REVIEW

Shoulder arthroplasty for acute proximal humerus fracture☆

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KEYWORDS
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Summary Proximal humerus fracture devascularizing the humeral head may require management by prosthesis. Hemiarthroplasty is a logical attitude in such cases, but analysis of functional results and complications has identified a certain number of risk factors limiting indications. Strict analysis of patient characteristics and of fracture type is an essential prerequisite to deciding against treatment by immobilization or osteosynthesis. Results in hemiarthroplasty are primarily dependent on respecting the rules of the art, which aim at stable anatomic osteosynthesis of the surrounding structures so as to restore normal shoulder function. The critical steps are the adjustment of implant height and retroversion, reduction and fixation of tuberosities and good management of the postoperative course. The recent development of fracture-dedicated shoulder implants should improve results. In elderly patients, when local conditions are unsuitable to hemiarthroplasty, a reverse prosthesis may be used, with an adapted surgical technique. Whatever the type of prosthesis, implantation for proximal humerus fracture is a demanding operation with definitive impact on the functional evolution of the shoulder.

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Introduction

Following Neer’s reports in 1970 [1,2] of results for shoulder prosthesis in proximal humerus fracture, several attempts were made to reproduce the encouraging initial findings. Most found good results in terms of pain, but much less satisfactory functional outcome. Analyzing the causes of failure identified risk factors and enabled solutions to be suggested. Among these, one of the first was to select indications, eliminating baseline situations of poor prognosis. Following good results reported in arthropathy involving rotator cuff tear and in revision of hemiarthroplasty for fracture, reverse prostheses were recommended as an alternative attitude in case of proximal humerus fracture in elderly subjects. This particular indication is currently under assessment.

Principles and indications

In proximal humerus fracture, conservative surgery seeks anatomic reconstruction conserving humeral head vascular-
ization. Implantation is indicated when stabilization of the humeral head is not feasible or in case of high risk of head necrosis. Classically, it is indicated for 4-part fracture, fracture dislocation, displaced fracture of the anatomic neck or impaction fracture of the humeral head involving more than 40% of the joint surface.

Indications for implantation have not basically changed over recent years, and hemiarthroplasty remains the reference technique. Given the difficulties involved, however, certain selection criteria have been defined, according to clinical aspect, type of fracture and specificities of the surgeon.

The patient

Preoperative assessment is essential, including not only the affected shoulder but general health status. Proximal humerus fractures are the third most frequent location in the elderly, after the proximal femur and distal radius. Incidence has considerably increased since the 1970s, especially in women, as Palvan et al. [3] showed in a Finnish study. They argued that, in a context of population aging, were this trend to continue the rate of proximal humerus fracture would rise three-fold by 2030. Indications for implantation to manage fracture in elderly patients are bound to increase in coming years. However, several studies have clearly shown that age to be a negative factor in the results of prosthetic management of fracture [4–7]. Concomitantly, the negative impact of associated comorbidity was highlighted by Robinson et al. [8] and Kabir et al. [9]. Padua et al. [10] recently stressed the interest of global assessment by quality-of-life questionnaires. Olsson et al. [11] reported 40% 1-year mortality secondary to proximal humerus fracture in fragile dependent patients. Given that surgery is not on an emergency basis, patients should be provided with complete and honest information concerning the means of intervention, the risks of complications, and the results and sequelae to be expected.

The fracture

Neer’s classification [12], which is widely used in the literature, is based on analyzing displacement of the four main segments of the proximal humerus: head, greater tuberosity, lesser tuberosity and proximal shaft. In this classification, a fragment is said to be displaced when displacement exceeds 1 cm or angulation exceeds 45°. Four-part displacement fracture constitutes the classic indication for implantation, given the risk of head necrosis. Duparc’s classification [13] is also essential, with a more detailed description of cephalo-tuberosity and cephalometaphyseal fractures: implantation is generally recommended in type 3 or 4 cephalotuberosity fracture, and sometimes in type 2 or in severely displaced cephalometaphyseal fracture.

In 4-part valgus impacted fracture, the rate of head necrosis varies widely in the literature—from 26 to 75%, according to Aschauer and Resch [14], who therefore recommend reduction and osteosynthesis, including in elderly patients. This attitude is shared by Iannotti et al. [15], for whom a conserved medial hinge and periosteal integrity enable humeral head vascularization to be conserved; implantation should be reserved for relatively inactive elderly patients with bone of poor mechanical quality and displaced joint fracture [16]. Tingart et al. [17] showed that cortex thickness is an index of proximal humerus bone density: a mean index (medial + lateral cortical thickness) of less than 4 mm is an indication for arthroplasty as opposed to osteosynthesis. Hertel et al. [18] showed that the risk of necrosis in 4-part valgus impaction fracture basically depends on the length (≥ 8 mm) of the postero-medial fragment and on conservation of a medial hinge. Fracture assessment requires at least two orthogonal radiographic incidences to determine fracture line location, head position and tuberosity displacement. Non-contrast CT-scan gives a more exact analysis of fragment position [19,20], shoulder joint status and rotator cuff muscle fatty infiltration. Hernigou et al. [21] recommend CT assessment of retroversion in the contralateral shoulder, to be reproduced during implantation. For preoperative planning, Boileau et al. [22] recommend taking X-ray views with ruler of the entirety of both humeri.

The ideal fracture-to-surgery interval is a matter of discussion. It seems advisable to take a few days in order to perform complete lesion assessment, detect and treat any associated pathology, make a complete scan of the fracture and fully inform patient and family [23–25]. After 20 days, on the other hand, tuberosity mobilization and fixation is imperiled by bone consolidation and resorption [24].

The surgeon

Implanting a prosthesis in proximal humerus fracture is a difficult operation, in which results are dependent on the experience of the surgeon and of the center, as shown by Kralinger et al. [5], Jain et al. [26] and Hasan et al. [27]. This illustrates the importance of training surgeons in this indication and of developing surgical techniques with good reproducibility.

Hemiarthroplasty

Technique

Approach and exposure

The classical approach is deltopectoral. A superolateral approach facilitates mobilization and location of the greater tuberosity [28] but requires the axillary nerve to be isolated in case of distal extension of the fracture [29]. The first step is to locate the tuberosities and humeral head. Next, the bicapital groove of the long head of the biceps should be identified, with the intertuberosity fracture line, which generally lies behind the groove. The rotator interval is opened along the axis of the intertuberosity fracture line. The lesser tuberosity is pulled forward along with the subscapularis, using a suture through the tendon/bone junction. Posteriorly, the greater tuberosity is identified. In some cases, the tuberosities are joined together and it is then preferable not to separate them when implanting the prosthesis.

Sutures are threaded through the tendon/bone junction, and the greater tuberosity is tilted backwards, conserving periosteal attachments to the shaft as well as possible. Certain authors [19] recommend conserving the biceps tendon...
Shoulder arthroplasty for acute proximal humerus fracture

Figure 1  Restored greater tuberosity lateralization using a narrow implant requiring lateral graft (1A) and, on the right, a wide implant without graft (1B).

and the pectoralis major insertion tendon, which can serve as landmarks for prosthesis height [30,31]. The long biceps tendon may be caught between fragments during consolidation, and we recommend systematic tenodesis or tenotomy [22,24,31].

Theoretic implant positioning
Implant positioning is an essential step influencing the functional result [4]. More than 10 mm lengthening, 15 mm shortening or 40° retroversion on revision have a negative impact on the Constant score. Christoforakis et al. [32] compared retroversion and humeral height between the two shoulders on CT-scan in 16 patients with hemiarthroplasty for fracture; less than 10° differential retroversion and 14 mm height were associated with better Constant scores. According to Boileau et al. [4], excessive retroversion or height induce faulty positioning and excessive greater tuberosity traction, increasing the risk of secondary displacement.

Theoretic tuberosity positioning
Tuberosity reconstruction should be as anatomic as possible, so as to restore rotator cuff function [4,32,33]. Frontally, the position of the greater tuberosity with respect to the head is defined by the head-to-tuberosity distance (HTD): i.e., the distance between the summit of the head and the superior edge of the greater tuberosity. On anatomic samples, HTD varies between 3 and 20 mm, with a mean value of 8 mm (±3 mm) [34]. Mighell et al. [33], Demirhan et al. [23] and Loebenberg et al. [35] demonstrated that restoring HTD was associated with a good functional result. According to the first two of these reports, the ideal HTD value is between 5 and 10 mm, while Loebenberg et al. [35] recommended a lower greater tuberosity position (10–16 mm) to compensate for the medialization induced by first-generation implants and to superimpose the lateral cortices, to improve consolidation. Greater tuberosity lateralization is important for restoring rotator cuff lever arm in elevation and rotation. Failure to restore humeral offset, defined as the distance between the center of rotation and the lateral cortex of the greater tuberosity, is associated with poor functional results [23]. Lateral offset is restored by introducing a graft between the implant and the greater tuberosity if forming by the implant is deficient, or by using a bulky-stem prosthesis without graft (Fig. 1A—B).

“In practice”
The first step is to adjust implant height (Table 1). Whatever the ancillary, it is preferable to plan the theoretic height on X-ray views with ruler of both humeri in entirety. Height can then be determined with respect to a point located on the X-ray: e.g., medial cortex at the neck. The other solution is to use a criterion of greater tuberosity reduction onto the lateral cortex, and then determine implant height with respect to the theoretic distance between the summit of the head and the greater tuberosity. Some authors recommend an

Table 1  Main landmarks for hemiarthroplasty positioning in fracture.

<table>
<thead>
<tr>
<th>Height</th>
<th>&lt; 1 cm lengthening, &lt; 1 cm shortening on whole humerus X-ray Head summit—sup. edge pect. major = 5.5 cm Restoration of medial &quot;gothic arch&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retroversion</td>
<td>20° /forearm Implant head facing glenoid cavity in neutral rotation</td>
</tr>
<tr>
<td>Tuberosity position</td>
<td>Head summit—sup. edge greater tub. = 5–10 mm Restored greater tuberosity lateralization</td>
</tr>
</tbody>
</table>
approximation, using soft-tissue tension as landmark. Theoretically, there should be some residual peroperative laxity, enabling anteroposterior translation for half the width of the glenoid cavity and inferior translation or half the height of the cavity [19]. Several means are available to ensure trial-implant stability. There are intramedullary [36] or transosseous systems for determining height with respect to the trial implant and then reproducing it on the final implant. Other authors recommend using an external jig. Boileau et al. demonstrated that an extramedullary jig fixed to the limb at elbow level improved implant positioning, with significant impact on the clinical result [22]. Krishnan et al. [24] recommend restoring the "gothic arch" aspect under fluoroscopy as a reliable criterion (Fig. 2).

Gerber and Warner [31] showed that the distance from the superior edge of the pectoralis major tendon to the summit of the head is relatively constant, at a mean 5.5 cm ± 0.5 cm (Fig. 3), independently of the patient’s height [37,38]. Certain implants include a system for definitive implantation of the stem, with peroperative height adjustment according to tuberosity reduction, soft-tissue tension or image intensification control [39].

Regarding implant rotation, 20 to 30° retroversion is classically recommended. Retroversion as measured with respect to the forearm with the elbow in flexion is 10° less than the anatomic retroversion measured on the biepicondylar axis, given the physiological valgus; it therefore seems preferable to implant with retroversion approximating 30°. In practice, the trial prosthesis is reduced so as to check that the head is facing the shoulder joint in neutral rotation and is stable in rotation. An external jig enables the implant to be stabilized in rotation and height during trials. Using the bicipital groove as retroversion landmark is highly controversial. According to Hempfing et al. [30], the mean distance between the equator of the humeral head and the center of the distal bicipital groove is 8.5 mm, and they recommend this as a basis for determining retroversion. Angibaud et al. [40] reported a mean 7.3 mm distance proximally and 7.2 mm distally between the intramedullary axis and the groove, and recommend using an implant with a lateral offset fin aligned on the bicipital groove. In contrast, Balg et al. [41] recently demonstrated that bicipital groove retroversion varies according to the height being considered: with respect to the epicondylar axis, it is significantly greater when measured at the surgical than at the anatomic neck, raising a risk of excessive retroversion using this landmark in hemiarthroplasty. In point of fact, these various studies are non-comparable, as they were not using the same humeral reference. Adjusting retroversion is a crucial step, as excessive retroversion induces excessive traction on the greater tuberosity when the limb returns to neutral rotation, with a risk of secondary migration [4].

Before fitting the final stem, two holes are made in the metaphysis for the non-resorbable suture used to fix the tuberosities vertically. Cementless humeral stems have not yet actually been proven to have any advantage, but the trend is to use proximally cementless hydroxyapatite-coated implants for improved proximal consolidation.

**Tuberosity fixation**

Tuberosity fixation should meet osteosynthesis requirements. Most authors use horizontal fixation around the implant associated to vertical fixation, usually with large-caliber non-resorbable suture (Fig. 4) threaded through the tendon/bone junction. In case of severe comminution, Franks et al. [42] recommend reinforcing the suture by threading several times in the tendon, using Krakow stitches. In an experimental study, they also demonstrated the advantage of circumferential intertuberosity cerclage to ensure tuberosity stability in rotation. The horizontal cerclage sutures are passed through a medial hole [42] or a hole in the implant neck [4]. The greater tuberosity should be fixed first, with the limb held in neutral rotation. Before finally tightening the sutures, cancellous grafts are inserted between bone and implant and between the tuberosities and the femoral shaft. The lesser tuberosity is then fixed by two horizontal sutures. To control assembly stability, Gerber and Warner [31] recommend fixing the greater tuberosity...
in its maximal course in internal rotation and the lesser tuberosity in external rotation. The vertical sutures create a rigging effect with intertuberosity compression. Boileau et al. [43] recommend peroperative X-ray monitoring of greater tuberosity reduction.

Evolution of anatomic fracture implants

Several models of implant have been developed in recent years to meet the specific requirements of fracture (Table 2). Kralinger et al. [8] demonstrated a significant impact of implant design on tuberosity consolidation [5]. Most implants involve cemented stems adapted in size to the medullary canal. In the metaphyseal area, certain dedicated fracture implants have surface treatment or a hydroxyapatite coating. Some models have a window through which to insert a graft taken from the head, so as to create a bone bridge between the two tuberosities. There are three types of system for stabilizing the implant during trial: extramedullary jig, diaphyseal or metaphyseal intramedullary blocking systems, and systems with a locking screw through the stem; long-stem versions are usually available in case of fracture extension involving the shaft.

There are two opposing concepts with respect to the proximal part of the implant. The first, low-profile or narrow implant, consists in reducing the volume of the metaphyseal part so as to maximize bone conservation. This requires a graft between the implant and greater tuberosity, to restore lateralization. Conversely, other models have a bulky metaphyseal part, so that the greater tuberosity can be lateralized without use of a graft. No prospective studies have as yet compared these two concepts. Boileau et al. [22] and Loew et al. [44] reported that tuberosity migration was halved by using low-profile dedicated implants instead of standard models, without significant impact on clinical results. Krishnan et al.’s [24] 81% consolidation rate using this kind of implant, however, suggests a considerable advantage over standard models.

The implant head should ideally be modular, so as to adapt curvature radius and diameter anatomically. The curvature radius should allow for a possible glenoid implant at revision. Modularity also allows the head to be removed in case of secondary totalization. De Wilde et al. [45] recommend an implant with 10—14 peripheral holes to anchor the rotator cuff to the tendon/bone junction. The Diademe implant (Lepine®) has lateral hooks that lean against the greater tuberosity to neutralize traction phenomena, and a metal hammock over the tuberosities. No clinical results have, however, yet been published for these new implants.

Postoperative rehabilitation

Postoperative rehabilitation protocols remain a matter of debate. A sling is generally recommended for 1 month to 6 weeks, with early passive rehabilitation to avoid stiffness. The resting position in internal rotation in the sling, however, induces greater tuberosity traction, and some authors prefer immobilization in neutral or slight external rotation [4,24] to limit the risk of tuberosity migration in elderly or osteoporotic patients. [22]. Agorastides et al. [46], comparing results after immobilization and early mobilization, found no significant difference except for a lower rate of tuberosity migration with immobilization. Moreover, Amirfeyz and Sarangi [47] showed that 4 weeks’ postoperative immobilization did not induce greater stiffness, but neither did it eliminate the risk of migration in elderly patients.

In practice, it is preferable to test tuberosity stability peroperatively after fixation and to define a mobility safety arc during initial passive rehabilitation [31]. Compliance is variable in elderly patients, who should often be referred to specialize centers [48]. X-ray control should be performed at 6 weeks, to check consolidation and non-migration, before authorizing active mobilization [49]. Muscle strengthening against resistance should be initiated after 12 weeks. The duration of rehabilitation varies, depending on the author. For Robinson et al. [8], clinical results are definitive at 6 months; others recommend continuing muscle strengthening up to 1 year [19,50].

Results

Table 3 shows results from recent series of fracture managed by hemiarthroplasty, according to type of implant [4—7,10,23,24,33,38,48,49,51—54]. Overall, following hemiarthroplasty for fracture the shoulder was pain free or almost pain free in 60 to 90% of cases. Functional results in terms of recovery of mobility, however, were more disappointing. Modular implants seemed to give better results than 1st-generation boneblack models. The first reports with dedicated models have been encouraging. Analysis of the literature reveals a wide range of results. In most series, complications had a significant adverse impact on the final result. Plausinis et al. [25] in 2005, published a comprehensive review analyzing complications (Table 4). Tuberosity fixation and consolidation issues were the most...
Table 2 Non-exhaustive list of fracture-dedicated hemiarthroplasties with main technical features.

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Trial Stem</th>
<th>Definitive Stem</th>
<th>Metaphysis</th>
<th>Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affinis fracture</td>
<td>Mathys® No trial, primary stem</td>
<td>Cemented</td>
<td>Bulky</td>
<td>3 sizes, ceramic head</td>
</tr>
<tr>
<td></td>
<td>fixation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aequalis fracture</td>
<td>Tornier® Extramedullary ancillary</td>
<td>Cemented</td>
<td>Cementless, adjustable</td>
<td>Modular, adaptable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fenestrated</td>
<td></td>
</tr>
<tr>
<td>Anatomica Zimmer</td>
<td>Trial rasps</td>
<td>Cemented</td>
<td>Bulky, Cementless, C and R models</td>
<td>Modular right and left</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comprehensive Biomet®</td>
<td>Intradmedullary ring system</td>
<td>Cemented</td>
<td>Cementless monobloc</td>
<td>Modular</td>
</tr>
<tr>
<td>Diademe Lepine®</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duocentric trauma</td>
<td>No trial implant, primary tuberosity</td>
<td>Cemented</td>
<td>Bulky</td>
<td>Modular with hooks</td>
</tr>
<tr>
<td></td>
<td>fixation around head</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epoca fracture</td>
<td>Synthes® Self-stable stem</td>
<td>Cemented or not</td>
<td>Bulky</td>
<td>Modular, adaptable</td>
</tr>
<tr>
<td>Equinoxe Exactech®</td>
<td>Trial stem metaphyseal fixation</td>
<td>Cemented</td>
<td>Cemented or not</td>
<td>Modular, adaptable</td>
</tr>
<tr>
<td></td>
<td>ancillary</td>
<td></td>
<td>Low profile, lateral offset fin</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global FX Depuy®</td>
<td>Extradmedullary ancillary with</td>
<td>Cemented</td>
<td>Bulky</td>
<td>Modular</td>
</tr>
<tr>
<td></td>
<td>metaphyseal support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humelock SBI®</td>
<td>No trial, Extramedullary</td>
<td>Non-cemented,</td>
<td>Low profile, Cementless</td>
<td>Modular</td>
</tr>
<tr>
<td></td>
<td>locking ancillary</td>
<td>locked</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polaris modular shoulder</td>
<td>No trial, Extramedullary</td>
<td>Non-cemented,</td>
<td>Bulky</td>
<td>Modular</td>
</tr>
<tr>
<td>Acumed®</td>
<td>ancillary</td>
<td>locked</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reunion Stryker®</td>
<td>Expansion trial stem</td>
<td>Cemented</td>
<td>Low profile, Cementless, Fenestrated</td>
<td>Modular</td>
</tr>
<tr>
<td>SMR trauma Lima-Lto®</td>
<td>Trial stem and metaphysis</td>
<td>Cemented or not</td>
<td>Wide, Modular (3 sizes)</td>
<td>Modular</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulys fracture Ceraver®</td>
<td>Intradmedullary metaphyseal</td>
<td>Cemented</td>
<td>Low profile Cementless</td>
<td>Monobloc, 3 diameters</td>
</tr>
<tr>
<td></td>
<td>diaphyseal ancillary and adjustable trial implant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Univers fracture Arthrex®</td>
<td>Extradmedullary ancillary, no trial implant</td>
<td>Cementless</td>
<td>Bulky</td>
<td>Modular, adjustable</td>
</tr>
</tbody>
</table>

widespread and represented the prime cause of failure and revision. Glenoid wear was found in long-term studies, but was often well tolerated and seldom required revision. Antuna et al. [49] reported generally stable results over time, with 84% of shoulders free or almost free of pain, but with limited recovery of mobility. Cumulative 10-year survivorship was 96.5%. They observed (generally limited) glenoid wear in 37% of cases.

Reverse prostheses in case of fracture

Indications

The use of reverse prostheses in fracture is not new. Paul Grammont himself recommended them for the treatment of fracture and fracture sequelae (22 cases between 1989 and 1993), but his results were not published. Since then, the interest of reverse prostheses has been demonstrated for arthroplasty where the rotator cuff has been destroyed or the proximal humerus resected for tumor [55–57]. In parallel, analysis of results with hemiarthroplasty for fracture has shown the main cause of failure to be tuberosity migration or non-consolidation, preventing rotator cuff function. In case of failure of hemiarthroplasty, moreover, replacing the implant by a reverse prosthesis significantly improves function [58–61]. In view of these findings, reverse prostheses are recommended in first intention in elderly patients, a population at risk of failure of hemiarthroplasty. There have as yet been few reports in the literature, but their results are encouraging. Reversed prostheses may be recommended in elderly patients with risk factors for poor results in hemiarthroplasty: age greater than 75 years, associated comorbidity, poor tuberosity status, preoperative rotator cuff lesion, or inability to support prolonged immobilization and specific rehabilitation [4,5,8,47].
Table 3  Results from recent studies of hemiarthroplasty for fracture.

<table>
<thead>
<tr>
<th>Authors (date)</th>
<th>Number of cases (FU)</th>
<th>Number/Type of implant</th>
<th>FU</th>
<th>Mean active ant. elevation%</th>
<th>% Pain free/almost pain free shoulders</th>
<th>Mean functional score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prakash et al. (2002) [6]</td>
<td>33 (22)</td>
<td>6 1G</td>
<td>33 mo</td>
<td>93°</td>
<td>86%</td>
<td>—</td>
</tr>
<tr>
<td>Robinson et al. (2003) [8]</td>
<td>163 (138)</td>
<td>85 1G</td>
<td>6.3 yrs</td>
<td>128°</td>
<td>93%</td>
<td>Constant 64 pts</td>
</tr>
<tr>
<td>Mighell et al. (2003) [33]</td>
<td>80 (72)</td>
<td>80 M</td>
<td>36 mo</td>
<td>128°</td>
<td>93%</td>
<td>ASES 76.6 pts</td>
</tr>
<tr>
<td>Demirhan et al. (2003) [23]</td>
<td>48 (32)</td>
<td>11 1G</td>
<td>38 mo</td>
<td>113°</td>
<td>97%</td>
<td>Constant 68 pts</td>
</tr>
<tr>
<td>Kralinger et al. (2004) [5]</td>
<td>167</td>
<td>39 1G</td>
<td>29 mo</td>
<td>41.9% &gt; 90°</td>
<td>79%</td>
<td>Constant 55.3 pts</td>
</tr>
<tr>
<td>Jacquot et al. (2004) [52]</td>
<td>72</td>
<td>72 DF</td>
<td>18 mo</td>
<td>130°</td>
<td>—</td>
<td>Constant Pond 73%</td>
</tr>
<tr>
<td>Anjum et al. (2005) [48]</td>
<td>22 (20)</td>
<td>9 1G</td>
<td>33 mo</td>
<td>117°</td>
<td>—</td>
<td>Constant 47.5 pts</td>
</tr>
<tr>
<td>Krishnan et al. (2005) [24]</td>
<td>34 (32)</td>
<td>32 DF</td>
<td>18 mo</td>
<td>117°</td>
<td>—</td>
<td>ASES 52 pts</td>
</tr>
<tr>
<td>Grönhagen et al. (2007) [7]</td>
<td>82 (46)</td>
<td>12 1G</td>
<td>53 mo</td>
<td>85%</td>
<td>—</td>
<td>Constant 42 pts</td>
</tr>
<tr>
<td>Pavlopoulos et al. (2007) [53]</td>
<td>51</td>
<td>35 1G</td>
<td>5.5 yrs</td>
<td>85%</td>
<td>—</td>
<td>Constant 57.5 pts</td>
</tr>
<tr>
<td>Fallatah et al. (2008) [51]</td>
<td>56 (45)</td>
<td>18 1G</td>
<td>48 mo</td>
<td>87°</td>
<td>—</td>
<td>WORC score: 63.3%</td>
</tr>
<tr>
<td>Greiner et al. (2008) [38]</td>
<td>43 (30)</td>
<td>30 M</td>
<td>22.7 mo</td>
<td>—</td>
<td>—</td>
<td>Constant 47 pts</td>
</tr>
<tr>
<td>Padua et al. (2008) [10]</td>
<td>21</td>
<td>1G et M</td>
<td>41 mo</td>
<td>113°</td>
<td>—</td>
<td>ASES 73.8 DASH: 39.2</td>
</tr>
<tr>
<td>Antuna et al. (2008) [49]</td>
<td>85 (57)</td>
<td>57 1G</td>
<td>10.3 yrs</td>
<td>100°</td>
<td>84%</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 Main postoperative complications in hemiarthroplasty in the literature [25].

<table>
<thead>
<tr>
<th>Complication</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infection</td>
<td></td>
</tr>
<tr>
<td>Deep</td>
<td>0–6%</td>
</tr>
<tr>
<td>Superficial</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Axillary palsy</td>
<td>0–5%</td>
</tr>
<tr>
<td>Dislocation</td>
<td>0–5%</td>
</tr>
<tr>
<td>Tuberosity migration</td>
<td>0–23%</td>
</tr>
<tr>
<td>Tuberosity non-union</td>
<td>0–17%</td>
</tr>
<tr>
<td>Tuberosity malunion</td>
<td>0–39%</td>
</tr>
<tr>
<td>RSD</td>
<td>0–4%</td>
</tr>
<tr>
<td>Secondary glenoid wear</td>
<td>0–35%</td>
</tr>
<tr>
<td>Revision for glenoid wear</td>
<td>0–4%</td>
</tr>
</tbody>
</table>

On the other hand, reversed prostheses are contraindicated in young active patients, except in exceptional salvage situations, or in case of infection or axillary nerve involvement. They can be implanted when bone stock is sufficient, which requires precise preoperative assessment on CT-scan. Given the specific risk of hematoma following implantation of a reverse prosthesis due to the resultant subacromial dead space, we recommend waiting 2 or 3 days, to reduce peroperative bleeding.

### Preoperative assessment

Given the age of the patients, it is important to assess general health status and to detect and treat any comorbidity contra-indicating anesthesia. Planning should take account of any associated fracture, which is frequent in this age group (femoral neck, radial fracture, etc.). It is useful to assess the contralateral shoulder, given the limited internal rotation frequently associated with reverse prostheses. In all cases, precise neurological assessment is needed to rule out axillary nerve lesion. In case of doubt, electromyography should be performed. Standard radiological assessment should comprise AP and lateral views and a CT scan with enhancement. The scan serves to specify the type of displacement, tuberosity status and, indirectly, rotator cuff status by assessment of fatty infiltration of the muscles [19,20], although associated rotator cuff lesions are in fact rare, at 0–5% [8,33,62]. CT is indispensable, to analyze glenoid bone capital and plan the positioning of the glenoid base plate at the beginning of surgery. Radiography with ruler of both entire humeri may be useful for planning implant height setting, especially in case of associated metaphyseal comminution.

### Surgical technique

#### Approach

Superolateral and deltopectoral approaches are used. Dislocation risk is higher with the latter [63] and is elevated in case of fracture, due to hematoma and tuberosity fracture. We therefore recommend a superolateral approach. If the approach needs to be extended downwards, it is mandatory to locate and isolate the axillary nerve through the fibers [64]. A deltopectoral approach is useful in case of extension of fracture to the shaft, requiring complementary osteosynthesis or cerclage sutures. Tuberosity preparation is as in hemiarthroplasty. The rotator interval is identified and opened, so as to free the supraspinatus tendon completely for resection up to the tendon/muscle junction.

Posterolaterally, the greater tuberosity is mobilized by the insertion of the infraspinatus and teres minor. Four non-resorbable woven sutures are threaded through the tendon/bone junction (Fig. 5). The greater tuberosity is then retracted backwards using a hooked retractor. Anteriorly, two traction sutures are placed across the subscapularis tendon/bone junction.

With the tuberosities retracted, glenoid exposure is facilitated by mild traction along the diaphysis axis. If needed, a forked retractor can be positioned on the inferior edge of the glenoid cavity. The cavity is prepared in the classic way, identifying the ideal location for the plug on the preoperative CT-scan. The glenoid base plate should be flush with the inferior edge, positioning it, so far as possible, so as to tilt 10° downward [65–67].

#### Humeral preparation and trial

To facilitate humeral exposure, the limb is positioned in extension and adduction. Metaphysis and shaft are prepared with reamers of increasing size, until cortical bone is contacted. Two holes are made in the metaphysis for the non-resorbable sutures to stabilize the tuberosities at end of surgery. The trial implant is positioned in 20° retroversion, given the risk of dislocation. Implant height is adjusted according to the proximal bone loss and preoperative X-rays. After reduction, the implant must be stable before the tuberosities can be fixed. The height must be sufficient to enable deltoid and conjoint tendon tension to be restored. One advantage of the reverse prosthesis is that different polyethylene heights can be used so as to adapt tension to local conditions. Where fracture extends to the shaft, a long stem may be used, associated to cerclage sutures.
Final implantation and tuberosity fixation
The trial implant is removed, and the final implant is positioned. We recommend a hybrid implant, with cemented stem and a non-cemented hydroxyapatite-coated proximal part to promote tuberosity consolidation. The final implant is cemented to the predefined height, in 20° retroversion. To reinforce the sutures through the shaft, we recommend positioning one suture around the implant stem before bringing it down to the shaft, especially in elderly patients. The implant is then reduced, after another trial if necessary to define the definitive polyethylene height. It is useful to lead the four sutures from the greater tuberosity around the implant neck before reduction. The tuberosity fixation technique is that described by Boileau et al. for hemiarthroplasty [68]. After reduction, the greater tuberosity is mobilized and temporarily reduced around the shaft (Fig. 6). The remaining sutures are led around the lesser tuberosity and tightened on the lateral side. This provides a horizontal assembly, holding the tuberosities around the implant, and fixation is completed using the sutures threaded through the shaft and led in a figure-of-8 through the tendon/bone junction to ensure vertical stability. The medialization of the proximal humerus and the resection of the supraspinatus reduce rotator cuff tension. Tuberosity stability is tested at end of surgery. Given the risk of hematoma, it is important to set up 48 hours' aspiration drainage in the subacromial space. The deltoid is then reinserted by non-resorbable transosseous suture through the acromion, care being taken to include the superficial and deep deltoid aponeurosis [65].

Postoperative course
Given the risk of initial dislocation, the limb should first be held in elbow-to-body immobilization, avoiding hyperextension in the lying position by placing a cushion behind the elbow. Immobilization in a simple sling then enables passive rehabilitation to be initiated, avoiding active mobilization against resistance for the first 6 weeks so as to facilitate tuberosity consolidation and avoid migration.

Results
In a prospective preliminary study, proximal humerus fracture patients managed by reverse prosthesis showed a mean 113° elevation [66]. Overall, results seemed poorer than those reported for reverse prostheses in cuff-tear arthroplasty. Mobility can be recovered in elevation even with incomplete tuberosity consolidation, which on the other hand severely limits amplitude following hemiarthroplasty.

In 2006, Cazeneuve et al. [69] reported on a series of 23 cases, 16 of which were followed up to a mean 86 months (mean age, 75 years). Implants were cemented in all cases, and tuberosities were fixed around the implant in only five cases. Four complications were reported: one dislocation and one infection, with implant replacement in both cases, and two cases of reflex sympathetic dystrophy. Mean Constant score was 60, with anterior elevation greater than 120° in all cases except for the two requiring revision. Active external rotation recovered better in those cases in which the tuberosities were fixed. The axillary margin of the scapula showed notching in 69% of cases, and there was one case of glenoid base-plate loosening.

Bufquin et al. [70] reported on a large series of reverse prostheses for fracture: 43 cases, including 40 with follow-up; mean age, 78 years. The complications rate was 28%: one peroperative glenoid fracture, five transitory neurologic involvements, one acromial fracture, one dislocation, one secondary deltoid tear and three cases of reflex sympathetic dystrophy. At a mean 22 months' FU (range, 6—58 mo), mean active anterior elevation was 97°, mean Constant score 44, and mean active external rotation in abduction 30°. Results were poorer in patients over 75 years of age, and active external rotation recovered better when tuberosity consolidation was achieved. In 53% of cases, control X-ray showed secondary tuberosity displacement, and periprosthetic ossification in 90% of cases.

In a prospective multicenter study of 15 cases with a minimum FU of 2 years (mean age, 78 years) [71], at a mean 46 months' FU mean Constant score was 55, mean active anterior elevation 107° and mean external rotation 10°. Active external rotation recovered when the tuberosities were consolidated, although the small number of cases precluded statistical demonstration. Compared to a series of hemiarthroplasty in the same indication, results did not seem to be significantly different, although distribution differed according to type of prosthesis: with a reverse prosthesis, elevation was less than 90° in only one patient but never exceeded 150°, while with hemiarthroplasty elevation exceeded 150° in 11% of patients but was less than 90° in 50%. Comparing the two prostheses in cases in which the tuberosities failed to consolidate, the better results were obtained with the reverse prosthesis (Constant score 55, vs. 41 with hemiarthroplasty). Thorough tuberosity repair with reverse prosthesis provided recovery of active external rotation and reduced the postoperative hornblower sign rate. Gallinet et al. [72], in a retrospective study of 40 cases comparing reverse prosthesis and hemiarthroplasty for fracture in elderly patients, reported 29% postoperative complication...
with the latter versus 18.7% with the former; reverse prosthesis results were significantly better in terms of mobility and Constant score.

Reverse prostheses offer an alternative to hemiarthroplasty in elderly patients. They can provide recovery of mobility in elevation even in cases in which the tuberosities have not consolidated. Tuberosity consolidation, nevertheless, remains a prerequisite for recovery of mobility in active external rotation (Fig. 7).

Results with reverse prostheses for fracture are affected by technical factors, and the associated risk of complication, which may impair shoulder function and the patient’s autonomy, is always to be borne in mind. Moreover, Guery et al. [73] reported that long-term follow-up showed a risk of deterioration after 7 years, with poorer long-term implant survivorship than in cuff-tear arthropathy [73]. A reversed prosthesis may be indicated for fracture in case of factors of poor prognosis for tuberosity consolidation with hemiarthroplasty. The choice between the two types of implant should be guided by rigorous analysis of the advantages and disadvantages of each. In future, reverse prostheses specifically adapted to fracture, with a design facilitating tuberosity positioning and consolidation, may improve results, as was found with dedicated hemiarthroplasty.

Conflict of interest statement

The author has a financial relation with the Tornier® company.

References


