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Anatomic and reverse shoulder prostheses in fracture sequelae of the humeral head

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Objectives: Arthroplasty for the proximal humerus problems secondary to fractures is troublesome, because of necrosis of the tubercles and the resulting insufficiency of the rotator cuff. The aim of this study was to investigate whether better results can be achieved with the differential use of anatomic and reverse shoulder prostheses, in comparison to the preoperative status.

Methods: Fifty-five patients with secondary fracture prostheses due to sequelae of fractures of the humeral head were followed. Anatomic prostheses were implanted in 36 cases (fracture sequelae types 1 and 2 according to Boileau), and reversed prostheses were implanted in 19 cases (fracture sequelae types 3 and 4).

Results: The mean scores of the patients improved from 19 to 68 points (anatomic prosthesis) for fracture sequelae types 1 and 2, and from 9 to 47.5 points (reverse prosthesis) for fracture sequelae types 3 and 4.

Conclusion: The differential use of anatomic and reversed shoulder prostheses in secondary fracture treatment leads to an improvement in postoperative results. In fracture sequelae types 1 and 2, the anatomic prosthesis is a better choice. However, in fracture sequelae types 3 and 4 with severe deformities, the reversed prosthesis is clearly superior to the anatomic prosthesis.

Key words: Fracture sequelae; humeral head fracture; prostheses; shoulder.

The treatment of malunion of fractures, pseudarthrosis, necroses of the humeral head, and persistent luxations after fractures of the proximal humerus presents a challenge. Furthermore, erosion is often documented, and sometimes there is advanced destruction of the glenoid due to screw perforation and other irritations caused by the osteosynthesis material. An aggravating factor in many cases is the loss of function of the rotator cuff, often as a result of osteolysis of the tubercles. Scar formation and fibrosis of the capsular ligament apparatus may complicate the process as well. These conditions resulting from a fracture are often called "fracture sequelae" in literature (Fig. 1).

Most of the time, a fundamental change of the condition can be attained only with the implantation of a prosthesis, called a "secondary fracture prosthesis". Even after such an intervention, the results are often unsatisfactory.[1-3] The conclusions in the literature are contradictory though, due to the fact that most reports do not specify whether the rotator cuff

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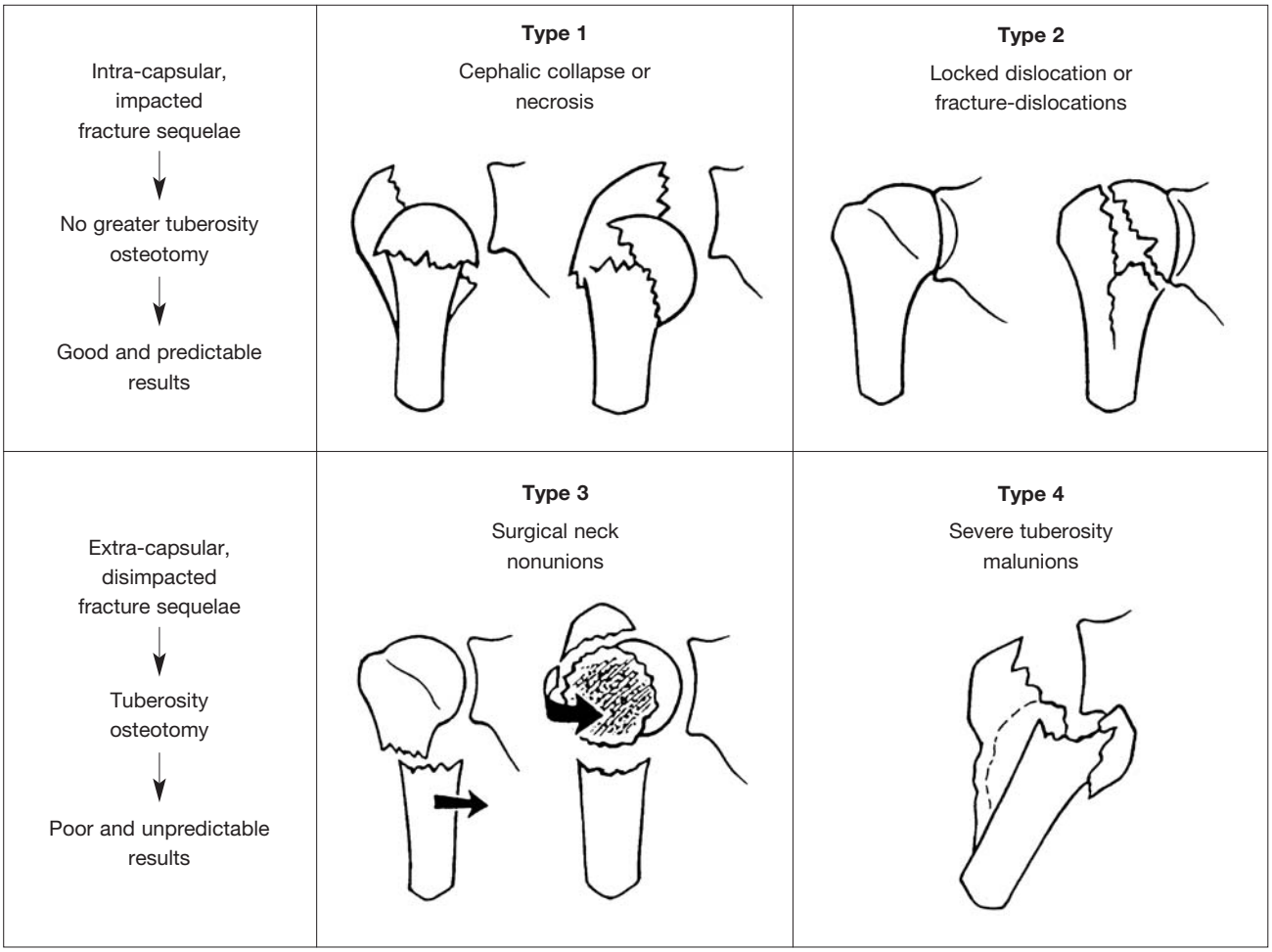

Fig. 1. Classification of fracture sequelae of the proximal humerus according to Boileau and Walch.[11,23]

functions is sufficient after the implantation.[4,5] There are two factors limiting rotator cuff function, based on the pattern of damage. In one situation, if there is a functional rotator cuff tear after implantation of an anatomic shoulder prosthesis, adequate function is not to be expected. Alternatively, if mobilization or osteotomy of the malaligned tubercles is needed in order to implant the prosthesis, there is a risk of secondary necrosis of the tubercles with resultant loss of function of the rotator cuff.[6-8] Postoperative Constant score of 41-47 points is required for implantation requiring osteotomy of the greater tubercle, and 56-60 points if no osteotomy is required.[9-12]

The chance to achieve a positive result is therefore much better if the prosthesis can be adapted to the malalignment of the tubercles, and an osteotomy is avoided. The modern, adjustable prostheses of the 3rd and 4th generation (Fig. 2) are obviously much better suited for this task than are the older, conventional models.[13-15]

Boileau et al.[6,10] introduced a classification of fracture sequelae highlighting the significant prognostic criterion of whether the implantation of a prosthesis is possible without mobilization of the tubercles (type 1 and 2, Fig. 1) or whether the mobilization is inevitable (type 3 and 4). An intracapsular impacted fracture of the humeral head or humeral head necrosis with a relatively slight malalignment between the greater tubercle and the humeral shaft corresponds to type 1. The fragments show osseous consolidation. Locked luxations and old luxation fractures are considered type 2. These tubercles do not require an osteotomy; therefore positive and reliable results can be expected after implantation of an anatomic prosthesis. Type 3 and type 4 include conditions with substantial malalignment or failure of

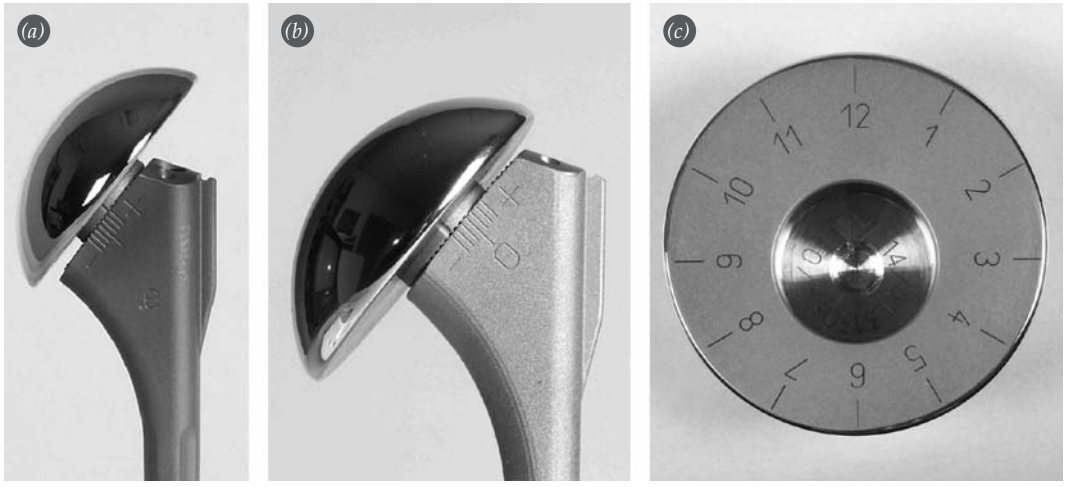

Fig. 2. Prostheses of the 3rd and 4th generation are equipped with an eccentric, in parts with a double eccentric adjustment possibility of the head (e.g. Affinis prosthesis, from Irlenbusch et al.[13]). **(a)** Maximal lateral and **(b)** medial head position, and **(c)** eccentric cone accommodation in the humeral head. This results in a setting range of 12 mm mediolateral and 6 mm anterior-posterior. The head position can be freely adjusted within this range.

the tubercles to heal, for example pseudarthroses in the surgical neck with additional fracture of the head, as well as malaligned extracapsular fractures with substantial malalignment of the tubercles and impaction of the calotte. Osteotomy and osteosynthesis of the tubercles is therefore necessary to implant the prosthesis. Due to the risk of secondary necrosis, the results can be unsatisfactory and cannot be predicted with certainty.

The implantation of a reversed prosthesis presents a solution for type 3 and type 4 fractures, since it allows the replacement of the joint surfaces as well as the reconstruction of a stable rotation center.[14,16-21] The unremarkable elevation is seen as a result of the effect of the external shoulder muscles alone, due to the fact that the rotator cuff is severely damaged and no longer balanced. However, at least partial function of the rotator cuff, especially of the infraspinatus muscle and the teres minor muscle, is required to permit rotation.[22-25]

The objective of this study was to investigate whether optimal results can be achieved through the differential use of anatomic and reverse prostheses in secondary fracture treatment.

Patients and methods

Fifty-five patients who received secondary fracture prosthesis due to a malaligned humeral head fracture were examined. An anatomic prosthesis (Affinis, Mathys Ltd., Bettlach, Switzerland) was implanted in 36 cases (fracture sequelae type 1 and 2 according to Boileau) and a reverse prosthesis (Delta III, DePuy International Ltd., Leeds, UK) was implanted in 19 cases (fracture sequelae type 3 and 4).

Head prostheses were implanted in a total of 126 patients included in a multicenter study (Arnstadt

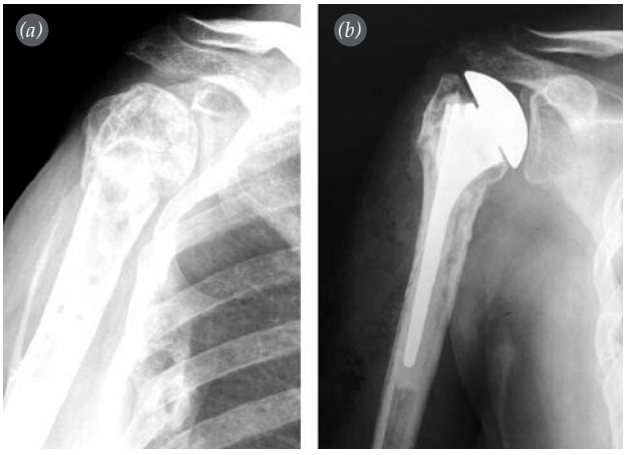

Fig. 3. Radiographics of secondary fracture prostheses. **(a)** Severe fibrous ankylosis after intracapsular impacted humeral head fracture with relatively minor malalignment. Fracture sequela is type 1 according to Boileau. **(b)** Adjustment of an Affinis prosthesis through lateral implantation of a small shaft, lateral position of cone and eccentric head, and medial cortical osteotomy on the calcar.

49, Wien 36, Heiden 21, Magdeburg 20). There were 41 men and 85 women. The mean age was 68.1 years. The patients had follow-up exams at an average of 3, 6, 12, and 24 months. There were 71 surgeries of the right side and 55 surgeries of the left side. Fifty-six prostheses were implanted without cement, and 70 were implanted with cement. There were 16 total prostheses and 110 head prostheses. Complete data were available for 113 shoulder joints. The implantation was performed due to fracture sequelae in 36 cases (Fig. 3), due to primary osteoarthritis of the shoulder in 51 cases, due to an underlying rheumatic disease in 15 cases, and for other indications in 11 cases (including seven head necrosis).

Reverse prostheses were implanted for different indications.[14] Of 51 consecutive patients (all Arnstadt), 44 patients were followed up for an average of 18.3 months (range 8-56 months). There were 36 women and eight men. There were 29 surgeries of the right side and 15 surgeries of the left side. The average age was 70.1 years (range 60-81 years). The implantation was performed 19 times to correct a malaligned fracture or fracture sequelae (Fig. 4), 14 times due to rotator cuff tear arthropathy, and 11 times for a change of prosthesis. The implantation was performed for a primary fracture in one patient and for a tumor in another patient.

Fig. 4. Radiographics of secondary fracture prostheses. **(a)** Luxation fracture of the humeral head with massive malalignment with dislocation and pseudarthrosis of the tubercles. Fracture sequela is type 4 according to Boileau. **(b)** Implantation of a reversed Delta III prosthesis.

Some patients were lost to follow-up due to different reasons: time-consuming trip (four in group 1, two in group 2); very satisfied, did not see the reason for an exam (four in group 1, two in group 2), unhappy or had another surgery (three in group 1, one in group 2); could not be reached (two in group 1, two in group 2).

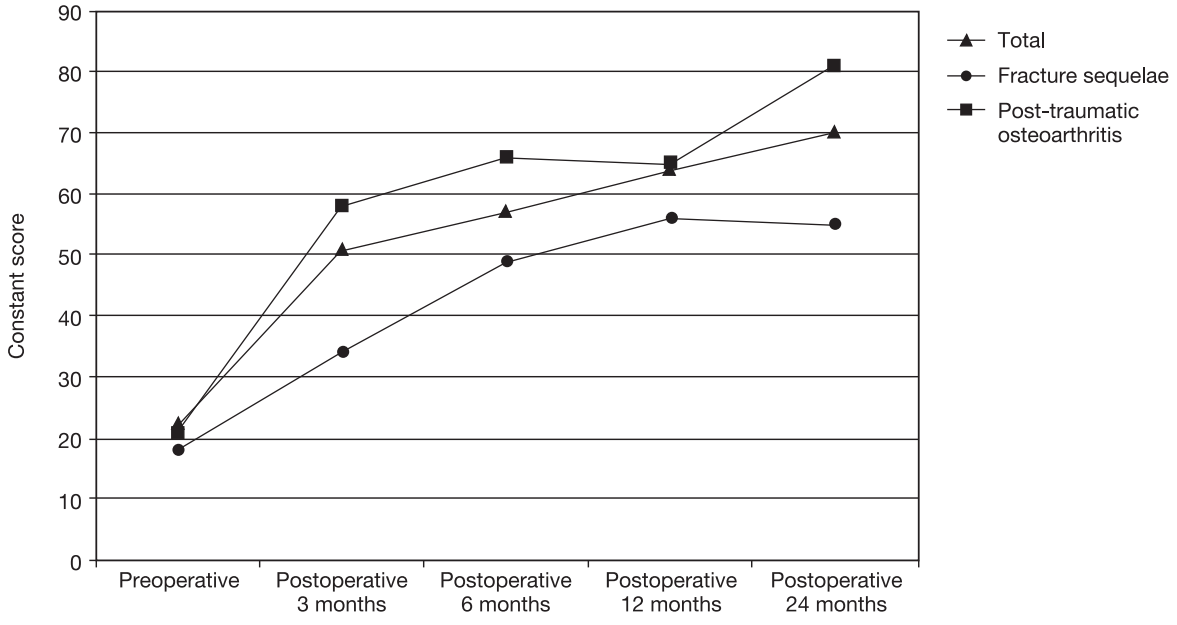

Fig. 5. The median Constant score for anatomic head prostheses (Affinis) during follow-up according to the diagnosis.

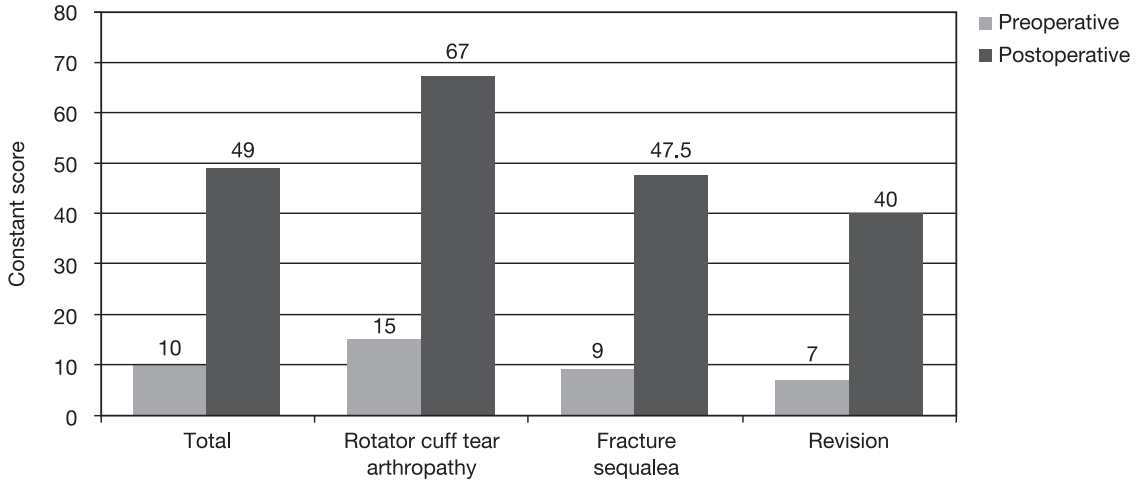

Fig. 6. The preoperative and postoperative median Constant score for reverse prostheses (Delta III) according to the diagnosis.

Clinical criteria

The clinical results based on the Constant score were determined by independent examiners, not by the surgeons. Strength measurement in the scapular plane at 90° or maximum abduction was performed by a tensiometer at the deltoid insertion. The maximum strength that could be maintained for 3 sec was measured. The mean value of three measurements was calculated. Preoperative and postoperative range of motion, active external rotation, strength, and pain relief were evaluated.

Statistical methods

The mean, median, 25th and 75th percentile were calculated for the descriptive depiction of the Constant score distribution. The date of the last follow-up exam was used in each case.

Abduction, flexion, and strength values with respect to the diagnoses were tested with nonparametric Wilcoxon tests. The p values of each comparison were adjusted with the Bonferroni correction.

Multiple regression models were used (variance analysis with consideration of age and gender) to compare the Constant scores with respect to the diagnoses. Separate models for the follow-up exams after 12 and 24 months, as well as pooled data for 3 to 24 months were estimated. The pooled models also used the month as a covariate. The data was tested for normal distribution with QQ plots and scatter plots.

Results

Of the 36 patients who received an Affinis prosthesis due to a malaligned fracture or fracture sequelae, 32 patients had fracture sequelae of type 1 or 2 according to Boileau and Walch, and four patients had type 3 or 4. The opposite was the case for implantation of a reverse prosthesis: only two patients had type 1 or 2, and 17 patients had type 3 or 4.

The improvement in fracture sequelae after implantation of an anatomic prosthesis was less than the average improvement of the group, collectively (Fig. 5). In the group with implantation of an anatomic prosthesis, improvement from 19 to 61 points was recorded after 12 months, and an improvement to 68 points was recorded after 24 months. The results were inferior to those with primary osteoarthritis of the shoulder, but superior to those with an underlying chronic inflammatory disease (preoperative/postoperative changes $p<0.001$, differences between the groups $p<0.01$).

An increase from 9.0 to 47.5 points for fracture sequelae was recorded on an average of 19.3 months after implantation of a reversed prosthesis (Fig. 6). The results were therefore intermediate between those of rotator cuff tear arthropathy and revision surgeries (preoperative/postoperative changes $p<0.001$, with no significant differences between the groups).

The preoperative score of patients who underwent implantation of a reverse prosthesis to treat a malaligned fracture or fracture sequelae was 10 points

lower than the score of patients who received an anatomic prosthesis ($p<0.003$). The preoperative difference should be taken into account when evaluating the postoperative difference of 20.5 points ($p<0.01$). Thus, an improvement from 19 to 68 points was achieved for the anatomical prostheses, corresponding to an improvement of 49 points (72% of the postoperative score), and an improvement from 9 to 47.5 points, corresponding to a 38.5 point improvement (81.1% of the postoperative score) was achieved for the reverse prostheses.

The median abduction increased from 45° preoperatively to 75° after 3 and 6 months, and 105° after 12 months and 24 months for the Affinis prosthesis. The median forward flexion was 75° preoperatively and after 3 months, 105° after 6 months, and 135° after 12 and 24 months. In the fracture sequelae group, active external rotation with the arm abducted was measured at 1.5° preoperatively, and 6.1° after 24 months (preoperative/postoperative change $p<0.001$, differences between groups, $p<0.05$).

The median improvement of the abduction from 36.4° to 86.4° and of the flexion from 41.0° to 90.9° was achieved after implantation of a reversed prosthesis. The active external rotation at 90° with abducted upper arm increased from -2.8° to 23.6° (preoperative/postoperative change $p<0.001$; the differences between the groups are not significant).

An improvement was also seen in the development of strength. For the anatomic prosthesis, strength increased in the study group from 5.0 points preoperatively to 9.0 points after 3 months, 13.0 points after 6 months and 12 months, and 17.0 points after 24 months. In the fracture sequelae group, strength was clearly below the median of strength in the study group collectively, with 9.0 points after 24 months. However, an improvement of only 0.7 to 10.0 points could be observed for the reversed prostheses. The group with rotator cuff tear arthropathy achieved the best postoperative result, with 11.6 points compared with 9.7 points in the fracture sequelae group, and 9.0 points in the revision surgery group (preoperative/postoperative change for the rotator cuff tear arthropathy group $p<0.004$, fracture sequelae $p<0.001$, revision surgery $p<0.008$, the differences between the groups are not significant).

The facts are slightly different with respect to the reduction of pain. Almost the same results were achieved in both groups. The values for the collective group with the reverse prosthesis increased from 1.5 preoperatively to 11.8 points postoperatively. The group with rotator cuff tear arthropathy achieved the best results with 12.9 points, followed by the fracture sequelae group with 11.9 points, and the revision surgeries group with 8.6 points (preoperative/postoperative change in all groups $p<0.001$, differences between the groups $p<0.047$); however, with the Affinis prosthesis, an improvement from 1.7 to 11.5 points was achieved for the collective group, and to 10.0 for the fracture sequelae group (preoperative/postoperative change $p<0.001$, the differences between the groups are not significant).

Specific complications listed for anatomic prostheses are glenoid loosening in total shoulder arthroplasty and secondary glenoid erosion in hemiarthroplasty. Neither of the two phenomena described above was recorded, nor were there any luxations or infections in this study.

As for specific complications resulting from reverse prostheses, we recorded one acromion fracture and a luxation rate of 6.8%. The notching rate was 52.3% (21 instances of Sirveaux grade 0, nine grade 1, ten grade 2, two grade 3, and two grade 4). A disconnection of the components occurred in 4.6% of the cases. Nonspecific complications that were recorded were a relatively high infection rate of 11.4% (all had previous surgeries, and two cases had infectious arthropathy), hematoma requiring revision surgery in 9.1%, and temporary loss of neurologic function in 2.3% of cases.

Discussion

The treatment of fracture sequelae of the humeral head presents a challenge. Aside from contractures, adhesions, neurological complications, and destruction of the joint parts, there is often an unstable rotation center as a result of an insufficient rotator cuff. This leads to a highly painful loss of function, which is difficult to treat. Secondary fracture prosthetic surgery is therefore a technically challenging procedure. Aside from the implantation of the prosthesis, additional procedures are regularly required such as capsular and soft tissue release, corrective osteotomies, reconstructions of the rotator cuff, and muscle replacement surgeries.[4,26] The implantation of an anatomic, unconstrained prosthesis does not automatically lead to the recreation of a stable rota-

tion center.[3] Only a very limited benefit can be expected if sufficient function of the rotator cuff cannot be attained.[16,27] Neer et al.[28] have counted these patients in the "limited goal group of rehabilitation". The recovery of function depends considerably on the severity of the preoperative situation.

This is also represented in the classification of fracture sequelae according to Boileau et al.[6,10] The Aequalis multicenter study reported an improvement from 28 to 62 points (by 34 points, 54.8% of the postoperative value) for type 1, and an improvement from 28 to 61 points (by 33 points, 54.1%) for type 2 after implantation of 203 unconstrained shoulder prostheses.[8,29,30] We achieved an average improvement of the score from 19 to 68 points (by 49 points, 72%) for groups 1 and 2. The postoperative results are clearly more favorable since the preoperative score is 9 points lower; however, exact rules to assess the Constant score do not yet exist, and differences in points between different publications might be related to differences in the methods used.

We believe that this good result can be attributed to the great adaptability of modern prostheses (Fig. 2), so that an osteotomy of the tubercles can be avoided more often. Furthermore, the exact adaptation of the head to the resection surface allows the reconstruction of the anatomical rotation center to a great extent, which is the prerequisite for a good functional result.[4]

The situation is less favorable for fracture sequelae types 3 and 4,[6,10] if they also require the implantation of a humeral head prosthesis. The Aequalis study achieved an improvement from an initial score of 21 and 20 points to a postoperative score of 36 and 42 points, thus an improvement of 15 (41.7% of the postoperative score) and 22 points respectively (52.4%).[8,29] It therefore seems obvious to implant a semi-constrained reverse prosthesis in these cases of severe deformations, in which the osteotomy of the tubercles cannot be avoided, because it allows the reconstruction of a stable rotation center. If the reconstruction of the rotator cuff is not possible in a younger patient, and the implantation of a reverse prosthesis is not an option, arthrodesis should be considered as an alternative.

We achieved an improvement of the Constant score from 9.0 to 47.5 points in 19 patients in our study with fracture sequelae 3 or 4, who received a reverse Delta III prosthesis. The postoperative result presents an improvement by 38.5 points (81.1%) and therefore a much more significant improvement compared with 41.7% and 52.4%, respectively for head prostheses. The result is clearly inferior to the results achieved with reverse prostheses in less complicated cases, especially in cases of rotator cuff tear arthropathy.[20,24,31]

The situations described for the Constant score are also reflected in the evaluation of the individual components such as abduction, forward flexion, external rotation, and strength. The pain relief, however, is nearly the same for both types of prostheses, despite the unfavorable patient population in the reversed prosthesis group. This can be attributed to the fact that it is a partially constrained total prosthesis, and both joint components are therefore being replaced. Furthermore, generation of subacromial pain is no longer possible due to the stable rotation center.

Glenoid loosening presents the limiting problem of anatomic total prostheses. Radiologic margins of bone lysis are described in up to 77% of the cases;[32] however, only 5-14% are clinically apparent and require revision.[2,32,33] A glenoid erosion rate between 5.1% and 72% is listed in the literature as another specific complication of hemiprostheses.[23,34] However, only 1.8-3.9% of those required a revision. Neither of the two phenomena described above was a factor in our study due to the short follow-up period and the relatively small number of prostheses. There were no luxations or infections. The literature describes a rate of 4-38% for luxations, and 3.9% for infection.[35-37]

Scapular notching, luxations, and acromion fractures are specific complications of reverse prostheses.[23] Only one acromion fracture occurred in the examined group. The luxation was rare with a rate of 6.5%, compared with up to 25% described in the literature.[21,23,24,38,39] We had a relatively low notching rate of 68% despite our emphasis on precise orthograde radiography technique, since this is the only way that slight changes can be determined (grade 1 and 2 according to Sirveaux). Values between 47% and 76% were reported in the literature.[20,40-42] The relatively high infection rate is probably due to the fact that the affected patients all had previous surgeries, and 50% of these were due to infectious arthropathy. The overall revision rate was 11.4% and the complication rate 25% (without scapular notching). Therefore,

reverse prostheses present a much higher risk of complications than do anatomical prostheses; however, one must consider that reversed prostheses are used in desperate situations, when other procedures would no longer be effective.

Obviously only a limited comparison of the groups is possible. The prosthesis models feature a completely different design, the sizes of the patient populations are different, follow-up periods may differ, and different surgeons follow a variety of follow-up protocols. Nevertheless, the clinical experience suggests that the implantation of a reverse prosthesis can achieve better results in complicated cases with severe destruction of the joint parts, contracted capsular ligament apparatus, and insufficient musculature. The following is a simple interpretation of the results; the poorest function following implantation of a hemiprosthesis is observed in fracture sequelae types 3 and 4 according to Boileau. However, the implantation of a reverse prosthesis in this group enables an increase of the Constant score by more than 10 points. The results after implantation of an anatomic prosthesis in type 1 and 2 are again 10-20 points higher.

The result of secondary, i.e. posttraumatic, implanted shoulder prostheses is often just as poor as the result of primary fracture prostheses. For the most part this can be attributed to necrosis of the tubercles, resulting in a failure of the rotator cuff. We demonstrated in our study that the differential use of reverse or anatomic prostheses can improve the results.

The implantation of an anatomic prosthesis is recommended in mild, posttraumatic situations that do not require an osteotomy of the malaligned tubercles for the implantation of the prosthesis (type 1 and 2 according to Boileau). In severe cases (type 3 and 4), however, the use of the reverse prosthesis is preferred, provided that the age or general condition of the patient does not contraindicate it. On the other hand, because of the known problems with scapular notching and the resulting limited durability, a reverse prosthesis should not be used if the implantation of an anatomic prosthesis is possible.

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