Tuberosity malposition and migration: Reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus

P. Boileau, S. G. Krishnan, L. Tinsi, G. Walch, J. S. Coste, and D. Molé, *Nice, France*

The purpose of this study was to evaluate the results of hemiarthroplasty for displaced proximal humeral fractures and to assess clinical and radiologic parameters that could explain unsatisfactory results. Sixty-six consecutive patients (45 women and 21 men) with a mean age of 66 years (range, 31-85 years) were followed up postoperatively for a mean of 27 months (range, 18-59 months), both clinically and radiologically. Subjectively, 29 patients were very satisfied, 9 were satisfied, and 28 were unsatisfied. Postoperative active elevation averaged 101° ± 33°, external rotation averaged 18° ± 15°, and internal rotation averaged the L3 level (±3 vertebrae). The absolute Constant score averaged 56 of 100 points (range, 20-95 points). Initial tuberosity malposition was present in 18 patients (27%). Tuberosity detachment and migration were noted in 15 patients (23%). Tuberosity migration could be observed after initial tuberosity malpositioning, as well as after initial correct positioning. Final tuberosity malposition occurred in 33 patients (50%) and correlated with an unsatisfactory result, superior migration of the prosthesis, stiffness or weakness, and persistent pain. Factors associated with failure of tuberosity osteosynthesis were poor initial position of the prosthesis (specifically, excessive height and/or retroversion), poor position of the greater tuberosity, and women over age 75 years (likely with osteopenic bone). Techniques to improve tuberosity osteosynthesis, including modifications to current prosthetic design and instrumentation to allow for a more anatomic reconstruction, should lead to more predictable and satisfactory results. (J Shoulder Elbow Surg 2002;11: 401-12.)

From the Department of Orthopaedic Surgery, Hôpital de L'Archet–University of Nice, Nice, France.

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

1058-2746/2002/$35.00 + 0 **32/1/124527**
doi:10.1067/mse.2002.124527

INTRODUCTION

Although displaced proximal humeral fractures involving the tuberosities and the articular surface are often treated by hemiarthroplasty, the results remain unpredictable. In 1970 Neer[30] reported the results of prosthetic replacement in displaced 3- and 4-part fractures and fracture-dislocations of the proximal humerus: excellent or satisfactory results were obtained in 90% of the patients.[29-32] However, a critical review of the literature reveals that no other studies have been able to reproduce the results obtained by Neer.* These other authors have reported less satisfactory or even disappointing results with stiff and painful shoulders, demonstrating that shoulder replacement itself is not a guarantee of successful outcome in these complex injuries.

Unpredictable results may be related to the relative infrequency of these fractures, and a lack of experience of the treating surgeon potentially may contribute to inexact technique.[1,2,4,6,10,27,43] In fact, recent authors have questioned the original recommendations of Neer and Stableforth that comminuted fractures of the proximal humerus should be treated with prosthetic replacement.[30,39]

The purpose of this prospective multicenter study was to evaluate the results after hemiarthroplasty for displaced proximal humeral fractures and to assess clinical and radiologic parameters that could both explain unsatisfactory results and guide future treatment considerations.

MATERIALS AND METHODS

Between 1991 and 1996, 73 consecutive acute 3- and 4-part displaced proximal humeral fractures underwent operative treatment with the same nonconstrained shoulder prosthesis. All patients were treated under the direct supervision of a senior shoulder surgeon at 8 different centers. All fractures were classified by the Neer and AO systems.[22,29] The classification was established by the preoperative radiographs, a preoperative computed tomography (CT) scan (performed in 38 four-part fractures), and the intraoperative findings, to minimize intraobserver and interobserver variability of the different classifications.[25,36,37] Three patients

*References 8, 12-17, 19, 20, 24, 26, 33, 39, 41, 42, 44.

Table I Anatomopathology of 66 acute fractures (Neer and AO classifications)

Type of fracture	No.
4-Part displaced or dislocated (C3)	30
Anterior	14
Posterior	3
Lateral	8
Inferior	5
4-Part valgus impacted (C2)	21
4-Part varus impacted (C2)	8
3-Part with displaced greater tuberosity (B2)	4
3-Part dislocation with surgical neck and greater tuberosity displaced (B3)	3
Total	66

who died and 4 who were lost to clinical follow-up were excluded from the study, leaving 66 patients for clinical and radiographic evaluation.

The mean age of the patients at the time of the trauma was 66 years (range, 31-85 years). There were 45 women (68%) and 21 men. The right side was affected in 45% of patients, and the dominant arm was involved in 62%. The cause of the initial fracture was a simple fall in 63%, a motor vehicle accident in 28%, and a seizure with a subsequent fall in 9%. There were associated fractures in 8 cases: 4 contralateral upper limb fractures (1 olecranon fracture, 2 distal radial fractures, and 1 metacarpal fracture) and 4 lower limb fractures (1 pubic ramus fracture, 1 femoral fracture, 1 tibial fracture, and 1 medial malleolar fracture).

In 3 cases an unsuccessful attempt at reduction with the patient under general anesthesia had been made prior to the definitive surgery. In 2 cases osteosynthesis had been attempted, either in the days preceding the arthroplasty (1 case) or at the same time as the arthroplasty (1 case). All fractures underwent operative treatment with prosthetic hemiarthroplasty within 3 weeks of injury and, on average, within 5 days of the inciting trauma.

Of the 66 fractures available at review, there were 7 three-part fractures and 59 four-part fractures (Table I).

Surgical technique

The operative technique was standardized and followed the principles detailed by Neer.[4,10,30,31,43] An extended deltopectoral approach, without detachment of the anterior deltoid, was used in all cases, and the coracoacromial ligament was preserved. A longitudinal cuff tear involving the supraspinatus was present in 4 cases of anteroinferior fracture-dislocation and was repaired by side-to-side sutures in each case. Whenever possible, the periosteal attachments between the tuberosities and the diaphysis were preserved. A glenoid fracture at the anteroinferior border of the articular surface was present in 5 cases; all were small enough to be ignored without compromising glenohumeral joint stability.

After sutures were placed through the bone-tendon junction of the lesser and greater tuberosity fragments, the humerus was prepared through use of cylindrical broaches. All surgeons used the same nonconstrained implant (Aequalis prosthesis; Tornier, Inc, St Ismier, France). The prosthesis was cemented in all cases. The size of the prosthetic head was chosen after measurement of the diameter of the fractured head with a caliper. Nine fractures, which had metaphyseal-diaphyseal extensions, required complementary osteosynthesis, with either cerclage sutures (8 cases) or cerclage wire (1 case). In 2 cases an extra-long stem was required because of extension of the fracture into the diaphysis.

Tuberosity osteosynthesis was performed with the use of heavy (No. 5), nonabsorbable sutures. The goal was to attach the tuberosity fragments to the humeral shaft, to each other, and to the prosthesis.[4,30,43] Cancellous bone graft, taken from the humeral head, was placed between the tuberosities and the diaphysis to facilitate bony union. The biceps tendon was tenodesed in 26 cases (43%).

Rehabilitation was started with pendulum exercises on the first postoperative day and followed the principles of early passive motion emphasized by Neer.[5,30] Forty-seven patients (seventy-one percent) were transferred to a rehabilitation center for a mean stay of 6 weeks (range, 3-12 weeks). The initial rehabilitation period lasted 6 to 8 weeks and consisted of only passive pendulum exercises, passive external rotation, and passive anterior elevation. After 6 to 8 weeks, active rehabilitation was started. Patients were instructed to participate in a supervised therapy program for at least 1 year after the surgery. Unsatisfactory cooperation with rehabilitation occurred in 20 patients (30%) who were elderly (15 cases over 80 years old) or had alcoholism (5 cases).

Patients were clinically and radiographically evaluated postoperatively at 3, 6, 12, and 24 months and then yearly. Their charts, operative reports, and preoperative/postoperative radiographs were reviewed by 2 observers (P.B. and L.T.). The mean follow-up was 27 months (range, 18-59 months). The functional result was calculated by the Constant scoring system.[11] Pain was assessed with a visual analog score and was categorized on a 4-level scale as none, mild, moderate, or severe. Range of motion was measured with a goniometer. Muscular strength was measured with a spring balance that measured up to 50 kg; 2 points were given for each kilogram pulled. The patient was sitting and the elbow was held straight while the patient maintained resisted elevation for a period of 5 seconds. The test was done at 90° of flexion or whatever level below 90° could be reached without pain. Three power measurements were carried out. The mean of the 3 readings was accepted as the shoulder power. Activities of daily living were assessed according to the recommendations of Constant, achieving points for ability to work, to perform leisure or sports activities, and to attain undisturbed sleep.

A detailed questionnaire concerning 10 tasks of daily living was also used to evaluate the functional ability of each patient. Finally, patients were asked if they were very satisfied, satisfied, disappointed, or unhappy with the functional result.

The clinical results were also graded as excellent, satisfactory, or unsatisfactory, according to Neer and McIlven.[32] For an excellent result, the patient had no or slight pain, had active elevation superior to 140°, had external rotation superior to 50°, and was very satisfied or satisfied with the result. For a satisfactory result, the patient had no, slight, or moderate pain only with vigorous activities, had

more than 90° of active elevation, had external rotation to 50% of the normal side, and was satisfied with the procedure. For an unsatisfactory result, these criteria were not met. In the shoulders in which revision or reoperation was necessary, the grade assigned was unsatisfactory.

All preoperative and postoperative radiographic evaluations were standardized anteroposterior (AP) in 3 rotations (internal, neutral, and external) and the lateral and axillary views. The quality of the humeral reconstruction was analyzed preoperatively and at the last review by evaluation of the position of both the tuberosities and the prosthesis in the horizontal and vertical planes. Bilateral scaled radiographs of humeri were obtained at the most recent follow-up in 39 cases to measure and compare humeral length on both sides. A CT scan of the operated shoulder was carried out in 23 cases, in which the greater tuberosity could not be clearly seen on the standard radiographs, in an attempt to localize it and measure prosthetic retroversion.

Initial tuberosity malposition

Initial tuberosity malposition in the vertical plane (ITMV) was evaluated on the immediate postoperative AP radiograph in neutral rotation. A line, tangent to the top of the prosthetic head and perpendicular to the axis of the stem of the prosthesis, was drawn. According to previous anatomic studies, the greater tuberosity was considered correctly positioned when it was visible, and its summit was between 5 and 10 mm below the summit of the prosthetic head.[4,21,35] If the greater tuberosity was 10 mm inferior to the tangent line of the head, it was considered to be too low. If the greater tuberosity was 5 mm superior to the tangent line of the head, it was considered to be too high.

Initial tuberosity malposition in the horizontal plane (ITMH) was also evaluated. The greater tuberosity was considered to be malpositioned if it was not visible on the postoperative AP view in neutral rotation. In these cases, the greater tuberosity was found to be hidden behind the prosthetic head and neck, with no bone lateral to the prosthetic fine. The AP radiograph in internal rotation, axillary view, or lateral view then showed the piece of greater tuberosity.

The total number of initial tuberosity malposition (ITMs) was given by summing the numbers of vertical and horizontal tuberosity malpositions (ITM = ITMV + ITMH). However, this number took into account the fact that some patients may have tuberosity malposition of both tuberosities.

Final tuberosity malposition

Final tuberosity malposition in the vertical plane (FTMV) was evaluated on the last postoperative AP radiograph with the same technique of measurement and the same criteria used for the ITM.

Final tuberosity malposition in the horizontal plane (FTMH) was diagnosed when the greater tuberosity was not found on the last postoperative AP view in neutral or external rotation but was found either on the AP view in internal rotation, axillary view, or lateral view or on CT scan.

The total number of final tuberosity malpositions (FTMs) was given by summing the numbers of vertical and horizontal tuberosity malpositions (FTM = FTMV + FTMH). Again, this number took into account the fact that some patients have malposition of both tuberosities.

Tuberosity detachment and migration

Tuberosity detachment and migration (TDM) was evaluated by comparing the initial and final position of the tuberosities on AP radiographs or on CT scans (or both). Malunion, nonunion, and bone resorption were carefully assessed.

Prosthetic "height" (or humeral length)

The humeral length was determined on bilateral scaled radiographs in 39 cases by plotting the prosthetic axis (middle of the proximal medullary canal) and measuring the distance between two perpendicular tangents to this axis: one at the top of the prosthetic or humeral head and the other at the middle of the medial epicondyle. According to a previous anatomic study, a difference of less than 10 mm between both humeri was considered to be normal.[6] When humeral lengths were compared, the prosthesis was considered to be too high if the difference in length was superior to 10 mm and too low if it was inferior to 10 mm.

Prosthetic retroversion

Prosthetic retroversion was measured on CT scans in 23 cases. Axial images of both the proximal humeral articular surface and the distal medial and lateral epicondyles of the elbow were superimposed on the same panel. Retroversion was calculated by measuring the angle subtended by the articular surface of the prosthesis relative to the transepicondylar axis of the elbow. According to previous anatomic studies, prosthetic retroversion was considered to be normal when it was between 0° and 40° in relation to the transepicondylar line.[4,9,21,23,35,40]

Proximal migration of prosthesis

Proximal migration of the prosthesis was evaluated by measurement of the acromiohumeral distance on the final AP radiograph in neutral rotation—the distance between the summit of the prosthetic head and the line of sclerosis of the acromion, measured on an AP view in neutral rotation. A distance of less than 7 mm indicated proximal migration of the humerus.[21]

Periarticular ectopic bone formation

Periarticular ectopic bone formation, as classified by Sneppen et al,[38] was also evaluated.

Radiolucent lines around prosthetic stem

Radiolucent lines around the prosthetic stem were also evaluated. A complete lucent line, greater than or equal to 2 mm at the bone-cement interface, was considered evidence of radiographic loosening of the humeral prosthesis.

Statistical analysis

Statistical analysis was performed with the Student *t* test for numerical data and correlation and regression tests for

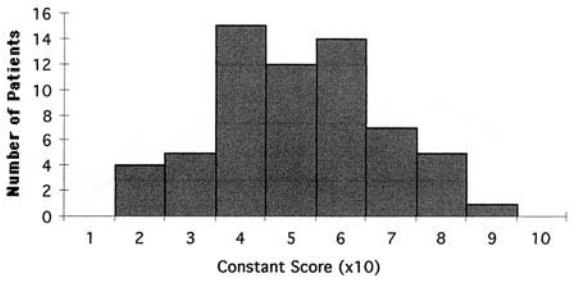

Figure 1 Absolute Constant score (mean, 56 points).

Table II Active anterior elevation at final review (mean, 101°)

Active anterior elevation	No. (n = 66)	%
0°-30° (0 points)	0	0
30°-60° (2 points)	5	7.5
60°-90° (4 points)	12	18
90°-120° (6 points)	30	45.5
120°-150° (8 points)	15	22.5
150°-180° (10 points)	4	6.5

Table III Severity of pain (mean, 11.5/15 points)

Severity of pain	No. (n = 66)	%
Severe (0-4 points)	1	1.5
Moderate (5-9 points)	7	11
Mild (10-14 points)	38	57.5
None (15 points)	20	30

nonparametric data. The level of significance was set at $P < .05$.

RESULTS

Clinical results

At final review, the absolute Constant score averaged 56 out of 100 points (range, 20-95 points). Figure 1 summarizes the values of the absolute Constant score. The Constant score, normalized for age and sex, averaged 74% (range, 31%-116%).

The results were rated as excellent in 15 patients (22.5%), good in 16 (24.5%), fair in 22 (33%), and poor in 13 (20%). Postoperative active elevation averaged 101° (range, 30°-175°) (Table II). Mean active external rotation was 17.5° (range, 0°-42°). Mean active internal rotation was L3 (range, greater trochanter to T8).

Postoperative pain scores averaged 11.5 of 15 points (range, 0-15 points). The severity of pain is summarized in Table III. Eight patients (12.5%) had moderate or severe pain.

Mobility scores averaged 22.1 of 40 points (range, 2-40 points), activity 12.5 of 20 points (range, 4-20 points), and muscular strength 8.5 of 25 points (range, 2-18 points). The mean strength, in active anterior elevation measured with a spring balance, was 3.7 kg (range, 0-9 kg).

Table IV Scoring for activities of daily living

Function (normal or with mild compromise)	Rating (%)
Use back pocket	92
Wash opposite axilla	76
Comb hair	38
Carry 4-6 kg with arm at side	56
Use hand with arm at shoulder level	65
Use hand with arm above head	47
Care for perineum	87
Eat with utensils	76
Sleep on affected side	56
Dress self	70

The functional evaluation for 10 activities of daily living is summarized in Table IV. The most common limitations in case of fair or poor results were inability to sleep on the affected side, carry a weight, comb hair, or use the hand above shoulder level.

Patient satisfaction was also evaluated; 29 patients (44%) were very satisfied with the results, 9 (14%) were satisfied, 28 (42%) were disappointed, and 1 was unhappy. The objective functional results obtained by calculating the Constant score were in significant agreement with the patients' own subjective opinions of outcome ($P = .001$).

Radiographic results

Initial Tuberosity Malposition. ITMV was present in 12 cases (18%). The greater tuberosity was considered to be too low (10 mm inferior to the tangent line of the head) in 8 cases; it was considered to be too high (5 mm superior to the tangent line of the head) in 4 cases.

ITMH was present in 15 cases (23%), the greater tuberosity being too posterior (not visible on the postoperative AP view). The lesser tuberosity was too medial in 3 cases (ie, it was located medial to the humerus on the AP radiograph in neutral rotation).

The total number of ITMs, given by summing both vertical and horizontal tuberosity malpositions (ITM = ITMV + ITMH), was 18 (27%). Both tuberosity malpositions could be present in the same patient; for instance, the greater tuberosity could be too low and too posterior or too high and too posterior (Figure 2).

Final Tuberosity Malposition. FTMV was present in 20 cases (30%). The greater tuberosity was too high in 11 cases and too low in 9 cases.

FTMH, evaluated on the last postoperative AP radiograph, on axillary views, and on CT scan, was present in 19 cases (28%).

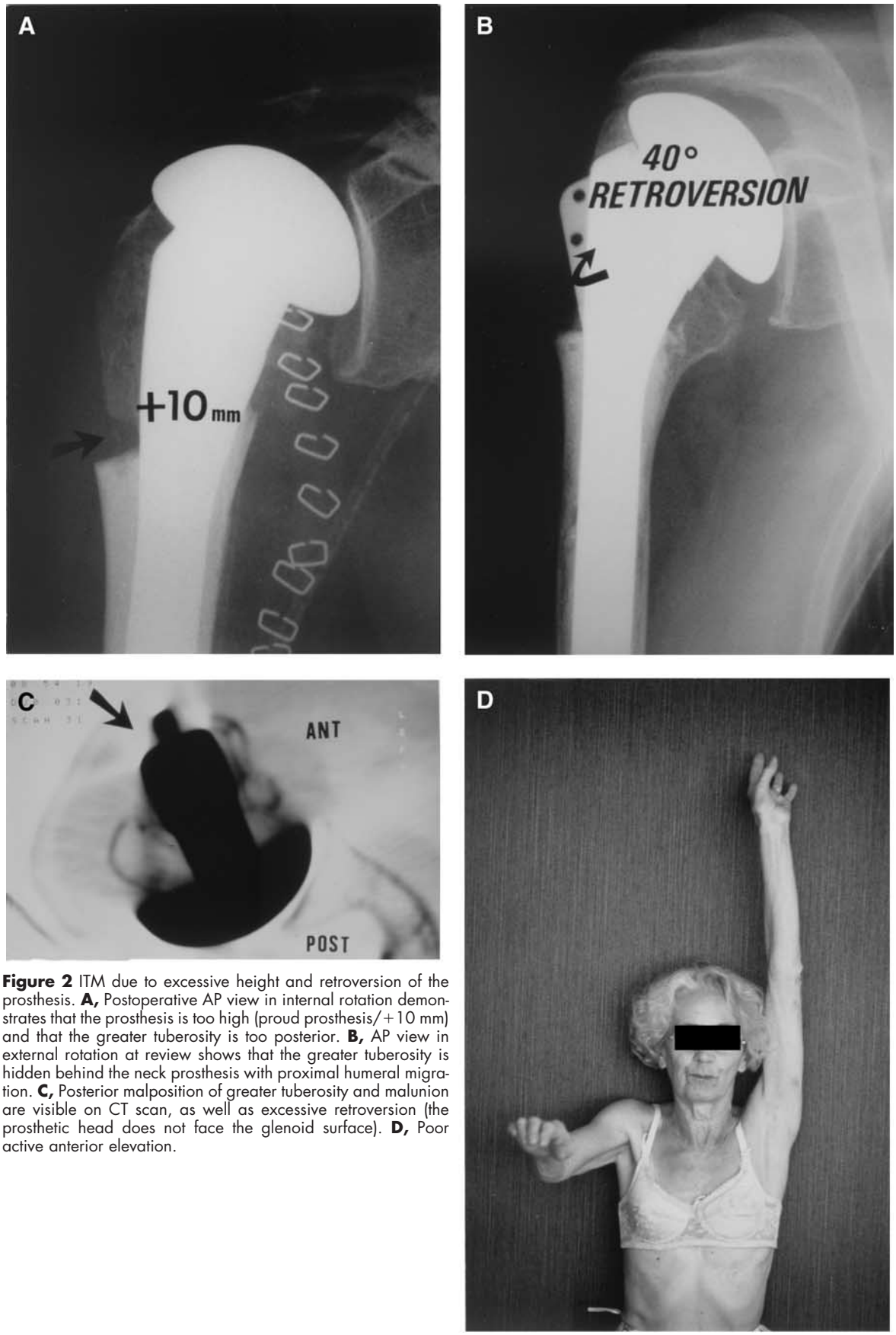

Figure 2 ITM due to excessive height and retroversion of the prosthesis. **A,** Postoperative AP view in internal rotation demonstrates that the prosthesis is too high (proud prosthesis/+10 mm) and that the greater tuberosity is too posterior. **B,** AP view in external rotation at review shows that the greater tuberosity is hidden behind the neck prosthesis with proximal humeral migration. **C,** Posterior malposition of greater tuberosity and malunion are visible on CT scan, as well as excessive retroversion (the prosthetic head does not face the glenoid surface). **D,** Poor active anterior elevation.

The total number of patients with an FTM was 33 (50%). This number takes into account the fact that some patients may have tuberosity malposition in both the vertical and horizontal planes. It includes the number of ITMs plus the number of TDMs.

Tuberosity Detachment and Migration. TDM was observed in 15 cases (23%). Tuberosity migration could be observed after initial tuberosity malpositioning, as well as after initial correct tuberosity positioning: 5 patients had tuberosity migration despite an anatomic initial tuberosity reconstruction and synthesis (Figure 3). Tuberosity resorption was present in only 3 cases (4%). This bone resorption was only partial and was associated with tuberosity malposition or migration in every case. Finally, there were 11 cases of tuberosity nonunion (17%) and 26 cases of tuberosity malunion (39%).

Prosthetic "height" (or humeral length). The prosthesis was considered to be too high, or "proud," (>10 mm), when compared with the contralateral humerus, in 10 of 39 cases (26%). The prosthesis was considered to be too low (>10 mm) in 14 of 39 cases (36%).

Prosthetic retroversion. Prosthetic retroversion was greater than 40° (relative to the transepicondylar axis) in 9 of 23 cases (39%). No prosthesis was found to be anteverted.

Proximal migration of prosthesis. Proximal migration of the prosthesis was present in 15 cases (22%), as demonstrated by an acromiohumeral distance (AHD) less than 7 mm on the final AP radiograph in neutral rotation.

Periarticular ectopic bone formation. Periarticular ectopic bone formation was present in 7 shoulders (10.5%): only 2 patients had grade III ossifications (true scapulohumeral bridge). Ectopic bone formation did not correlate with the functional results in this series.

Radiolucent lines around prosthetic stem. A complete radiolucent line around the prosthetic stem greater than 1 mm was present in 4 cases (6%), and 16 (24%) had an incomplete lucent line less than 1 mm in width. No radiographic loosening (complete lucent line ≥2 mm) of the humeral prosthesis was observed in this series.

Correlations

Final Tuberosity Malposition. FTM significantly correlated with a poor functional result. A high greater tuberosity, located 5 mm or more above the top of the prosthetic head, was associated with a poor functional result ($P = .01$). A low greater tuberosity, located 10 mm or more below the top of the prosthetic head, was also associated with a poor functional result ($P = .02$). A posterior greater tuberosity located behind the neck of the prosthesis was also associated with a poor functional result ($P = .007$).

Malposition of prosthesis. Malposition of the prosthesis, either in height and/or in retroversion, significantly correlated with a poor functional result. A proud prosthesis, with any elongation greater than 10 mm, was associated with a poor functional result ($P = .02$). This was detrimental for both active elevation ($P = .03$) and pain ($P = .02$). A proud prosthesis was also associated with proximal migration of the prosthesis under the acromion, as shown by a decrease in the AHD to less than 7 mm measured on the final AP radiograph in neutral rotation ($P = .001$). A low prosthesis was less detrimental for the functional result. A shortening of less than 10 mm was not associated with a poor result. However, if the shortening was greater than 15 mm, the Constant score decreased significantly ($P = .05$). Excessive prosthetic retroversion, greater than 40° (in relation to the transepicondylar axis of the elbow), was associated with a poor functional result ($P = .006$). In those cases, active anterior elevation averaged only 78° and active external rotation averaged only 6°. In addition, excessive retroversion was associated with a decrease in the AHD inferior to 7 mm ($P = .001$).

Malposition of the prosthesis significantly correlated with tuberosity malposition. A proud prosthesis was associated with a malposition of the greater tuberosity (superior and/or posterior, $P = .04$). A prosthesis implanted with retroversion greater than 40° relative to the transepicondylar axis of the elbow was significantly associated with a posterior malposition of the greater tuberosity ($P = .001$). The worst association was a prosthesis that was too high and too retroverted with a low greater tuberosity: this "unhappy triad" was present in 5 cases and was significantly associated with migration of the greater tuberosity and proximal migration of the prosthesis under the acromion in all cases. The functional result was also poor with persistent pain and stiffness in all cases.

Age and sex. Age and sex significantly correlated with greater tuberosity migration and poor outcomes. Women over 75 years old had poorer results ($P = .05$).

Complications

Three patients had perioperative neurologic complications involving the axillary nerve. All 3 lesions were partial and recovered. One patient sustained an anterior dislocation when she fell 18 months after surgery. The anterior dislocation was reduced with the patient under general anesthesia. Although the functional result was poor, with active anterior elevation of only 45°, the patient did not have pain and did not want to undergo further surgery.

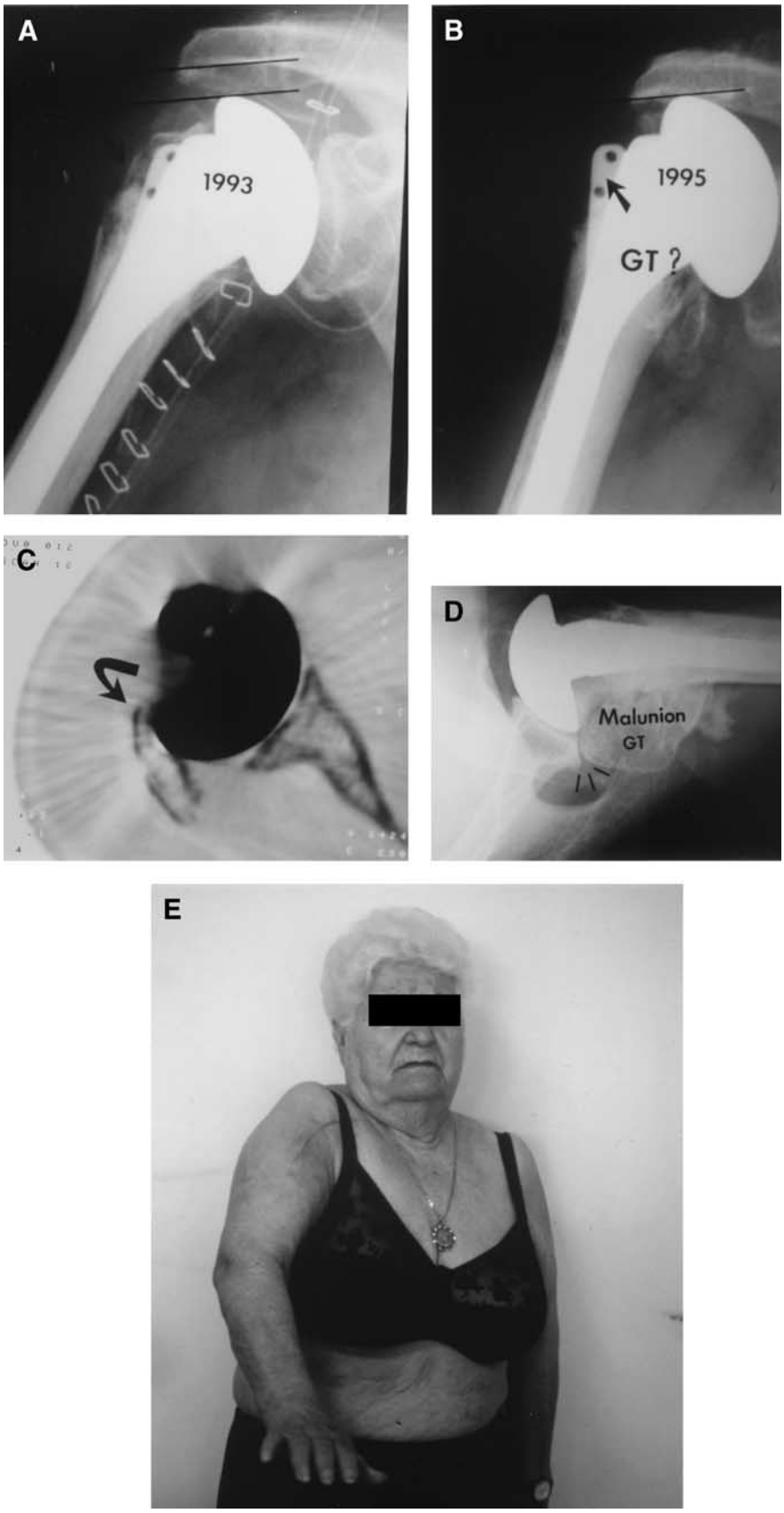

Figure 3 Tuberosity migration despite initial correct positioning of both the prosthesis and the tuberosities. **A,** Immediate postoperative radiograph demonstrates correct position of both the tuberosities and the prosthesis. **B,** Radiograph at review demonstrates both the tuberosity migration (greater and lesser tuberosities) and the prosthesis ascension under the acromion. *GT,* Greater tuberosity. **C,** Posterior migration of the greater tuberosity on CT scan. **D,** Axillary view demonstrates greater tuberosity *(GT)* malunion. **E,** Poor functional result with poor anterior elevation.

DISCUSSION

This study demonstrates that the functional results after hemiarthroplasty for 3- and 4-part proximal humeral fractures appear to be directly associated with tuberosity osteosynthesis. The most significant factor associated with poor and unsatisfactory postoperative functional results was malposition and/or migration of the tuberosities. Initial tuberosity malposition was present in 18 patients (27%). TDM was observed in 15 patients (23%). Final tuberosity malposition occurred in 33 patients (50%). Tuberosity malposition and migration resulted in an unsatisfactory result with superior migration of the prosthesis, stiffness, weakness, and persistent pain. Factors associated with a failure of tuberosity osteosynthesis in this study were as follows: poor initial position of the prosthesis, poor position of the greater tuberosity, and women over 75 years of age (likely with osteopenic bone).

The fact that tuberosity malposition and migration is associated with poor functional results is not surprising because of the modified lever arm for glenohumeral abduction.[6,34] Greater tuberosity displacement has been identified by Tanner and Cofield[41] as being the most common complication after prosthetic arthroplasty for proximal humeral fractures. Furthermore, Bigliani et al[1] examined the causes of failure after prosthetic replacement for proximal humeral fractures and found that, although almost all failed cases had multiple causes, the most common single identifiable reason was greater tuberosity displacement.

Neer[28-30] emphasized the importance of proper positioning of the shoulder implant with regard to humeral height and retroversion in replacement arthroplasty for proximal humeral fractures.[32] Correctly establishing the height and retroversion of the humeral prosthesis is difficult in fracture cases because, except in rare cases, the proximal anatomic landmarks have disappeared as a result of bone loss.[10,26,31,43] It may also be technically difficult to maintain the prosthesis in an accurate position during both trial positioning and final cementation: often, either the diameter of the stem is oversized and fills the canal (placing the prosthesis in a proud position) or it is undersized (placing the prosthesis in a low position).[6]

In this series of patients, lengthening of the humerus of more than 10 mm because of a proud prosthesis significantly correlated with tuberosity detachment and proximal migration of the prosthesis under the acromial arch with limited function. Lengthening of the humerus seems to create two potentially undesirable consequences: (1) a possible nonunion between the greater tuberosity and the humeral diaphysis because the prosthesis protrudes from the shaft and (2) a possible rotator cuff stretch or tear because of excessive tension on the supraspinatus (Figures 2 and 4).

Shortening of the humerus was much better tolerated clinically; functional results were not significantly altered until the humeral shortening exceeded 15 mm. This finding confirms previously published work[2,20] and is in agreement with Neer and Kirby,[31] who stated that a loss of humeral length is extremely common in prostheses for fractures and that a loss of 2 cm or more is necessary to adversely affect deltoid power.

Proper positioning of the shoulder implant with regard to humeral retroversion is another challenge in 3- and 4-part fractures. Neer,[28] in 1955, wrote that "the surgeon must remember that the normal humeral head faces posteriorly about 20 degrees. The proper amount of retroversion can be reselected daily if the two epicondyles are palpated at the elbow and the head is turned about 20 degrees from their plane." However, as shown in this study, properly selecting prosthetic humeral retroversion in fracture situations can be difficult, even for experienced shoulder surgeons. The most common mistake was found to be excessive retroversion of the prosthesis (Figure 2).

We believe that the functional consequences of increased retroversion of the humeral prosthesis in the treatment of proximal humeral fractures have been underestimated until now.[5,6] The 9 cases in this study with retroversion of the prosthesis exceeding 40° relative to the transepicondylar axis of the elbow were all associated with posterior migration of the greater tuberosity and a poor functional result at follow-up. Positioning the prosthesis with too much retroversion precludes the correct positioning of the greater tuberosity in the horizontal plane. Excessive prosthetic retroversion also has the potential effect of inducing a detachment of the greater tuberosity, because of excess tension on the tuberosity repair when the arm is in internal rotation (which is the usual postoperative position in a sling) (Figure 5).

As demonstrated by the results of this study, prosthetic positioning directly and significantly influenced both the final status of the greater tuberosity and the postoperative functional outcome. Surgeons should realize that it is almost impossible to reduce the tuberosities anatomically if the prosthesis is malpositioned. The worst combination in our series was a prosthesis that was too proud and too retroverted with a greater tuberosity that was positioned too low; this unhappy triad inevitably leads to posterior migration of the greater tuberosity with a poor functional result.

When the greater tuberosity is not visible on the AP radiograph, other authors have interpreted this finding as being the result of bone lysis or bone resorption in the healing phase of the osteosynthesis.[10,14,15,26,43] In our series the greater tuberosity was, in fact, present even in 3 cases of partial oste-

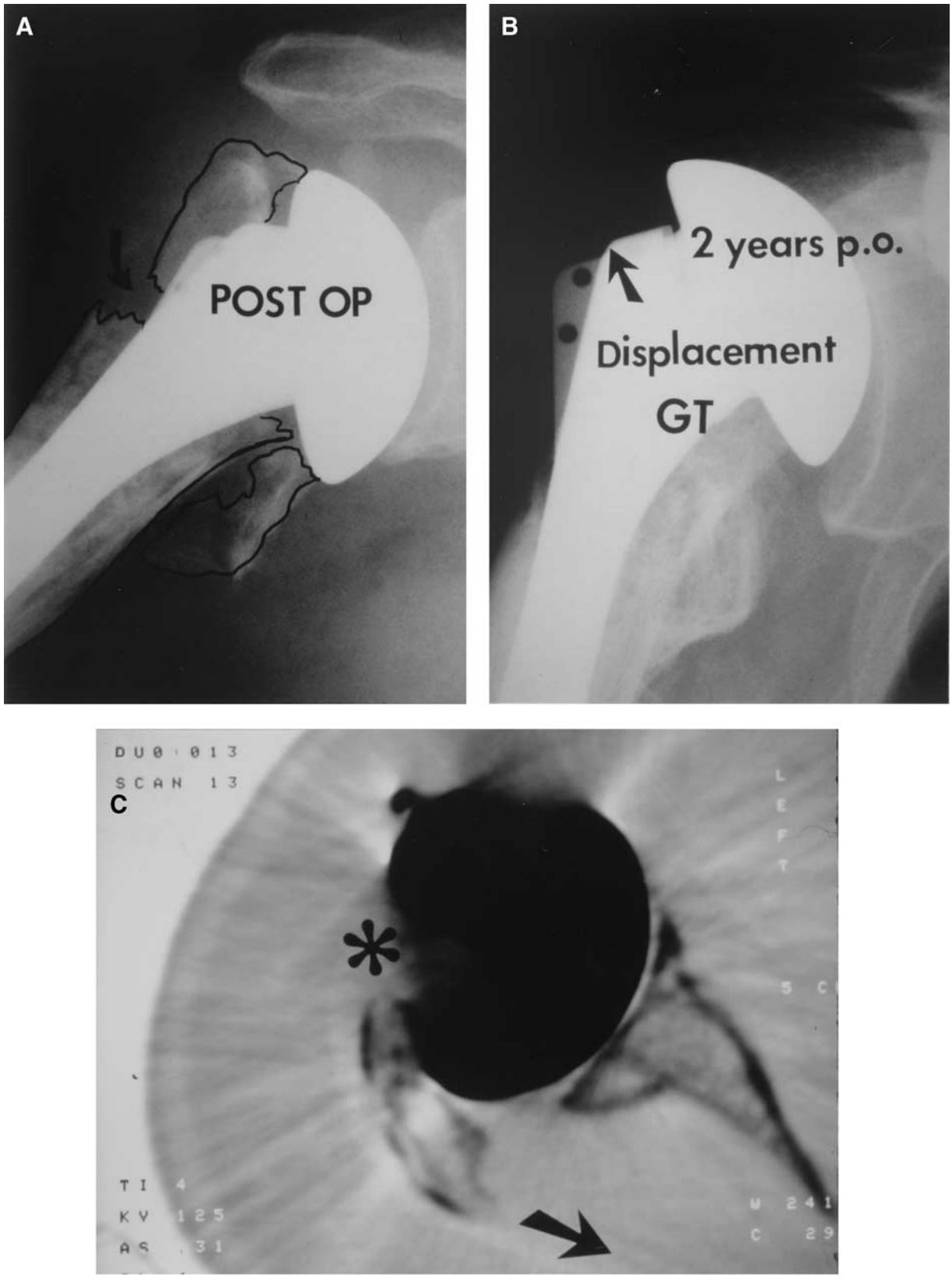

Figure 4 Tuberosity migration after shoulder replacement for fracture. **A,** Proud prosthesis and poor positioning of lesser tuberosity. **B,** Two years postoperatively *(p.o.)*, the greater tuberosity *(GT)* is not visible on the AP view and there is a proximal migration of the prosthesis. **C,** Posterior migration of greater tuberosity is visible on CT scan. *; initial position of greater tuberosity.

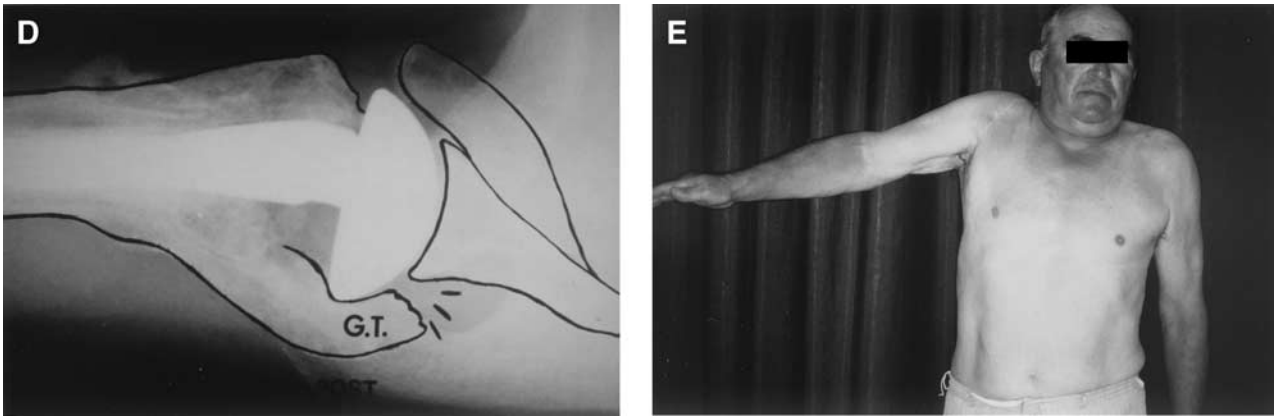

Figure 4 D, Posterior glenoid impingement due to greater tuberosity *(G.T.)* displacement and malunion is visible on axillary view. **E,** Poor abduction.

olysis. The greater tuberosity was posteriorly malpositioned (and/or migrated) behind the metal neck of the prosthesis, only being visible on an AP radiograph in internal rotation, an axillary radiograph, and/or a CT scan (Figure 4).

All of the authors since Neer have stressed the necessity of meticulous and strong fixation of the greater tuberosity osteosynthesis with nonabsorbable sutures.[4,10,13,31,32,43] In all cases in the present series, large-diameter (No. 5 or 7) nonabsorbable sutures were used to secure both tuberosity fragments horizontally and vertically, to ensure better stability and facilitate bony consolidation with the humeral diaphysis. Fixation of the tuberosities, regardless of quality, does not seem capable of withstanding the forces generated when the humeral prosthesis is positioned too high or too retroverted. However, some of the tuberosity failures occurred despite apparently anatomic prosthesis and tuberosity positioning (Figure 3). It is our inter-

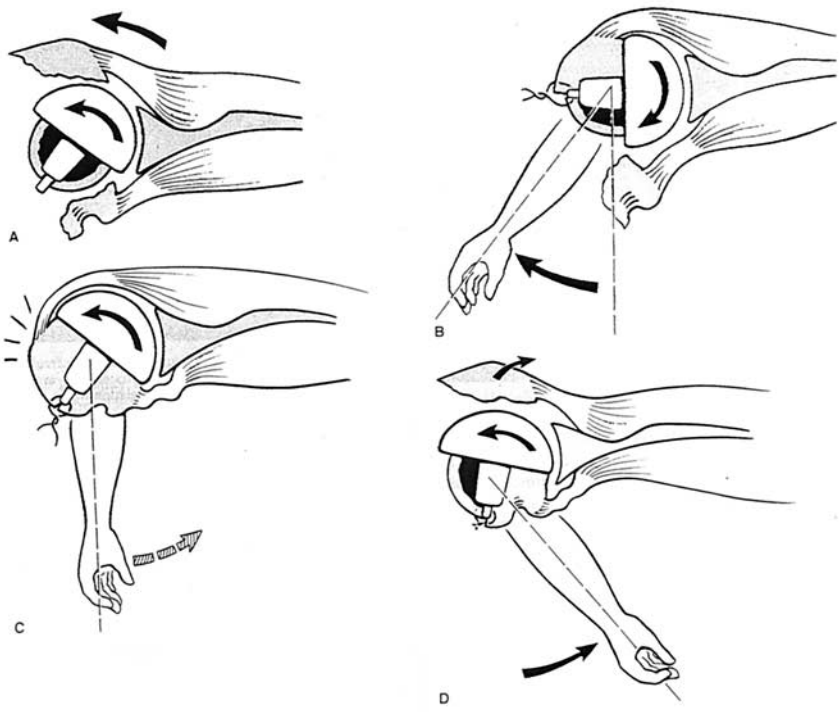

Figure 5 Consequences of an excessive prosthetic retroversion in fractures. **A,**The prosthesis is cemented with an excessive retroversion. **B,** Osteosynthesis is possible with the arm in external rotation **C,** but leads to pull-out the sutures when the arm is in neutral rotation **D,** and posterior migration of the greater tuberosity when the arm is placed in internal rotation (arm in a sling at the end of the procedure).

pretation that perhaps these tuberosity detachments and migration were related to suture breakage on the rough surface of the metal prosthesis and/or to obstruction of the healing process by the metal of the prosthesis.

Prevention of tuberosity malposition and migration appears to be of paramount importance in shoulder replacement for fractures. Exact and accurate positioning of the prosthesis in fracture situations, with regard to both height and retroversion, appears to be an essential step for a successful osteosynthesis of the tuberosities. Most of the errors in restoring anatomic humeral height and appropriate retroversion seem to occur because of eyeball positioning of the humeral prosthesis in fracture treatment. Thus, we believe that it may be relevant to consider the use of instrumentation to stabilize the implant and to position the humeral component more accurately and objectively in both height and retroversion during the treatment of acute proximal humeral fractures with a prosthetic hemiarthroplasty. Accurate tuberosity positioning, in both horizontal and vertical planes, is another important technical factor that surgeons should control. In case of doubt, we recommend an intraoperative radiograph to evaluate both the prosthetic and tuberosity position.

We believe that the current design of standard humeral prostheses may not be appropriate to the fracture situation; an excess of metal at the neck level, as demonstrated from the CT scan cuts, makes greater tuberosity placement difficult and may also obstruct bone healing. Modification in current prosthetic design to allow for more accurate tuberosity placement (and hence aid bone healing) should lead to more predictable and satisfactory results.

We also believe that the postoperative position of the arm should be altered in an attempt to decrease the horizontal plane forces on the greater tuberosity osteosynthesis from the infraspinatus and teres minor. It is now our practice to place the arm in a brace in neutral rotation instead of a sling in internal rotation.

Finally, the degree of osteopenia in these challenging cases should not be overlooked. We now recommend slowing the rehabilitation program in elderly patients, especially in women over 75 years of age. We do believe that the primary goal in shoulder replacement for fractures of the proximal humerus must be to obtain anatomic tuberosity healing. Everything, including technical and technologic innovations, should be aimed at reaching this goal.[3,7,40]

We thank M. Basso (Giens), J. F. Kempf (Strasbourg), L. Favard (Tours), J. C. Lehuec (Bordeaux), and H. Mestdagh (Lille) for providing some of the cases in this study.

REFERENCES

1. Bigliani LU, Flatow EL, McCluskey, Fischer RA. Failed prosthetic replacement for displaced proximal humeral fractures. Orthop Trans 1991;15:747-8.
2. Boileau P, Chau E, Perraud M, Arcamone H, Argenson C. Restoration of humeral length and humeral offset after shoulder prosthesis for fractures [abstract]. Rev Chir Orthop 1993;73: 150.
3. Boileau P, Walch G, Krishnan SG. Tuberosity osteosynthesis and hemiarthroplasty for four-part fractures of the humerus. Techniques Shoulder Elbow Surg 2000;1:96-109.
4. Boileau P, Walch G. Three dimensional geometry of the proximal humerus: implications for the surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79:857-65.
5. Boileau P, Cordero-Caligaris B, Payeur F, Tinsi L, Argenson C. Rehabilitation following shoulder surgery for fracture. Rev Chir Orthop 1999;85:106–16.
6. Boileau P, Walch G. Shoulder arthroplasty for fractures: problems and solutions. In: Walch G, Boileau P, editors. Shoulder arthroplasty. Heidelberg: Springer-Verlag; 1999. p. 297-314.
7. Boileau P, Tinsi L, Lehuec JC, Molé D, Sinnerton R, Walch G. Results of shoulder arthroplasty in acute fractures of the proximal humerus. In: Walch G, Boileau P, editors. Shoulder arthroplasty. Heidelberg: Springer-Verlag; 1999. p. 331-45.
8. Bosh U, Skutel M, Fremerey RW, Scherne H. Outcomes after primary and secondary hemiarthroplasty in elderly patients with fractures of the proximal humerus. J Shoulder Elbow Surg 1999.
9. Broca P. La torsion de l'humérus et le tropomètre, instrument destiné à mesurer la torsion des os (rédigée par L. Mamouvier). Revue d'Anthrop 1881;2(ème série 4):193-210, 385-423, 1577-92.
10. Compito CA, Self EB, Bigliani LU. Arthoplasty and acute shoulder trauma, reasons for success and failure. Clin Orthop 1994;307: 27-36.
11. Constant CR, Murley AHG. A clinical method of functional assessment of the Shoulder. Clin Orthop 1987;214:160-4.
12. De Anquin CE, De Anquin CA. Prosthetic replacement in the treatment of serious fractures of the proximal humerus. In: Bayley JL, Kessel L, editors. Surgery of the Shoulder. Berlin: Springer-Verlag; 1982. p. 207-17.
13. DesMarchais JE, Maurais G. Treatment of complex fractures of the proximal humerus by Neer's hemiarthroplasty. In: Bateman JE, Welsh RP, editors. Surgery of the Shoulder. St. Louis: Decker; 1984. p. 60-3.
14. Frich LH, Sojberg JO, Sneppen O. Shoulder arthroplasty in complex acute and chronic proximal humerus fractures. Orthopaedics 1991;14:949-54.
15. Goldman RT, Koval KJ, Cuomo F, Gallagher MA, Zuckerman JD. Functional outcome after humeral head replacement for acute three-and four-part proximal fractures. J Shoulder Elbow Surg 1995;4:81-6.
16. Green A, Barnard WL, Imbird RS. Humeral head replacement for acute four-part proximal humerus fractures. J Shoulder Elbow Surg 1993;2:249-54.
17. Hawkins RJ, Switlyk P. Acute prosthetic replacement for severe fractures of the proximal humerus. Clin Orthop 1993;289:156-60.
18. Hughes M, Neer CS II. Glenohumeral joint replacement and postoperative rehabilitation. Phys Ther 1975;55:850-8.
19. Huten D, Duparc J. L'arthroplastie prothétique dans les traumatismes complexes récents et anciens de l'épaule. Rev Chir Orthop 1986;72:517-29.
20. Huten D, Boileau P, Bonnevialle P, Maynou C, Renault E, Vogt F, et al. Résultats et indications de l'arthroplastie prothétique dans les fractures récentes complexes de l'extrémité supérieure de l'humérus. Paris: Conférences d'Enseignement de la SOFCOT, Expansion Scientifique Française Ed. 1996. p. 125-40.
21. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of the

hundred and forty shoulders. J Bone Joint Surg Am 1992;74:491-500.
22. Jakob RP, Kristiansen T, Mayo K, Ganz R, Muller ME. Classification and aspects of treatment of fractures of the proximal humeri. In: Bateman JE, Welsh RP, editors. Surgery of the Shoulder. St. Louis: Decker; 1984. p. 330-43.
23. Khral VE, Evans FG. Humeral torsion in man. Am J Phys Anthrop 1945;3:229-53.
24. Kraulis J, Hunter G. The results of prosthetics replacement in fractures dislocations of the upper end of the humerus. Injury 1977;8:129-31.
25. Kristiansen B, Andersen LS, Olsen CA, Vasmarken JE. The Neer classification of fractures of the proximal humerus: an assessment of interobserver variation. Skeletal Radiol 1988;17:420-2.
26. Moeckel BH, Dines DM, Warren RF, Altchek DW. Modular hemiarthroplasty for fractures of the proximal part of the humerus. J Bone Joint Surg Am 1992;74:884-9.
27. Muldoon MP, Cofield RH. Complications of humeral head replacement for proximal humeral fractures. Instr Course Lect 1997; 46:15-24.
28. Neer CS II. Articular replacement of the humeral head. J Bone Joint Surg Am 1955;37:215-28.
29. Neer CS II. Displaced proximal humeral fractures—part 1: classification and evaluation. J Bone Joint Surg Am 1970;52:1077-89.
30. 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.
31. Neer CS, Kirby RM. Revision of humeral head and total shoulder arthroplasties. Clin Orthop 1982;100:189-95.
32. Neer CS, McIlven SJ. Remplacement de la tête humérale avec reconstruction des tuberosités et de la coiffe des rotateurs dans les fractures déplacées à 4 fragments. Résultats actuels et technique. Rev Chir Orthop 1988;74(Suppl II):32-40.
33. Pietu G, Deluzarches P, Goin F, Letenneur J. Traumatismes complexes de l'extrémité supérieure de l'humérus traités par prothèse céphalique: à propos de 21 cas revus avec un recul moyen de 4 ans. Acta Orthop Belg 1992;58:159-69.
34. Rietveld ABM, Dannen HAM, Rozing PM, Oberman WR. The lever arm in gleno-humeral adduction after hemiarthroplasty. J Bone Joint Surg Br 1988;70:561-5.
35. Roberts SNJ, Foley APJ, Swallow HM, Wallace WA, Coughlan DP. The geometry of the humeral head and the design of prostheses. J Bone Joint Surg Br 1991;73:647-50.
36. Sidor ML, Zuckerman JD, Lyon T, Cuomo F, Shoenberg N. The Neer classification for proximal humeral fractures. J Bone Joint Surg Am 1992;75:1745-50.
37. Siebenrock KA, Gerber C. The reproducibility of classification of fractures of the proximal end of the humerus. J Bone Joint Surg Am 1992;75:1751-5.
38. Sneppen O, Kjaersgaard-Andersen P, Frich LH. Ectopic ossification after total shoulder arthroplasty. A study on 75 Neer total shoulder replacements. In: Post, Morrey, Hawkins, editors.. 1990. p. 298-301.
39. Stableforth PG. Four part fractures of the neck of the humerus. J Bone Joint Surg Br 1984;66:104-8.
40. Steel FLD, Tomlinson JDW. The carrying angle in man. J Anat 1989;92:315-7.
41. Tanner MW, Cofield RH. Prosthetic arthroplasty for fractures and fracture dislocations of the proximal humerus. Clin Orthop 1983; 179:116-28.
42. Willems WJ, Lim TEA. Neer arthroplasty for humeral fractures. Acta Orthop Scand 1985;56:394-5.
43. Zuckerman JD, Cuomo F, Koval KJ. Proximal humeral replacement for complex fractures: indications and surgical technique. Instr Course Lect 1997;46:7-14.
44. Zyto K, Kronberg M, Brostrom LA. Shoulder function after displace fractures of the proximal humerus. J Shoulder Elbow Surg 1995;4:331-6.
45. Zyto K, Wallace WA, Frostick SP, Preston BJ. Outcomes after hemiarthroplasty for three- and four-part of the proximal humerus. J Shoulder Elbow Surg 1998;7:85-9.