond the horizontal plane. The beneficial nature of an isolated lesser tuberosity osteotomy in old trauma of the proximal humerus has already been pointed out by Neer.[26] He described partially or totally excising the lesser tuberosity to reattach the subscapularis to the supraspinatus in order to recover full external rotation in such difficult post-traumatic conditions.

Analysis of each of the 4 individual types of lesions, within the 2 main categories of fracture sequelae, revealed that the functional results achieved with shoulder arthroplasty in nonunion of the surgical neck (type 3) were the worst in our series. The average normalized Constant score at last follow-up was only 57%. None of these patients regained elevation above the horizontal plane, and 3 still had annoying pain. The only real benefit of the surgery was the recovery of a satisfactory range of external rotation (Figure 6). Treatment of nonunion of the surgical neck is a difficult task, as first illustrated by the 35 failed repair attempts in the 50 nonunions in the series of Neer.[25] Nicholson et al[27] are the only authors to report that humeral head replacement is comparable, if not superior, to open reduction and internal fixation of these nonunions, providing 60% to 80% satisfactory results. Our own experience and that of other authors[4,8,13,28,29,34] runs contrary to this; filling of the intramedullary canal by the prosthesis often prevents union of the tuberosities to the humeral shaft. For these reasons, further emphasized by the poor results obtained in this study, we now believe that replacement arthroplasty should be abandoned in the treatment of surgical neck nonunions. We believe that arthroplasty should only be proposed in cases of long-standing nonunion, in which the humeral head has totally resorbed or collapsed. Union of the tuberosities to the humeral shaft should be the primary goal of treatment. We have previously reported our experience with a large intramedullary autogenous iliac crest bone graft (intramedullary bone peg) with internal fixation and cancellous bone grafting for the treatment of these nonunions.[39] This technique has resulted in satisfactory function and mobility of the shoulder in our series. In our opinion, this or a similar technique should be the first (and possibly only) treatment for nonunions of the surgical neck of the humerus.

Furthermore, as in other series in the literature, the poor results achieved with shoulder arthroplasty in severe tuberosity malunions (type 4) are also reflected in our study. Consequently, surgeons should anticipate a limited functional result when implanting a shoulder arthroplasty in type 4 sequelae of proximal humerus fractures (long-standing surgical neck nonunions and severe tuberosity malunions) because of the necessity to perform a concomitant greater tuberosity osteotomy. In those clinical situations, surgeons should inform the patient preoperatively of the postoperative prognosis, and both the surgeon and the patient should only expect a prosthetic replacement with a "limited goal" result. A promising option for such difficult situations is to consider implanting a reversed constrained prosthesis (Delta; Depuy Orthopaedics, Warsaw, Ind). Ongoing studies are currently investigating this technique in Europe.

Finally, we recognize the limitations of this study in attempting to establish treatment guidelines when the average postoperative follow-up is only short term, especially with a multicenter data collection. However, the essential message demonstrated by our results is consistent with that of the published literature: the risk of poor results associated with osteotomy of the greater tuberosity in prosthetic replacement should lead surgeons to abandon the idea of reconstructing normal anatomy of the proximal humerus "at any cost." It may be necessary to accept some deformity of the proximal humerus to preserve good postoperative functional results. If prosthetic replacement is possible without an osteotomy, surgeons should accept the distorted anatomy of the proximal humerus and adapt the prosthesis and their technique to the modified anatomy. Adaptation of the shoulder prosthesis to the distorted anatomy is extremely useful, avoiding the need for a greater tuberosity osteotomy in many cases. Because we had at our disposal a modular and adaptable shoulder prosthesis, it was often possible to reapproximate the distorted anatomy of the proximal humerus by changing the inclination and/or offsets of the prosthetic articular surface. The capability of varying inclination and translating the articular surface superiorly (superior offset) was particularly useful in the sequelae of 4-part valgus impacted fractures, whereas in locked posterior dislocations or fracture-dislocations, the prosthesis was inserted after translating the articular surface posteriorly. In our opinion the use of such adaptive surgical techniques, and the avoidance of a greater tuberosity osteotomy whenever possible, will result in a shoulder prosthetic replacement with a more predictable chance of a good or excellent functional result.

We thank D. Gouttallier (Paris); L. Favard (Tours); H. Mestdagh (Lille); D. Molé (Nancy); J. F. Kempf (Strasbourg); P. Habermeyer (Stuttgart); J. C. Le Huec (Bordeaux); M. Basso (Giens); and J. P. Franceschi (Marseille) for providing some of the cases in this study. We also thank B. Veneau for assistance with the statistical analyses.

**REFERENCES**

1. Beredjiklian Pk, Ianotti JP, Norris TR, Williams GR. Operative treatment of malunion a fracture of the proximal aspect of the humerus. J Bone Joint Surg Am 1998;80:1484-97.
2. Boileau P, Walch G. Adaptability and modularity in shoulder arthroplasty. Acta Orthop Belg 1995;61(Suppl I):49-61.
3. Boileau P, Walch G. The three dimensional geometry of the proximal humerus: implications for surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79:857-65.
4. Boileau P, Walch G, Trojani C, Sinnerton R, Romeo AA, Veneau B. Sequelae of fractures of the proximal humerus: surgical clas-

sification and limits of shoulder arthroplasty. In: Walch G, Boileau P, editors. Shoulder arthroplasty. Berlin: Springer-Verlag; 1999. p. 349-58.
5. Cofield RH. Shoulder replacement: prognosis related to diagnosis. In: Kôlbel R, Helbig B, Blauth W, editors. Shoulder replacement. Berlin: Springer-Verlag; 1987. p. 157-61.
6. Compito CA, Self EB, Bigliani LU. Arthroplasty and acute shoulder trauma: reasons for success and failure. Clin Orthop 1994;307:27-36.
7. Constant CR, Murley AHG. A clinical method of functional assessment of the shoulder. Clin Orthop 1987;214:160-4.
8. Dines DM, Klarren RF, Altcheck DW, Moeckel B. Posttraumatic changes of the proximal humerus: malunion, nonunion, and osteonecrosis. Treatment with modular hemiarthroplasty or total shoulder arthroplasty. J Shoulder Elbow Surg 1993;2:11-21.
9. Ficat P. Idiopathic femoral head necrosis. Rev Prat 1979;29: 479-89.
10. Flatow EL, Neer CS II. Chronic anterior dislocation of the shoulder. J Shoulder Elbow Surg 1993;2:2-10.
11. Frich LH, Sjoberg JO, Sneppen O. Shoulder arthroplasty in complex acute and chronic proximal humerus fractures. Orthopedics 1991;14:949-54.
12. Hawkins RJ, Neer CS II. Locked posterior dislocation of the shoulder. J Bone Joint Surg Am 1987;69:9-18.
13. Healy WL, Jupiter JB, Kristiansen TK, White RR. Nonunion of the proximal humerus. In: Post M, Morrey BF, Hawkins RJ, editors. Surgery of the shoulder. St. Louis: Mosby; 1990. p. 59.
14. Huten D, Duparc J. Prosthetic arthroplasty in recent and old complex injuries of the shoulder [in French]. Rev Chir Orthop Reparatrice Appar Mot 1986;72:517-29.
15. Ianotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg Am 1992;74:491-500.
16. Ianotti JP, Sidor ML. Malunions of the proximal humerus. In: Warner JP, Ianotti JP, Gerber C, editors. Complex and revision problems in shoulder surgery. Philadelphia: Lippincott-Raven; 1997. p. 245-64.
17. Jakob RP, Kristiansen T, Mayo K, Ganz R, Muller ME. Classification and aspects of treatment of fractures of the proximal humerus. In: Bateman JE, Welsh RP, editors. Surgery of the shoulder. Philadelphia: Decker; 1984. p. 330-4.
18. Jakob RP, Miniani A, Anson PS. Four part valgus impacted fractures of the proximal humerus. J Bone Joint Surg Br 1991;73:295-8.
19. Keene JS, Huizenga RE, Engber WD, Rogers SC. Proximal humeral fractures: a correlation of residual deformity with long term function. Orthopedics 1983;6:173.
20. Kyle RF, Conner TN. Post-traumatic avascular necrosis of the humeral head in displaced proximal humeral fractures. J Trauma 1981;21:788-91.
21. Lee CK, Hansen HR. Post-traumatic avascular necrosis of the humeral head in displaced proximal humeral fractures. J Trauma 1981;21:788-91.
22. Neer CS II. Displaced proximal humeral fractures part 1: classification and evaluation. J Bone Joint Surg Am 1970;52:1077-89.
23. Neer CS II. Displaced proximal humeral fractures part 2: treatment of three and four part displacement. J Bone Joint Surg Am 1970;52:1090-103.
24. Neer CS II, Watson KC, Stanton FJ. Recent experience in total shoulder replacement. J Bone Joint Surg Am 1982;64:319-37.
25. Neer CS. Nonunion of the surgical neck of the humerus. Orthop Trans 1983;3:389.
26. Neer CS. Oqld trauma in glenohumeral arthroplasty. In: Shoulder reconstruction. Philadelphia: Saunders; 1990. p. 222-34.
27. Nicholson GP, Flatow EL, Bigliani LU. Shoulder arthroplasty for proximal humeral fractures. In: Friedman RJ, editor. Arthroplasty of the shoulder. New York: Thieme; 1994. p. 183-93.
28. Norris TR, Turner JA, Bovill D. Nonunion of the upper humerus: an analysis of the etiology and treatment in 28 cases. In: Post M, Morrey BF, Hawkins RJ, editors. Surgery of the shoulder. St. Louis: Mosby; 1990. p. 63-7.
29. Norris TR, Turner JA. Late prosthetic shoulder arthroplasty for displaced proximal humerus fractures. J Shoulder Elbow Surg 1995;4:271-80.
30. Pritchett JW. Prosthetic replacement for chronic unreduced dislocations of the shoulder. Clin Orthop 1987;216:89-93.
31. Razemon JP, Baux S. Les séquelles des fractures de l'extrémité supérieure de l'humérus. Rev Chir Orthop 1969;55:479-90.
32. Resch H, Beck E, Bayley I. Reconstruction of the valgus impacted humeral head fracture. J Shoulder Elbow Surg 1995;4:74-80.
33. Rowe CR, Zarins B. Chronic unreduced dislocations of the shoulder. J Bone Joint Surg Am 1982;64:494-505.
34. Scheck M. Surgical treatment of nonunions of the surgical neck of the humerus. Clin Orthop 1982;167:255-9.
35. Sidor ML, Zuckerman JD. The Neer classification system for proximal humerus fractures. J Bone Joint Surg Am 1993;75: 1745-50.
36. Siebenrock, Gerber C. The reproducibility of classification fractures of the proximal end of the humerus. J Bone Joint Surg Am 1993;75:1751-5.
37. Tanner MW, Cofield RH. Prosthetic arthroplasty for fractures and fractures dislocations of the proximal humerus. Clin Orthop 1983;179:116-28.
38. Walch G, Boileau P, Martin B, Dejour H. Unreduced posterior dislocations and fracture-dislocations of the shoulder. A review of 30 cases. French J Orthop Surg 1990;4:461-75.
39. Walch G, Badet R, Nove-Josserand L, Levigne C. Nonunions of the surgical neck of the humerus: surgical treatment with an intramedullary bone peg, internal fixation and cancellous bone grafting. J Shoulder Elbow Surg 1996;5:161-8.
40. Watson KC. Indications and considerations of shoulder replacement in post-traumatic conditions. In: Kôlbel R, Helbig B, Blauth W, editors. Shoulder replacement. Berlin: Springer-Verlag; 1987. p. 129-33.