Primary Hemiarthroplasty for Treatment of Proximal Humeral Fractures

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Background: Primary hemiarthroplasty of the shoulder is used to treat complex proximal humeral fractures, although the reported functional results following this method of treatment have varied widely. The aim of this study was to prospectively assess the prosthetic survival and functional outcomes in a large series of patients treated with shoulder hemiarthroplasty for a proximal humeral fracture. By determining the factors that affected the outcome, we also aimed to produce models that could be used clinically to estimate the functional outcome at one year following surgery.

Methods: A thirteen-year observational cohort study of 163 consecutive patients treated with hemiarthroplasty for a proximal humeral fracture was performed. Twenty-five patients died or were lost to follow-up in the first year after treatment, leaving 138 patients who had assessment of shoulder function with use of the modified Constant score at one year postinjury.

Results: The overall rate of prosthetic survival was 96.9% at one year, 95.3% at five years, and 93.9% at ten years. The overall median modified Constant score was 64 points at one year, with a typically good score for pain relief (median, 15 points) and poorer scores, with a greater scatter of values, for function (median, 12 points), range of motion (median, 24 points), and muscle power (median, 14 points). Of the factors that were assessed immediately after the injury, only patient age, the presence of a neurological deficit, tobacco usage, and alcohol consumption were significantly predictive of the one-year Constant score ($p < 0.05$). Of the factors that were assessed at six weeks postinjury, those that predicted the one-year Constant score included the age of the patient, the presence of a persistent neurological deficit, the need for an early reoperation, the degree of displacement of the prosthetic head from the central axis of the glenoid seen radiographically, and the degree of displacement of the tuberosities seen radiographically.

Conclusions: Primary shoulder hemiarthroplasty performed for the treatment of a proximal humeral fracture in medically fit and cooperative adults is associated with satisfactory prosthetic survival at an average of 6.3 years. Although the shoulder is usually free of pain following this procedure, the overall functional result, in terms of range of motion, function, and power, at one year varies. A good functional outcome can be anticipated for a younger individual who has no preoperative neurological deficit, no postoperative complications, and a satisfactory radiographic appearance of the shoulder at six weeks. The results are poorer in the larger group of elderly patients who undergo this procedure, especially if they have a neurological deficit, a postoperative complication requiring a reoperation, or an eccentrically located prosthesis with retracted tuberosities.

Level of Evidence: Prognostic study, Level II-1 (retospective study). See Instructions to Authors for a complete description of levels of evidence.

The use of primary hemiarthroplasty to treat complex fractures of the proximal part of the humerus was first popularized by Neer[1,2]. The procedure has become the "gold standard" for the treatment of such fractures when the humeral head is deemed to be nonviable or not amenable to reconstruction with internal fixation techniques[2]. The current indications for primary hemiarthroplasty include a displaced and translated four-part fracture, with or without associated dislocation of the humeral head, and a head-splitting fracture with involvement of >40% of the articular surface[2].

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Opinion is divided regarding the success rate of this procedure when it is used as a primary treatment. The satisfactory overall results reported by Neer[2] were reproduced in six studies that included between thirteen and forty-nine patients[3-8]. However, in fourteen series that included between ten and seventy patients, the outcomes were disappointing, particularly when the procedure was performed in elderly patients[9-22]. Many of these previous series were small, with inadequate objective follow-up assessment.

The aim of the present study was twofold. The first aim was to prospectively assess the functional outcome at one year as well as the prosthetic survival rate in a large consecutive series of patients in whom a proximal humeral fracture had been treated with hemiarthroplasty. The second aim was to quantify the factors that affected the functional outcome in order to produce models that could be used clinically to predict the functional outcome at one year following injury.

Materials and Methods

Over the thirteen-year period from January 1988 until December 2000, we treated a total of 3463 proximal humeral fractures. During this time, 163 patients (forty-seven men and 116 women with an average age of sixty-nine years [range, thirty to ninety years]) who were residents in the catchment area of our Trauma Unit were treated with a primary shoulder hemiarthroplasty for a fracture of the proximal part of the humerus. Shoulder hemiarthroplasty was used only for cooperative, medically fit patients without dementia who had had good shoulder function prior to the injury. Also, replacement arthroplasty was performed only if the proximal humeral fracture was found, at surgery, to be not amenable to open reduction and internal fixation as a result of comminution or severe osteopenia, or if the humeral head was denuded of soft-tissue attachments.

All patients in the study reported normal shoulder function prior to the injury; all also reported that they had not had substantial preinjury shoulder pain and had had the ability to raise the affected arm above shoulder height. No patient had undergone previous surgery on the ipsilateral shoulder, although two patients had previously sustained a minimally displaced fracture of the greater tuberosity and three had previously sustained a fracture of the surgical neck, which had healed without major deformity of the proximal part of the humerus. In addition, three patients had had a previous clavicular fracture, which had healed, and one had a chronic posttraumatic acromioclavicular separation. Patients who were medically unfit (ASA [American Society of Anesthesiologists][23] Grade 3 or higher), were uncooperative, had dementia, or had had a stiff or painful shoulder prior to the injury were treated nonoperatively.

Five patients died within one year after the surgery from unrelated causes, and twenty were lost to follow-up or did not return for a follow-up functional assessment at one year. All deaths were confirmed by cross-referencing with the local death registry. A Constant score[24,25] was determined for all of the remaining 138 patients at one year after the operation. There were ninety-six women and forty-two men in the cohort that had functional assessment at one year; the average age was 68.5 years (range, thirty to ninety years).

Of the 138 fractures, eighty-two were sustained in a low-energy fall; thirty-eight, in a fall from a height; and eighteen, in a motor-vehicle accident. According to the Neer classification[1,2], twenty-one were three-part fractures, 112 were four-part fractures, and five were head-splitting fractures. The humeral head was dislocated in fifty-eight patients, and twenty-one patients had a preoperative nerve palsy (twelve had an axillary nerve palsy; seven, a brachial plexus palsy; one, a radial nerve palsy; and one, a median nerve palsy), although by six weeks postoperatively, twelve of the palsies had resolved. There were no additional postoperative neurological deficits. There were three open (Gustilo[26] Grade-I) fractures in the series, but no patient had a vascular injury.

Operative Technique and Postoperative Treatment Regimen

All procedures were performed by, or assisted by, one of eight experienced trauma surgeons within seventy-two hours after the injury. All patients were treated with a standard antibiotic and antithrombotic prophylaxis regimen. Surgical access was achieved through a deltopectoral approach. Following confirmation that a hemiarthroplasty was required, the Neer Mark-II prosthesis (3M, St. Paul, Minnesota) was implanted in eighty-five patients and the Osteonics prosthesis (Stryker-Howmedica-Osteonics, London, United Kingdom), in fifty-three. No cementless or total shoulder arthroplasties were used as a primary treatment. Although thinning, attenuation, and minor tears of the rotator cuff were commonly encountered, there were no chronic large tears of the cuff. After thorough medullary lavage, standard so-called second-generation techniques were used to insert antibiotic-impregnated cement, with hand-mixing of the cement and use of a cement gun to deliver the cement in a doughy state in a retrograde fashion. The tuberosities were placed under tension and were repaired with either stainless-steel wire (ninety-four patients) or number-5 Ethibond sutures (Ethicon, Edinburgh, United Kingdom) (forty-four patients); the rotator interval was closed with supplementary number-1 Ethibond sutures.

All patients wore a shoulder immobilizer sling with the upper limb in the so-called safe position (the shoulder in internal rotation, neutral flexion, and neutral abduction and the elbow flexed 90°) for two to three weeks after the surgery. Passive range-of-motion exercises with up to 90° of elevation were begun immediately, and active-assisted range-of-motion exercises were started at two weeks after the operation. Isometric rotator cuff exercises and graduated active range-of-motion exercises under the supervision of a physiotherapist were commenced after the sling was removed and were continued for six months after the operation.

Outcome Measures

The functional outcome was assessed at one year with a modification of the standard Constant score[24,25]. To accommodate for the decrease in muscle power with increasing age, abduction strength in pounds was initially assessed as a percentage of the strength of the contralateral shoulder and then divided by four to provide a score from 0 to 25. This score was then used to generate the final modified Constant score. With use of this methodology, the postoperative muscle power for each patient was "normalized" to his or her likely preinjury level of muscle power. The use of this technique had its own weaknesses, since it prevented direct comparison of our results with those reported in studies in which the traditional method of determining the Constant score was used. However, it had the advantage of generating an age-adjusted ordinal score, which could be used in subsequent linear regression analysis.

Secondary outcome measures included prosthetic survival to revision, radiographic outcome up to one year, and the prevalence of other complications. Radiographic outcome was assessed on standardized anteroposterior and so-called "modified lateral" radiographs made immediately postoperatively, at six weeks, and at one year for all patients. We used the known size of the prosthetic head on postoperative radiographs to adjust for magnification artifact. All radiographic parameters were individually measured by two of the authors (C.M.R. and R.S.P.), and their levels of agreement were consistently good or satisfactory (mean interobserver kappa value, 0.89). Repeat radiographic assessment was not performed after one year, unless clinically indicated.

Statistical Analysis

All data were analyzed with use of the SPSS Version-9 software package (SPSS, Chicago, Illinois). Prosthetic survival was analyzed with use of life-table methodology, with revision of the hemiarthroplasty for any reason as the primary end point. Individual cases were censored at death or at the end of follow-up. The log-rank test was used to compare survival curves.

We used a regression model (described below) to assess the impact of putative predictor variables (Fig. 1), including premorbid intrinsic, patient-related factors; injury-related factors; and surgery-related factors (assessed at six weeks post-injury), on the one-year modified Constant score. Candidate predictor variables were initially assessed with univariate linear regression analysis. All variables were also considered in a forward stepwise multiple linear regression analysis. We generated two separate models, with one based on the predictor variables that could be measured at the time of the original surgery (the early model) and the other based on predictor variables that could be assessed at six weeks after the surgery (the six-week model). Multiple systematic tests of the validity of the two models were performed, and the "goodness of fit" of each model was assessed by evaluating the F ratio (an assessment of the overall "fit" of the model to the data, with a higher value indicating a better fit) and adjusted r^2 statistics (an expression of the percentage of the variation in outcome that can be explained by the model)[27]. For all analyses, a p value of ≤0.05 for a Type-I error was considered significant.

Results

Survivorship Analysis and Radiographic Results

The average duration of follow-up in the overall cohort was 6.3 years (range, zero to thirteen years). Forty-three (26%) of the 163 patients in the original cohort died during the study period; five patients died in the first year, and thirty-eight patients died subsequently. The overall prosthetic survival rate at one year was 96.9% (95% confidence interval, 94.1% to 99.6%), which decreased to 95.3% (95% confidence interval, 91.8% to 98.7%) at five years and to 93.9% (95% confidence interval, 89.7% to 98.2%) at ten years (Fig. 2). Of the eight reoperations in which the prosthesis was revised, three were performed because of a periprosthetic fracture; three, because of dislocation; one, because of deep infection; and one, because of loosening. With the numbers available, none of the measured dependent variables, including the type of

Intrinsic variables	Injury-related variables	Surgery-related variables (assessment at six-weeks only)
Age Gender ASA grade[23] Medical comorbidity Level of ambulation Mental status Tobacco consumption Alcohol consumption	Mechanism of injury Grade of fracture[1] Presence of dislocation Presence of neurological deficit Presence of rotator cuff tear Presence of open fracture	Type of prosthesis used Time to surgery after injury Degree of superior or inferior displacement of the prosthetic humeral head from the central axis of glenoid[13] Degree of displacement of tuberosities (maximal extent) Occurrence of postoperative complications requiring reoperation Occurrence of all postoperative complications Occurrence of heterotopic ossification Adequacy of stem cement mantle Acromiohumeral distance[13] Lateral projection of greater tuberosity[13] Medial projection of the humeral head[13] Humeral offset[13]

Fig. 1

Measured variables used in regression analyses.

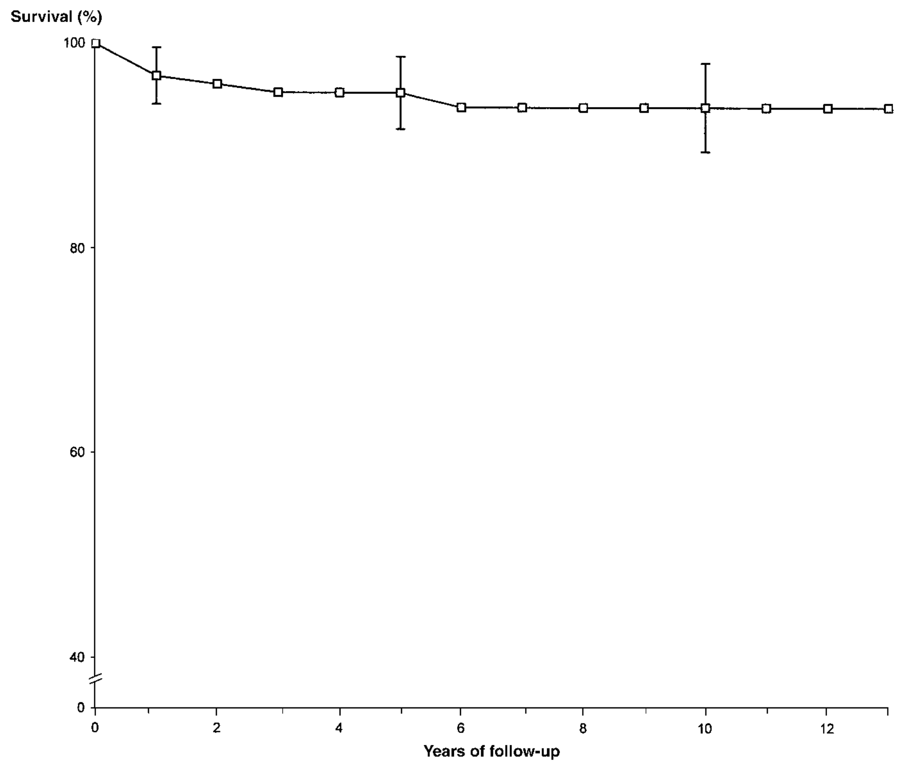

Fig. 2
Survivorship analysis of the shoulder hemiarthroplasties, with revision for any reason as the end point.

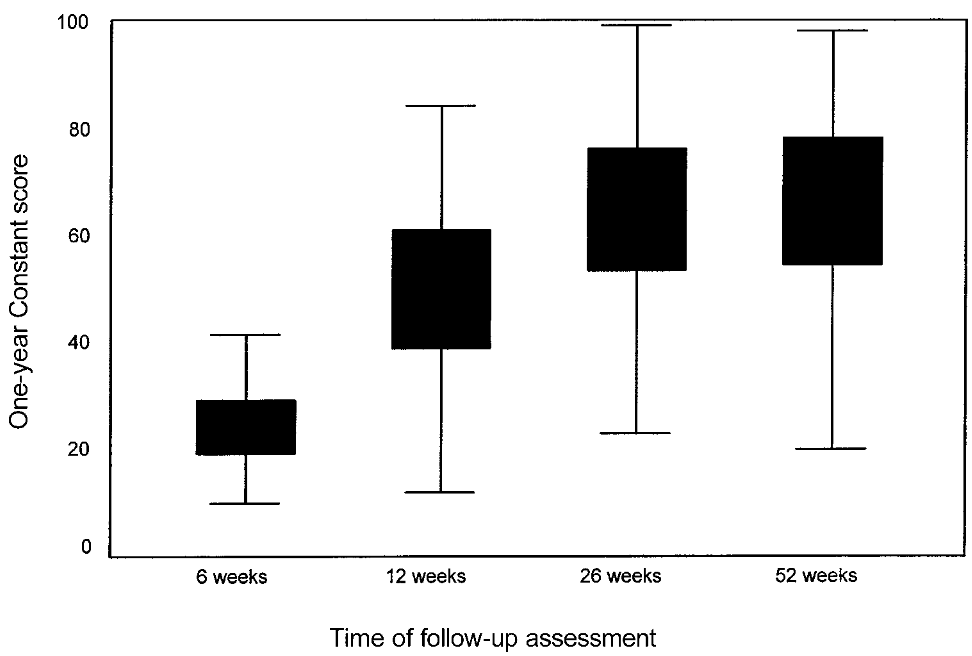

Fig. 3
The change in the modified Constant scores up to one year postinjury.

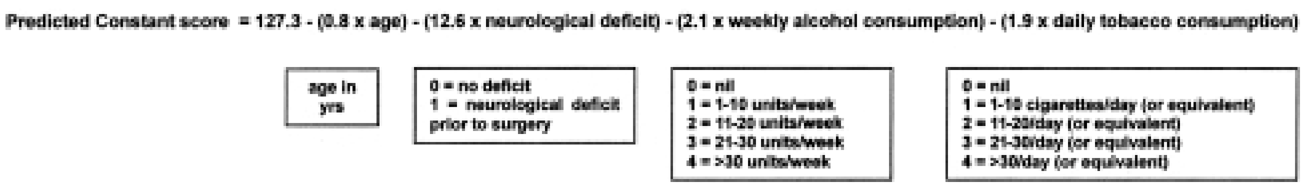

Fig. 4

The early multiple linear regression model to predict the modified Constant score at one year after the hemiarthroplasty.

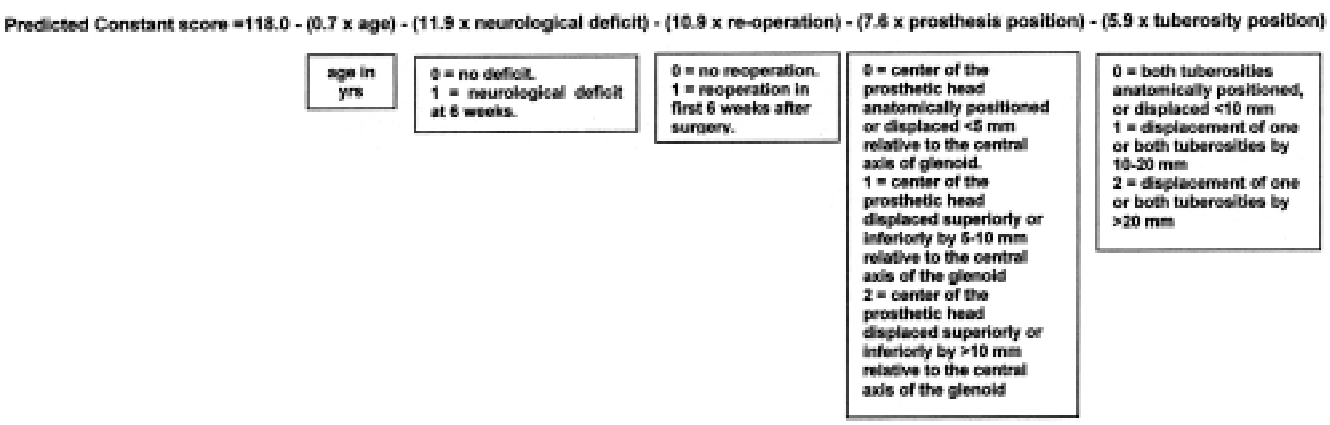

Fig. 5

The six-week multiple linear regression model to predict the modified Constant score at one year after the hemiarthroplasty.

prosthesis that was implanted and the type of suturing technique that was used to reattach the tuberosities, were found to have a significant effect on prosthetic survival.

There were nine early superficial infections, all of which were successfully treated with antibiotics. Reattachment of the tuberosities without revision of the primary prosthesis was performed in three patients who had early displacement of the tuberosities in association with subluxation of the prosthesis. In addition, an early infection developed in one patient, and a sterile deep hematoma developed in another. These were both treated with surgical drainage, without revision of the prosthesis.

Radiographic assessment in the early postoperative period revealed good prosthetic positioning with respect to the anatomic axis of the glenoid (<5 mm of displacement of the prosthetic head from the central axis of the glenoid) and anatomic reattachment or <10 mm of displacement of the tuberosities in all except the three patients who had early displacement as noted above.

Repeat radiographic examination at six weeks revealed that the center of the prosthetic humeral head was anatomically positioned or displaced <5 mm from the central axis of the glenoid in 101 patients. The prosthesis was displaced, superiorly or inferiorly, 5 to 10 mm from the central axis of the glenoid in twenty-eight patients, and the displacement was >10 mm in the remaining nine patients. In eighty-five patients, the tuberosities were anatomically positioned with respect to the prosthesis or were displaced <10 mm. Forty-three patients had 10 to 20 mm of displacement of one or both tuberosities, and the remaining ten patients had >20 mm of displacement of one or both tuberosities. There was little additional change in the position of either the prosthetic humeral head or the tuberosities on radiographs made at one year, although there was often substantial resorption of the tuberosities that had displaced.

Functional Assessment

The median modified Constant scores for the group as a whole improved consistently between six weeks and three months and between three months and six months (Wilcoxon matched-pair test, $p < 0.001$; Fig. 3). However, the score did not improve significantly between six months and one year (Wilcoxon matched-pair test). The overall median modified Constant score at one year was 64 points (interquartile range, 48 to 78 points). The procedure typically resulted in good pain relief (median Constant score for pain, 15 points; interquartile range, 10 to 15 points), whereas the median scores for function (median, 12 points; interquartile range, 10 to 14

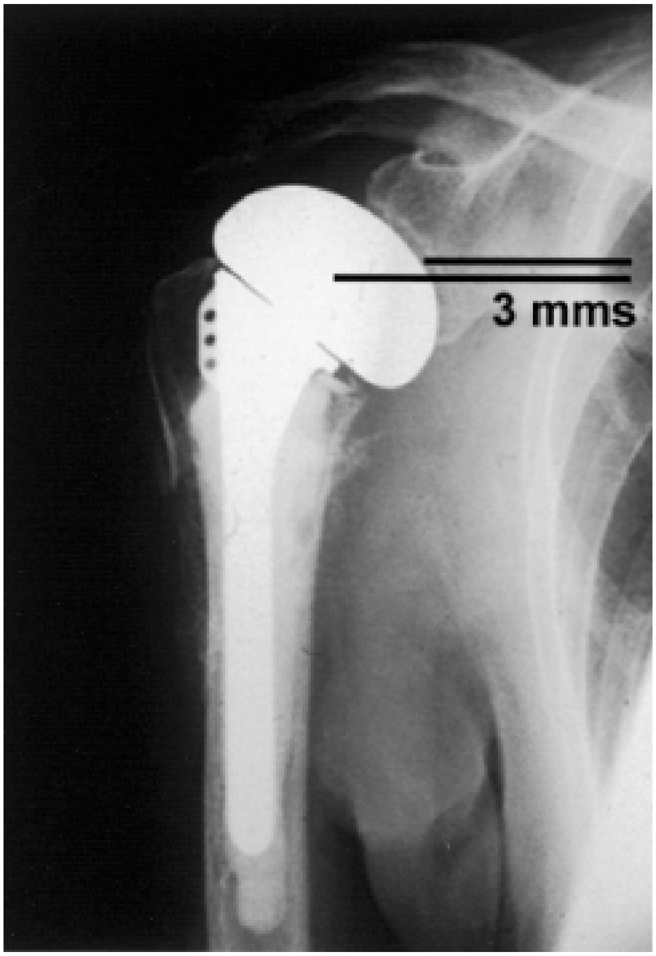

Fig. 6-A
A six-week postoperative radiograph of a forty-eight-year-old man in whom a four-part fracture-dislocation of the proximal part of the humerus was treated with a hemiarthroplasty. On the basis of the early model, the initial predicted one-year Constant score was 89 points. At six weeks, the prosthesis and the tuberosities were minimally displaced. The predicted one-year score on the basis of the six-week model was 84 points. The actual modified Constant score at one year was 87 points.

points), range of motion (median, 24 points; interquartile range, 20 to 28 points), and muscle power (median, 14 points; interquartile range, 10 to 18 points) were poorer and showed greater scatter of values.

Regression Analysis and Development of the Models

Univariate linear regression analysis of the variables that could be measured at the time of the original surgery showed that only the age of the patient, the presence of a preoperative neurological deficit, alcohol consumption, and smoking had a significant association with the modified Constant score at one year ($p < 0.05$). Neither the severity of the fracture seen radiographically nor the presence of subluxation or dislocation at the time of the fracture appeared to influence the outcome at one year. The factors measured at six weeks that were found, with univariate analysis, to be significantly associated with the functional outcome at one year included the age of the patient, postoperative complication requiring reoperation, a persistent neurological deficit, radiographic evidence of eccentricity of the prosthesis as a result of either superior or inferior displacement, and radiographic evidence of retraction of one or more of the tuberosities ($p < 0.05$). The Constant score at six weeks was not significantly predictive of the score at one year.

Examination of all dependent variables with forward stepwise multiple linear regression analysis produced a stable model for predicting the one-year modified Constant score.

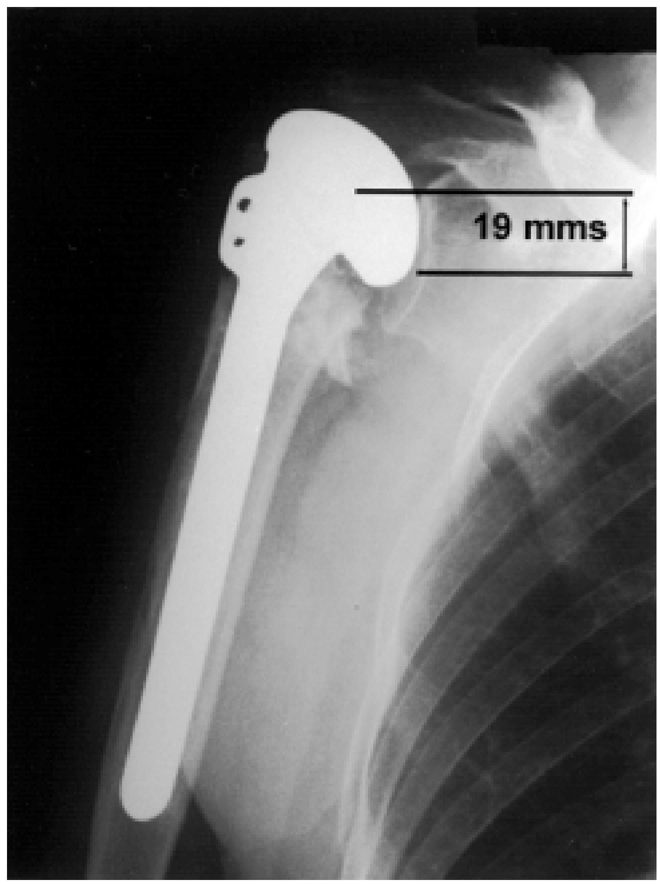

Fig. 6-B
Six-week postoperative radiograph of a seventy-eight-year-old woman in whom a four-part fracture of the proximal part of the humerus was treated with a hemiarthroplasty. The initial predicted one-year Constant score on the basis of the early model was 63 points. At six weeks, the prosthesis was superiorly displaced 19 mm from the central axis of the glenoid. The predicted one-year score on the basis of the six-week model was 48 points. The actual modified Constant score at one year was 52 points.

The equation for predicting the one-year Constant score on the basis of the factors that were apparent preoperatively is shown in Figure 4. The adjusted r^2 "goodness-of-fit" value was 0.46 (F ratio = 28.6, $p < 0.001$). The equation for predicting the one-year Constant score on the basis of the variables considered at six weeks is shown in Figure 5. The adjusted r^2 "goodness-of-fit" value was 0.63 (F ratio = 4.9, $p < 0.001$). Both models appeared to be robust and accurate for the sample and generalizable to the population as a whole, on the basis of the analysis of residuals and outliers and the tests for lack of multicolinearity and heteroscedasticity of the predictive variables.

Discussion

Primary shoulder hemiarthroplasty performed for the treatment of a proximal humeral fracture was associated with satisfactory early survival of the prosthesis in our series. Although the procedure was reserved for medically fit individuals without dementia, there was substantial attrition due to death in this predominantly middle-aged and elderly population, with more than a quarter of the patients dying during the study period. It is possible that complications such as loosening, instability, infection, and rotator-cuff-related problems could have developed in many of these patients had they not died, as greater numbers of such complications have been reported in other studies of shoulder arthroplasty performed either for nontraumatic indications[28] or in younger patients[29].

Although the shoulder was usually free of pain at one year following the hemiarthroplasty, the overall functional results, in terms of range of motion, function, and muscle power, were disappointing compared with those reported after replacement arthroplasty performed for degenerative joint disease[30-32]. The greater average age of patients who have the arthroplasty to treat a traumatic injury, the impaired function of the rotator cuff (from either pre-existing rotator cuff degeneration or tears), or the requirement for repair of one or both tuberosities probably accounts for some of the differences in outcome. These findings are in concordance with the findings of other, smaller studies, which have suggested that shoulder arthroplasty performed for traumatic indications provides satisfactory pain relief but poor function[9-22]. As we did not use patient-perceived outcome measures, we were unable to assess the impact of the poor shoulder function on the general health status of our patients.

We generated two models: the first, "early" model can be used to predict the outcome of hemiarthroplasty on the basis of factors that can be assessed at the time of surgery. This model can be used to counsel patients after their injury about their expected level of recovery following a hemiarthroplasty (Figs. 6-A and 6-B). The factors that predict the outcome in the early model are predominantly intrinsic and patient-related, rather than associated with the severity of the injury (except for the presence of a neurological deficit). The age of the patient appears to be the single most important factor determining the predicted outcome at one year in this model: the expected modified Constant score at one year decreased by 8 points for every ten-year increase in the age of the patient. The influence of age on the predicted outcome is likely to reflect many factors that adversely affect outcome, including degenerative change within the rotator cuff, osteoporosis, and the lack of motivation to achieve a range of motion beyond the limited functional needs of an elderly patient.

A neurological deficit after the injury also adversely affected the predicted one-year outcome in the early model. The most common nerve palsies were of the axillary nerve or the brachial plexus. Patients who had a neurological deficit more often sustained the original fracture by a high-energy injury mechanism and more commonly had a fracture-dislocation. It is therefore possible that the neurological deficit adversely affected outcome by reflecting a more severe initial injury.

The influence of tobacco use and alcohol consumption on the predicted outcome in the early model is also probably multifactorial. Patients with alcohol dependency may have lacked motivation or not complied with the physiotherapy. High alcohol consumption and tobacco use may have also adversely influenced the healing of the tuberosities after the hemiarthroplasty.

The second (six-week) model, based on additional information that becomes apparent during the first six weeks after surgery, provided a more precise estimate of the one-year outcome. Here, surgery-related factors assumed greater importance. The need for a reoperation due to complications of the primary surgery, a persistent neurological deficit, an eccentric position of the prosthesis relative to the central axis of the glenoid, and displacement of one or both tuberosities were all predictive of a poorer outcome at one year in the six-week model. From these variables, it is clear that intact function of the rotator cuff is an important factor predicting the one-year outcome. Some of the early reoperations were performed because of early displacement of the tuberosities, and persistent retraction of the tuberosities would be expected to limit function of the rotator cuff attachment. In addition, superior displacement of the prosthetic humeral head usually suggests that a complete disruption of the rotator cuff has occurred[28], and inferior displacement of the head is often attributed to rotator cuff inhibition or inadequate tensioning of the prosthesis[28]. While many of these factors have been alluded to in previous studies[9,10,12-22], their relative contribution to the eventual outcome has not been quantified before.

Both models appeared stable and robust when subjected to the usual assessments of validity. However, a weakness of our study is that, in the first model, <50% (adjusted $r^2 = 0.46$) of the variation in functional outcome can be explained by factors that can be assessed at the time of the injury, although this value improves by an additional 17% (adjusted $r^2 = 0.63$) with use of the factors that are apparent at six weeks. The two models can therefore only provide an estimate of the likely outcome, although the F ratios were highly significant for both ($p < 0.001$ in each case). The remainder of the variation in outcome is likely to be attributable to factors such as the level of residual function of the intact rotator cuff after performance of the hemiarthroplasty, the degree of the patient's motivation to move the shoulder in the early stages of rehabilitation, and the impact of early intensive physiotherapy. These factors would be more difficult to measure objectively. The models are also likely to be unreliable if used to predict the outcome of hemiarthroplasty in patients who are beyond the age limits of our cohort (thirty to ninety years).

Although all procedures were performed or supervised by one of eight senior orthopaedic trauma surgeons, we were unable to assess the technical adequacy with which the original hemiarthroplasties were performed. Shoulder hemiarthroplasty performed for an acute fracture is more demanding than one performed for other indications. Soft-tissue tensioning, assessment of the stability and the degree of retroversion of the prosthesis, and ensuring adequate reattachment and tensioning of the tuberosities are often more difficult because many of the normal osseous landmarks are obliterated by the fracture.

When the humeral head can be reconstructed and is potentially viable, open reduction and internal fixation should remain the primary treatment for complex proximal humeral fractures in the majority of patients up to seventy years of age. However, if the humeral head is devoid of soft-tissue attachments or is technically unreconstructable, shoulder hemiarthroplasty can be performed in medically fit, cooperative patients with the reasonable prospect of a good early functional outcome. The prospects of success are improved if the patient has no neurological deficit and has a history of no or low tobacco and alcohol use; they are further enhanced by the absence of complications requiring a reoperation, by successful reattachment of the tuberosities, and by a well-seated prosthesis at six weeks. It is not possible to state, on the basis of our study, how this satisfactory level of function will change in the longer term.

Unfortunately, the largest group of individuals who have an unreconstructable humeral head following a fracture are elderly (older than seventy years of age). These individuals, in general, fare less well following this procedure, and a pain-free but somewhat stiff shoulder is the typical outcome at one year postinjury. There is a need for reevaluation of the role of hemiarthroplasty in the treatment of such fractures in this age group. Elderly individuals often have much lower functional requirements, and the results of nonoperative treatment may thus be satisfactory[33,34]. If primary hemiarthroplasty is likely to be palliative only, with a low predicted functional score, a case can be made for primary nonoperative intervention, with reservation of hemiarthroplasty for patients who have persistent late pain. However, it is generally believed that the results of hemiarthroplasty performed as a late reconstructive procedure after initial nonoperative treatment are worse than the results of hemiarthroplasty performed as a primary procedure[10,35-37]. Additional work, in the form of a controlled clinical trial, is required to resolve these issues more fully. ■

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