

Prosthetic Version and Healing of the Greater Tuberosity: Their Influence on Functional Outcome in Implanted Hemiarthroplasties due to Fractures of the Proximal Humerus

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Purpose. To determine the influence of the prosthesis used and of greater tuberosity healing on the final functional result of shoulder hemiarthroplasties due to fracture of the proximal third of the humerus.

Materials and methods. This was a prospective study of 32 hemiarthroplasties with a mean followup of 43.51 months. X-ray control was carried immediately after surgery and at the end of the followup to assess the reduction of the greater tuberosity. Also at the end of the followup axial CAT scans (implant retroversion study), a functional assessment (Constant functional scale), and a health status determination (EuroQol-5D) were performed.

Results. The mean global value of the Constant scale for this series was 61.12. As to retroversion: values of 20–40° were seen in 8 patients, 0–20° in 20 patients and anteversion >0 in 4 patients. When the prosthesis model variable was compared using the Constant scale to determine functional outcome, no significant differences were seen ($p=0.558$). However, there was a trend to a better value in the Constant scale when the version of implant used was more anatomical, but this was not statistically significant.

Conclusions. There was a correlation between the quality of immediate postoperative reduction of the greater tuberosity, healing of the greater tuberosity and final functional outcome. There was a trend towards worse functional outcome in hemiarthroplasties with retro and anteversion values that were further from normal, but this was not statistically significant.

Key words: hemiarthroplasty, shoulder, fracture.

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Influencia de la versión protésica y de la consolidación del troquíter en el resultado funcional de las hemiarthroplastias implantadas por fractura de húmero proximal

Objetivo. Determinar la influencia de la versión protésica y la consolidación de la tuberosidad mayor en el resultado funcional final de las hemiarthroplastias de hombro por fractura del tercio proximal de húmero.

Material y método. Estudio prospectivo de 32 hemiarthroplastias con un seguimiento medio de 43,51 meses. Se ha efectuado un control radiológico en el postoperatorio inmediato y al final del seguimiento para evaluar la reducción obtenida del troquíter. También al final del seguimiento se ha realizado un estudio mediante tomografía axial computarizada (estudio de retroversión del implante), una evaluación funcional (escala funcional de Constant) y una valoración del estado de salud (EuroQol-5D).

Resultados. El valor global medio de la escala de Constant de la serie fue de 61,12. En cuanto a la retroversión, en 8 pacientes se obtuvo un valor entre 20–40°, en 20 pacientes un valor entre 0–20° y en 4 pacientes anteversión superior a 0°. Al comparar la variable versión protésica con el resultado funcional mediante la escala de Constant no se encontraron diferencias significativas ($p = 0,558$), aunque existe una tendencia hacia un mejor valor en la escala de Constant cuanto más anatómica sea la versión del implante.

Conclusión. Existe una correlación entre la calidad de la reducción postoperatoria inmediata de la tuberosidad mayor, la consolidación de la misma y el resultado funcional final. Existe una tendencia a presentar un peor resultado funcional en aquellas hemiarthroplastias cuya colocación se aleja más de los valores considerados como normales de versión, aunque sin significación estadística.

Palabras clave: hemiarthroplastia, hombro, fractura.

Fractures of the proximal third of the humerus are usual and account for 4% of all fractures. The expected growth in life expectancy in the next few years will lead to an increased prevalence of these fractures, mainly due to their relatedness to senile osteoporosis². Unlike fractures of the proximal third of the femur, humeral fractures tend to occur in more autonomous individuals, which means that these fractures could lead to changes in social requirements such that their treatment might not only have a effect on the patient but also on society at large.

Many of these fractures involve a very slight displacement and scholars seem to agree that their prognosis is good with conservative treatment. Around 15% of all fractures of the proximal third of the humerus are considered instable and their treatment is still a moot point^{3,4}. As far as treatment is concerned, there are many possibilities including conservative treatment, osteosynthesis (screws, plates, intramedullary nails and suture, cerclage, percutaneous fixation, etc) and humeral head replacement by means of a hemiarthroplasty. The indication for each of these options is based upon multiple factors such as fracture classification, age, bone quality and displacement. There is evidence in the literature that conservative treatment in complex proximal humerus fractures is usually accompanied by persistent pain, stiffness and functional shoulder alterations⁴. Nevertheless, we can also find studies that point to a lack of significant differences between the result of treating these fractures conservatively or surgically⁵.

When it comes to the surgical treatment of the more complex fractures (four-part fractures and fracture-dislocations according to Neer's classification⁶) one may choose either stabilized open reduction with different types of osteosynthesis or a hemiarthroplasty. The indication for each of these modalities is still controversial. Authors like Neer^{7,8} advocate osteosynthesis for three-part fractures and hemiarthroplasty for four-part ones, whereas other authors like Jakob et al⁹ recommend minimal internal fixation and early rehabilitation for four-part impacted valgus fractures. Before deciding to use one type of treatment rather than another it is important to determine the presence of the typical complication of fractures of the proximal third of the humerus, i.e. avascular necrosis of the humeral head. Fractures at the highest risk are three-part (3-14%) and four-part (13-34%) ones¹⁰. Anatomical studies have experimentally shown the discontinuance of blood supply to the humeral head in the fracture types mentioned¹¹. To the risk inherent in each fracture type one should add an increase in the percentage of necrosis when a surgical treatment is used that requires a wide exposure of soft tissues or the removal of the periosteum of the fracture site.

As regards the use of hemiarthroplasty for displaced fractures, the results reported in the literature are extremely varied¹²⁻¹⁶ and its indications and appropriate use are still a

matter of controversy. Functional results depend mainly on factors related to the patient and the fracture type, but also on factors inherent in the surgical technique and the postoperative treatment. As far as the surgical technique is concerned, an accurate anatomical implantation of the prosthesis in terms of height, medialization and retroversion is very important for the final result¹⁷⁻¹⁹. Another important factor that seems to exert an influence on the functional performance of the prosthesis is the capacity the tuberosities (especially the greater tuberosity) have to heal in the right place^{12,13}, which means that the surgical technique is a key factor for the functional result of the treatment of these fractures. Given that of all factors that influence the final result of hemiarthroplasties implanted in complex proximal humeral fractures the surgical technique is a surgeon-dependent one, we have designed a study aimed at determining the influence of the version in which the prosthesis is placed on the healing capacity of the greater tuberosity, as well as the repercussion of the healing of the greater tuberosity on the final functional result and on the patients' perception of their quality of life.

MATERIALS AND METHODS

This is a prospective study of 42 patients with a fracture of the proximal third of the humerus who were treated with a hemiarthroplasty (one patient had a prosthesis implanted in both shoulders). Patients were operated on between 1996 and 2002, and had a mean age of 74.51 years (range: 54-90). Thirty-two were female and 10 were male. Twenty-five were right shoulders and 19 were left shoulders. Taking into account that 11 patients were lost to follow-up as a result of death or health problems that made the final assessment impossible, we were left with a sample of 31 patients (32 hemiarthroplasties including one bilateral case). Mean follow-up was 43.51 months (range: 13-72). We used Neer's fracture classification. All patients were implanted with an anatomical modular hemiarthroplasty with an offset humeral head. The mean time elapsed from fracture production to surgical treatment was 5.41 days (range: 1-20).

All patients were subjected to a pre-op radiological study that included A/P and lateral views of the scapular plane, as well as a CT scan. The final fracture classification, based on the x-ray and CT images and on the naked-eye inspection of each fracture, resulted in the following distribution: 2 cases of two-part fractures of the anatomical neck, 14 cases of three-part fractures, 5 cases of three-part fracture-dislocations, 7 four-part fractures, 2 four-part fracture-dislocations and 2 cases of impressed fractures. All these patients were subjected to a radiological evaluation during the immediate post-op in order to assess the degree of reduction achieved in the greater tuberosity and three cate-



Figure 1. Successful immediate post-op reconstruction of the greater tuberosity.

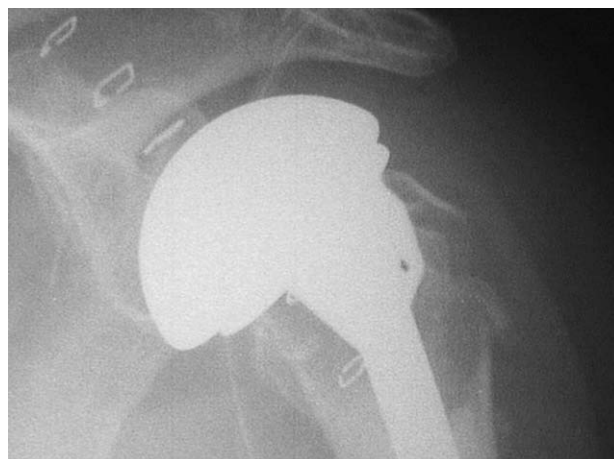


Figure 3. Poor greater tuberosity reconstruction in the immediate post-op.

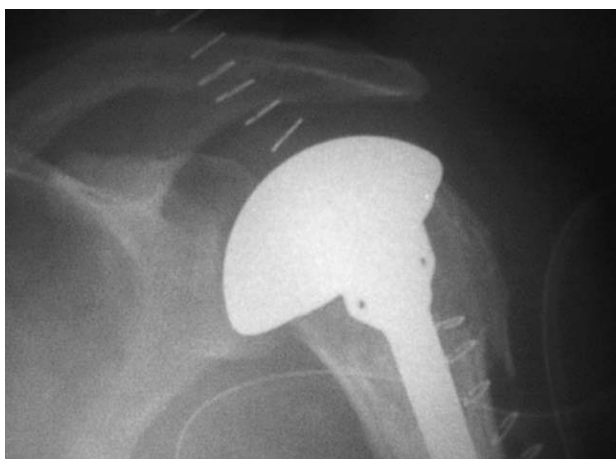


Figure 2. Fair greater tuberosity reconstruction in the immediate post-op.

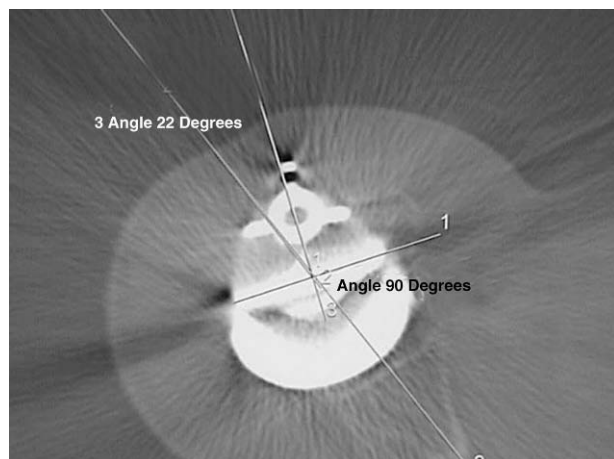


Figure 4. Calculation of the retroversion angle obtained transporting the epicondylar-epitrochlear axis to the proximal axial section.

gories were established: good, fair and poor. These categories were established on the basis of two parameters. The first was the fixation of the greater tuberosity onto the diaphysis and the second was the distance between the greater tuberosity and the upper end of the prosthesis, which ought to range between 5 and 10 mm. If the x-ray complied with these two parameters, the reduction was deemed good (Fig. 1), if it fulfilled only one parameter, it was considered fair (Fig. 2) and if neither parameter was met the reduction was considered poor (Fig. 3). At the end of follow-up, fresh plain x-rays and a CT-scan were performed, as well as a functional evaluation and an assessment of the patient's health status.

The CT-scan helped in two ways. On the one hand, it made it possible to determine the degree of healing of the greater tuberosity at the end of follow-up (at least one year); three categories were established: correct healing,

posterior healing and displaced or absent greater tuberosity. The CT-scan also allowed us to study the degree of retroversion of the prosthesis¹⁷⁻¹⁹, calculated by reference to the epicondylar-epitrochlear angle at the elbow¹⁹. The patient was placed in supine position on the CT table with the involved limb parallel to the table and parallel to the longitudinal axis of the body with the thumb pointed to zenith. Subsequently, the axial images are captured from the proximal third of the humerus and the distal humerus. At the proximal third of the humerus, an image is taken which shows the prosthetic head as a semicircle with the posterior lip. A line is drawn that joins the two posterior endings on the head (it corresponds to the posterior line that closes the semicircumference of the head in the axial image) and a line is drawn perpendicular to the previous one that runs through the posterior lip, thus obtaining the orientation axis of the humeral head.

As far as the distal humerus is concerned, we chose the image that showed it most fully and drew a line that ran between the innermost point in the epitrochlea and the most external point in the epicondyle, thus obtaining the epitrochlear-epicondylar axis. This axis is transferred to the proximal third of the humerus and the angle formed with the orientation axis of the humeral head is calculated, thus obtaining the prosthesis' retroversion angle (Fig. 4). Two measurements are taken of this angle in CT images like those described above, albeit at a different level, and the average of both is calculated.

Constant's Shoulder Scale²⁰ was used to perform the functional assessment of both the affected arm and the contralateral one, using a dynamometer to measure force in *pounds* (1 kg corresponds to 2 *pounds*). Finally, an assessment of the patients' health condition was performed, using the EuroQol-5D21 scale.

For the statistical analysis, quantitative variables were analyzed with Student's «t» test when two categories were compared, or with a single factor variance analysis (ANOVA) when there were more than two, applying Tukey's correction for multiple comparisons.

For categorical variables, the chi square test was used. Also, in order to analyze the relationship between two quantitative variables, Pearson's correlation coefficient was calculated. Finally, the kappa index was used to establish concordance across variables.

RESULTS

Results were obtained on the basis of a sample of 32 hemiarthroplasties implanted in patients with fractures of the proximal third of the humerus.

Clinical Results

The mean global result on Constant's Scale for the involved arm was 61.12 (range: 22-91), whereas the score for the contralateral limb was 82 (range: 63-95), which means that the differential Constant's Scale score between both extremities was 21.56 (range: 4-52).

If we break down Constant's Scale into its different categories, the mean score obtained for pain was 12.5 points (range: 0-15). As regards activities of daily living, the mean score was 16.8 points out of 20 (range: 4-20). The mean score for each of the categories related to joint balance was as follows: forward elevation: 6.1 (range: 2-10) (contralateral limb: 9.1 (range: 6-10); abduction: 5.7 (range: 2-10) (contralateral limb: 8.9 (range: 4-10); external rotation: 6.1 (range: 0-10) (contralateral shoulder: 9.5 (range: 6-10) and lastly for internal rotation in the involved shoulder the mean score was 6.7 (range: 2-10) and in the contralateral limb 8.6 (range: 6-10).

Table 1. Clinical results of the sample according to different retroversion categories

Constant	Retroversion		
	20-40°	0-20°	Anteversion
Total	64.0	60.50	58.50
Pain	11.25	13.0	12.50
DAs	15.50	16.50	16.0
FE	7.0	5.90	6.0
ABD	6.25	5.50	6.0
ER	7.25	5.90	5.0
IR	7.0	6.70	6.50
Strength	9.0	6.90	6.50

DA: Daily activities; FE: Forward elevation; ABD: abduction; ER: external rotation; IR: internal rotation.

Mean muscular strength, measured in pounds, was 7.3 lb (range: 2-20), which compared with the mean strength of the contralateral limb was 11.1 lb (range: 6-20). The Constant's Scale scores obtained for each one of the retroversion categories are shown in Table 1.

Radiological Results

Great tuberosity reduction as seen in the the early post-op x-rays was deemed good in 16 patients, fair in 12 and poor in 4. As regards great tuberosity healing, as determined by CT and plain radiographs at the end of follow-up (minimum one year), it was established that healing was satisfactory in 15 patients, with 15 patients healing in a posterior position and 2 patients showing no healing at all.

As far as retroversion calculations are concerned, 8 patients showed physiological healing between 20 and 40°, 20 had retroversion between 0 and 20° and four obtained anteversion higher than 0°.

Complications

The patients included in the series showed no peroperative complications, immediate or late infections or neurological lesions. In the 11 patients lost to follow-up no preoperative or postoperative complications were recorded up to the interruption of controls. The only noteworthy complications were the 17 cases of migration and poor healing of the greater tuberosity mentioned above, which occurred during the follow-up period and which it was decided not to reoperate given the fragmented condition of the greater tuberosity, which would prevent a new fixation from succeeding.

Health Status Assessment

The mean Euroqol-5D score for these patients according to the Visual Analog Scale (VAS) was 0.68 (range:

Table 2. Contingency expressing the correlation between immediate post-op reduction of the greater tuberosity and its final healing at the end of follow up

GT	Rx			Total
	Good	Fair	Poor	
Satisfactory	11	4	0	15
Posterior	5	7	3	15
Absent	0	1	1	2
Total	16	12	4	32

Rx: Post-op great tuberosity reduction variable; GT: greater tuberosity healing at the end of follow-up variable

0.17-1.0) out of 1. The EQ 2 questionnaire, which compares current health status with that of the last 12 months, showed that 5 patients (15.6%) improved, 17 (53.1%) underwent no changes vis-à-vis their previous situation and 10 (31.25%) complained that their health status had worsened. Finally, on the EQ 3 survey, which assesses health status on a Visual Analog Scale, gave a mean score of 64.5 out of 100.

Study of statistical correlations across variables

We established several correlations across the variables in our study following the pattern of the statistical tests mentioned in the Material and Method section.

On comparing Constant's Functional Scale with the degree of healing achieved in the greater tuberosity, we found statistically significant differences ($p = 0,000$), which means that the better the consolidation of the greater tuberosity, the better the functional result of the prosthesis as measured by Constant's Scale. Moreover, if Constant's Scale is broken down into its different categories, significant differences are found with respect to daily activities ($p = 0,002$), forward elevation ($p = 0,000$), abduction ($p = 0,001$), external rotation ($p = 0,000$) and strength ($p = 0,000$). On the other hand, no statistical significance is obtained with respect to pain ($p < 0,192$) or internal rotation ($p < 0,260$). Analyzing the values obtained one might conclude that practically no patient in the series experienced pain after implantation of the hemiarthroplasty, regardless of the degree of greater tuberosity healing. Likewise, with respect to internal rotation, we found no statistically significant differences. When comparing immediate post-op reduction of the greater tuberosity with the tuberosity's healing at the end of follow-up, one observes the correlation shown in the contingency table (Table 2).

If we give the variable Rx a value of 1 for cases of good post-op reduction, 2 for fair reductions and 3 for poor ones; and if we give the variable TC the value 1 if healing is satisfactory, 2 if it is posterior and 3 if it is nonexistent, we can observe in the first column that out of the 16 patients whose initial reduction was satisfactory in the immediate post-op,

11 healed correctly and 5 did so posteriorly. In the second column, of the 12 patients for whom the post-op reduction obtained was fair, 4 healed correctly and 7 posteriorly. And in the third column, of the 4 patients for whom post-op reduction was poor, none healed correctly.

When comparing the "post-op reduction of the greater tuberosity (Rx)" with Constant's Scale through a variance analysis, the Constant Scale scores for the Rx variable classified as 1 (good reduction), 2 (fair) and 3 (poor) were 65.9; 59.1; 48.0 respectively; a statistically significant lineal relation was obtained ($p = 0,037$).

When comparing the EuroQol-5D variable (health status perception test) with the "greater tuberosity healing (TC)" variable no significant differences were found ($p = 0,521$), in the same way as no significant differences were found when comparing the EuroQol-5D variable with the different categories of Constant's Scale.

When comparing the "prosthetic version" variable with Constant's Scale, if we consider two categories for the version variable (physiological (20-40°) and non-physiological (the remaining ones), the Constant Scale scores for each of these categories were 64.0 and 61.1 respectively, with no significant differences being found ($p = 0,558$). This means that the higher the Constant Scale scores the more anatomical the prosthetic version, although this finding had to statistical significance. Likewise, considering three categories for the "prosthetic version" variable, i.e. physiological (20-40°), non-physiological (0-20°) and anteversion over 0°, Constant Scale scores were 64.0; 60.5 and 58.5 respectively, there being no significant differences. In spite of this, the previously mentioned relation was still observed, that is, the more physiological the prosthetic version, better the functional outcome.

Finally, an assessment was made of the relationship between the "prosthetic version" and "greater tuberosity healing" variables through a Contingency Table and the chi square test. The "prosthetic version" variable was given two categories: physiological and non-physiological; the "healing" variable was also given two categories: appropriate and pathological. In this way, it can be seen that in patients presenting with a physiological prosthetic retroversion (20-40°) the greater tuberosity healed appropriately in 62.5% of cases, whereas in those who had a non-physiological prosthetic version the greater tuberosity healed appropriately in 41.7% of cases ($p = 0,306$). Although no statistically significant differences were observed, a greater healing capacity can be attributed to greater tuberosities with a more physiological prosthetic version.

DISCUSSION

The treatment of proximal humeral fractures is still a controversial issue. The fact that these fractures tend to be

osteoporotic², and therefore tend to occur in the elderly¹, means that the choice between surgical and conservative treatment should be based on multiple variables. If we opt for surgical treatment, we can resort to a wide range of osteosynthesis systems for which different types of outcomes have been described depending on the fracture type, the mean age of the series analyzed and the system used for the assessment of results. The functional results of the hemiarthroplasties indicated as a result of complex fractures of the proximal third of the humerus also vary widely in the literature¹²⁻¹⁵, probably because they depend on multiple factors, which may be of an epidemiological¹³ nature, may be related to the surgical technique employed^{12,13,22} or may have to do with the patient's ability to comply with an often long and demanding rehabilitation process. Epidemiologically, the sample in our study is in line with what has been published in the literature^{1,2}, i.e. showing a higher incidence of these fractures in the female (32/10) and older (74 years of age on average) population.

Classifications of these types of fractures, including the two most widely used, i.e. Neer's⁶ and the AO Classification, still lack the degree of reproducibility and concordance necessary to make it possible to assess and compare results across the different published series^{23,24}. In the present study, final fracture classification was carried out after an analysis of the imaging tests (plain x-rays and CT) and after naked-eye inspection of the fracture during surgery. Neer's classification is based on an anatomico-pathological image-based interpretation, so that in fractures treated by means of open surgery imaging studies establish a presumptive classification that is either confirmed or refuted after naked-eye inspection of the fracture during surgery as was recently described by Neer²⁵. Recently popularized imaging techniques such as 3D reconstructions of CTs may contribute in the future to better selecting those patients with a proximal humeral fracture who are eligible for hemiarthroplasty; these techniques were not in systematic use when this study was completed.

Of all the factors that influence the final outcome of hemiarthroplasties implanted to treat complex proximal humeral fractures, surgical technique constitute one of the most important surgeon-dependent ones. The essential technical goal is to restore the patient's anatomy through a well placed implant where the tuberosities may heal, between them and with the diaphysis, thus leading to the functional restoration of the joint. Given that the integrity of the rotator cuff is necessary for the deltoid muscle to function properly, thereby guaranteeing proper shoulder function, the healing of the tuberosities is essential to allow posterior functionality²⁶. One of the most significant technical difficulties consists in the accurate positioning of the implant in terms of height and version^{13,22}. Once the fractured tuberosities have been identified and the humeral head has been ex-

cised, there are no references left as to what the correct height and version at which the prosthesis should be implanted are. Traditionally rather unreliable references have been used such as the bicipital groove^{27,28}, the fit between the prosthetic head and the glenoid and the distance between the prosthetic head and the acromium¹². Some recent implants feature instruments like external guides to try and improve prosthetic positioning, but these are also inaccurate and subject to technical error.

The global functional results obtained in this study are comparable to those in the literature^{12,15}, in spite of the difficulty posed by the use of different evaluation systems. The mean score obtained on Constant's Scale was 61.2 points, with good results for pain and daily activities (probably owing to the fact that the patients were elderly and had low functional demands), an average degree of forward elevation and 90° abduction and an acceptable level of external and internal rotation.

Looking at the results of the study, we could conclude that there is a statistically significant relationship between correct implant positioning and greater tuberosity consolidation and the final functional outcome achieved, so that patients showing a satisfactory degree of greater tuberosity healing obtained a significantly higher score on Constant's Functional Scale than those where there was no healing. When an assessment was made of pain and internal rotation, no statistical significance was found in terms of the functional outcome, probable because the majority of patients did not report pain, and internal rotation could occur even in the absence of tuberosity healing because of the action of the pectoralis major muscle. Moreover, the greater tuberosity's healing capacity is related with the likelihood of being able to reduce it correctly in the early post-op. Good post-op reduction was obtained in 50% of patients, it was fair in 37% and poor in 12%; this led to satisfactory healing of the greater tuberosity healing in 46% of patients, posterior healing in 46% and no healing in 6%. Achieving good post-op reduction is likewise significantly related to a better final functional outcome. From the results obtained in this study it could be claimed that greater tuberosity healing is a crucial factor for the final outcome of hemiarthroplasties implanted to address proximal humeral fractures. Different authors like Boileau et al¹³, who have studied the factors associated to poor results in hemiarthroplasties indicated in cases of fractures of the proximal third of the humerus, conclude that the most significant factor associated to poor functional results is the malposition or the migration of the tuberosities. Tanner and Cofield²⁹ identify greater tuberosity displacement as the most common complication after implanting a prosthesis in a case of proximal humeral fracture.

Our study shows that there is a correlation between retroversion and the prosthesis' functional outcome; thus the smaller the difference between prosthetic and physio-

logical retroversion (20-40°) the better score will be obtained on Constant's Scale, although differences are not significant. Moreover, a correlation (albeit not a statistically significant one) was observed between prosthetic version and the greater tuberosity's healing capacity, which means that when the prosthetic version is physiological (20-40°), the greater tuberosity heals correctly in 62.5% of cases, whereas when prosthetic version is not physiological the greater tuberosity heals correctly in 41.7% of cases ($p = 0.306$). This could be attributable to the fact that we have used a small sample for each retroversion group studied and to the fact that the prosthesis' functional outcome is multifactorial, thus a larger sample being necessary to ascertain the existence of statistical significance. The most common error found in the series is an excess of anteversion, probably reflecting an attempt to avoid too much retroversion, which as shown by Boileau et al¹² leads to an excess of tension at the point where the tuberosity attaches to the diaphysis and causes it to migrate and to heal in an inappropriate position. Increasing anteversion also favors non-union since the suture is subjected to too much tension on internal rotation.

As regards the influence that the functional outcome of these prostheses have on the patients' perception of their health status as measured by the EuroQol-5D scale, it must be said that the majority of these patients (96.8%) report either mild pain or the absence of pain altogether. This is of crucial importance for this series made up of elderly patients (mean 74 years) with low functional demands. This is why we were not able to obtain a correlation between health status perception and prosthetic version or greater tuberosity healing.

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