

Proprioception 3 years after shoulder arthroplasty in 3D motion analysis: a prospective study

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Received: 11 July 2011 / Published online: 9 March 2012
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Abstract

Background This prospective study evaluated the development of proprioception over the course of 3 years after shoulder arthroplasty.

Methods Twenty-one patients were enrolled who underwent total shoulder arthroplasty ($n = 10$) or hemiarthroplasty (HEMI) ($n = 11$) for shoulder osteoarthritis. All patients were examined 1 day before the operation, 6 months and 3 years after surgery in a motion analysis study with an active angle-reproduction (AAR) test.

Results Overall proprioception measured by the AAR deteriorated significantly 3 years after surgery [from 6.6° (SD 3.1) to 10.3° (SD 5.7); $p = 0.017$] and was significantly worse than in the control group [10.3° (SD 5.7) vs. 7.8° (SD 2.3); $p = 0.030$]. In the HEMI subgroup, 3 years after shoulder replacement, there is a significant deterioration of proprioception at 30° of external rotation [from 3.1° (SD 3.5) to 12.8° (SD 10.7); $p = 0.031$]. On average, in the TSA subgroup proprioception deteriorated from 7.1° (SD 3.1) to 8.6° (SD 1.4) and in the HEMI subgroup from 6.1° (SD 2.1) to 12.4° (SD 8.3). The comparison of postoperative impairment of proprioception between the TSA and HEMI subgroup showed significantly worse proprioception for the

HEMI subgroup at 30° of external rotation [9.8° (SD 10.1) vs. 1.6° (SD 6.3) in the TSA group; $p = 0.046$].

Conclusion In conclusion, proprioception that was measured by an AAR test remained unchanged or deteriorated 3 years after shoulder arthroplasty. The postoperative deterioration of proprioception was more distinctive in HEMI than in TSA group.

Keywords Shoulder arthroplasty · Proprioception · Joint position sense · Angle reproduction test · Total shoulder arthroplasty · Hemi arthroplasty · 3D video analysis

Introduction

Shoulder arthroplasty can significantly improve the function of osteoarthritic shoulders [6, 14, 15, 23]. In our practice, patients with glenohumeral osteoarthritis will receive a total shoulder arthroplasty (TSA). As an exception, patients with osteoarthritis which is limited to the humeral head without eccentric erosion of a stable sclerotic glenoid (Typ A1 glenoid according to [24]) can be treated with hemiarthroplasty. If the glenoid shows eccentric posterior wear ($>A1$), a TSR is recommended. In order to use the shoulder for activities of daily living the concerted interaction of the active stabilizers and the passive restraints of the replaced shoulder joint is necessary. It is known that joint proprioception plays a considerable role in stabilization of the normal healthy shoulder by helping to control muscular action [1]. However, there are little data available about proprioception of the osteoarthritic shoulder before and after surgery [5, 13]. Parameters routinely examined in previous studies include pain, satisfaction, range of motion, and strength [4]. Because proprioception is a complex system

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that relies on central integration of various afferent and efferent elements, it is more difficult to measure proprioceptive performance. Up to now, there is no consensus on how proprioception should be measured because the different components of proprioception are difficult to examine at the same time. For clinical purposes, most authors differentiate between static proprioception and dynamic proprioception [17]. Static proprioception is usually defined as the position sense, what means conscious perception of the orientation of different parts of the body with respect to another. Dynamic proprioception is defined as kinesthesia and the sense of rates of movement [12].

Since the shoulder joint is balanced and centered by the rotator cuff and the glenohumeral ligaments, it can be postulated that proprioception plays an important role in the postoperative outcome and rehabilitation. However, to date there are only two studies analyzing proprioception after shoulder replacement [5, 13]. These studies have a short follow-up period, in both cases 6 months. Cuomo et al. [5] performed a passive and guided angle-reproduction test in 20 patients with shoulder osteoarthritis before and 6 months after TSA with only one degree of freedom at a time and reported improvement of proprioception. The other study found out that 6 months after shoulder arthroplasty, proprioception remained unchanged or deteriorated, as assessed by an active and unlimited angle-reproduction test with 3D motion analysis [13]. It was assumed that this finding was most likely attributable to the relatively short rehabilitation period of 6 months. Therefore, the purpose of this study was to examine patients treated by shoulder arthroplasty preoperatively, 6 months and 3 years postoperatively to find out whether proprioception changes after a longer rehabilitation period of 3 years. The same active and unlimited angle-reproduction test with 3D motion analysis was used as described before [13]. The findings may improve our understanding of the role of proprioception in the postoperative rehabilitation after shoulder arthroplasty.

Materials and methods

Subjects

Patients with two different types of shoulder arthroplasties were examined:

1. Ten consecutive patients underwent third-generation TSA (Aequalis Shoulder; Tournier, Lyon, France) for degenerative osteoarthritis of the humeral head and glenoid with a mean age of 75 years [standard deviation (SD) 4.7 years]. There were seven women and three men [mean height 167.0 cm (SD 11.0); mean weight 81.0 kg (SD 15.9)], with four right shoulders

and six left shoulders. In all cases the deltopectoral approach was used with detachment of the subscapularis tendon and release of all three glenohumeral ligaments. At the end of the surgery the subscapularis was reattached to the humeral bone. Primary osteoarthritis was found in eight cases and secondary posttraumatic osteoarthritis in two cases. The dominant side was involved in eight cases.

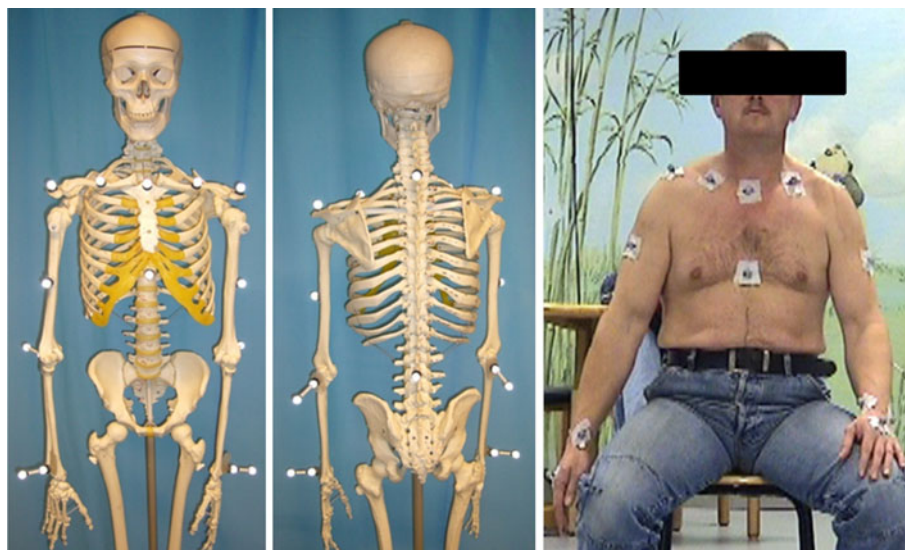
2. Eleven consecutive patients underwent hemiarthroplasty (HEMI) for degenerative changes limited to the humeral head and a stable/minimally deformed glenoid of type A1 or A2 according to Walch [25]. There were nine women and two men, with five right shoulders and six left shoulders, four on the dominant sides and seven non-dominant sides. In all cases the deltopectoral approach was used as described above. Osteoarthritis was primary in nine cases and post-traumatic in two cases. The mean age was 64 years (SD 13.8), mean height was 167.0 cm (SD 8.1), and the mean weight was 79.0 kg (SD 18.8). Six patients received a conventional third-generation hemiarthroplasty (Aequalis Shoulder) and five patients underwent humeral head resurfacing (Epoca RH CUP, Argomedical, Switzerland). Although these are distinct implants, these were pooled in one group because the operative approach was the same and the only difference was the fact that the Aequalis hemiarthroplasties have a stem within the proximal humerus. We are not aware of any data that show that insertion of a stem alters proprioception.
3. A matched control group consisted of five women and five men. Matched controls ($n = 10$; NORM) had a mean age of 64.5 years (SD 7.3). The mean height was 170.3 cm (SD 9.3), and the mean weight was 78.2 kg (SD 11.6). All controls were right-hand dominant, healthy, and had normal shoulders according to medical history, physical examination, and radiographs. The control group was examined twice at an interval of 3 years.

Joint angle analysis

The study protocol was approved by the local ethics committee (S-305/2007), and informed consent was obtained from all patients and controls. The patients were examined the day before shoulder arthroplasty, 6 months, and 3 years after surgery.

A 12-camera motion analysis system (Vicon 612; Vicon, Lake Forest, USA) working at 120 Hz was used to monitor the patients' movements. The spatial resolution of the system was approximately 1 mm. The underlying model consisted of seven segments: thorax, right and left clavicle, both upper arms and both forearms. The sternoclavicular joint and the glenohumeral joint were treated as a ball-and-socket joint, whereas the elbow was treated as a hinge joint.

Fig. 1 Position of markers for the 3D motion video analysis and test person sitting on the chair, prepared with the markers



Translational degrees of freedom were not considered in any of these joints.

For the measurement, the patients were prepared with four markers placed on the trunk as recommended by the International Society of Biomechanics [27]. Four markers were placed on each forearm: one at the radial and one at the ulnar styloid process of the wrist and two, connected with a wand, on the ulna close to the elbow joint (Fig. 1). One marker was placed laterally on the upper arm and one on the acromion. After a static trial, the patient was asked to perform isolated movements of elbow flexion/extension, shoulder flexion/extension, and shoulder abduction/adduction to determine the shoulder joint position and the location of the elbow joint axis. Specifically, in these shoulder calibration trials the sternoclavicular joint was treated as a cardan joint. Technical coordinate systems for the ulna/forearm, humerus, clavicle, and thorax were not deduced by optimization methods as was done for marker clusters [2]. Instead, they were based directly on marker trajectories, i.e. the direction vectors between them, using cross-products as reviewed by Chiari et al. [3]. The technical coordinate system of the clavicle was based on the four thorax markers and the shoulder marker. This coordinate system was used only for dynamic calibration movements, which were limited to a range of shoulder motion of 0°–40° flexion and abduction to assume constant glenohumeral movement and exclude skin motion artifacts. Constraint least squares optimization according to Gamage and Lasenby [8] was then used for joint center determination.

The anatomical co-ordinate system for the ulna/forearm, humerus, and thorax was based on the technical coordinate systems of these segments and on the joint axes and joint centers previously determined. A static trial was used to define the neutral position of the thorax. Angles of flexion and abduction were expressed as projection angles relative

to the proximal anatomical coordinate system, while internal/external rotation was defined according to the globe convention [7]. Elbow flexion was defined as the projected angle to the elbow axis. Custom software written in Java (Sun Microsystems, USA) was used to calculate each joint angle in each trial of the angle-reproduction tasks.

The system and biomechanical model was validated with the manual goniometer and intraclass correlation coefficients of 0.989 for intrasubject variability, 0.996 for inter-subject variability, and 0.998 for intertester variability were found [18]. Differences of more than 10° between the two methods were found for shoulder flexion of more than 160° [18, 19].

Angle-reproduction test

The test person sat on a chair with the arm hanging in 0° abduction and rotation (Fig. 1). They were blindfolded to eliminate visual clues and wore sleeveless shirts. We ensured that the arm did not touch the trunk and, consequently, skin contact was minimized. The arm was moved to the desired position by the examiner with visual control of a manual handheld goniometer. In detail, the positions were 30° and 60° abduction, 30° and 60° flexion, and 30° external (and afterwards 30° internal rotation) in 30° abduction (total six joint positions). In the target position the subjects were told to maintain the position for 10 s (in the meantime a mean value of the joint position was measured), and then the initial position with the arm hanging was resumed. Afterwards, the subject was asked to move the arm back into the target position. We measured the difference between the actual and the target joint position, and thus a smaller number indicates better proprioception. Standardized instructions were given to all subjects, and a test trial was conducted to acquaint them with each test

condition. All tests were randomized for side and movement. Two test trials were performed at each angle, and the mean value was used for further analysis. The total proprioceptive performance (total) was defined as the mean value of all single measurements (six joint positions) to have one quality to compare proprioceptive ability.

Statistics

The statistical analysis was performed using SPSS Version 16.0 (SPSS Inc., Chicago, IL, USA). Group mean values (MV) and SD were calculated. p values <0.05 were considered significant. The distribution of the data was checked with the Shapiro–Wilk test, and the homogeneity of variance was assessed using the Levene test. The angle between the long axis of the humerus and the trunk position was determined. Differences in shoulder joint angles between target and reproduced position were compared between the pre- and postoperative examination with a Wilcoxon-test for the overall arthroplasty group and the subgroups TSA and HEMI. Afterwards, as a second outcome measure differences among these groups and the controls were examined by a Mann–Whitney U test.

Results

In the overall arthroplasty group the total proprioceptive performance (total), defined as the mean value of all single measurements (six joint positions) deteriorates significantly 3 years after surgery from 6.6° (SD 3.1) to 10.3° (SD 5.7); ($p = 0.017$; Table 1). By trend, there is a deterioration of proprioception in five of six single measurements. Only at 30° of abduction (30° abd) there is no deterioration (Fig. 2). In comparison with the age- and gender-matched control group without a history of shoulder problems (NORM), measured once again 3 years later, the 3-year postoperative proprioception in the arthroplasty group is significantly worse [10.3° (SD 5.7) vs. 7.8° (SD 2.3)]; $p = 0.030$; Fig. 2).

The hemiarthroplasty (HEMI) subgroup revealed significant lower AAR at 30° of external rotation before surgery with 3.1° (SD 3.5) as compared to 3 years after surgery 12.8° (SD 10.7); ($p = 0.031$; Fig. 3). In the total TSA group there were no significant differences between preoperative, 6-month, and 3-year postoperative AAR.

By trend, in the TSA subgroup the total proprioceptive performance (total) deteriorated from 7.1° (SD 3.1) to 8.6° (SD 1.4) (Fig. 4) and in the HEMI subgroup from 6.1° (SD 2.1) to 12.4° (SD 8.3) (Fig. 5). By trend, the deterioration of the hemiarthroplasty (HEMI) group was in the short-term follow-up (6 months), whereas the TSA group deteriorated later in the middle-term follow-up. By trend, the 3-year postoperative proprioception of the control group was

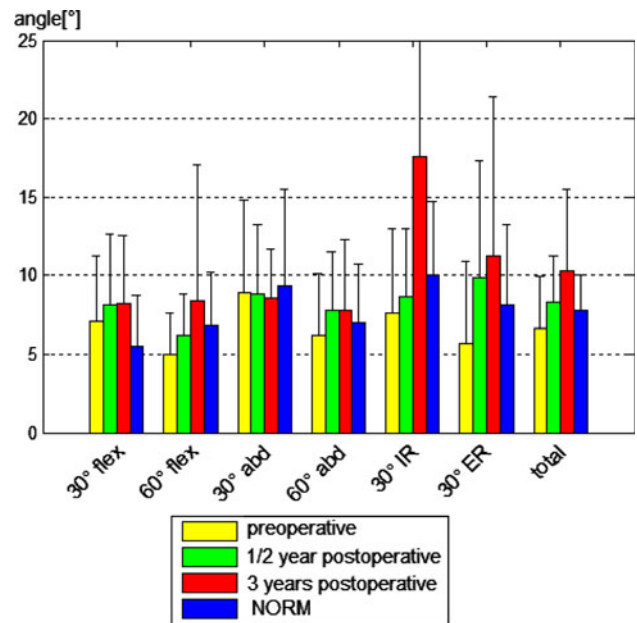


Fig. 2 Preoperative, 6-month, and 3-year postoperative proprioception for the overall arthroplasty group (TSA and HEMI) in comparison with the age- and gender-matched control group without a history of shoulder problems (NORM). The total proprioceptive performance (total) deteriorates significantly 3 years after surgery from 6.6° (SD 3.1) to 10.3° (SD 5.7); ($p = 0.017$). Three years postoperative, the total proprioceptive performance (total) is significantly worse in the arthroplasty group 10.3° (SD 5.7) versus 7.8° (SD 2.3) in the control group ($p = 0.030$)

Table 1 Active angle reproduction test (AAR) in the overall group (TSA and HEMI together) before operation and 3 years thereafter

Movement	Preoperatively		3 years postoperatively		p values
	Mean ($^\circ$)	SD ($^\circ$)	Mean ($^\circ$)	SD ($^\circ$)	
30° of flexion	6.8	± 3.1	8.3	± 4.7	0.382
60° of flexion	4.9	± 2.9	9.1	± 9.5	0.224
30° of abduction	8.8	± 5.4	8.3	± 2.7	0.861
60° of abduction	5.9	± 4.4	8.0	± 4.8	0.127
30° of external rotation	5.7	± 5.5	11.0	± 10.6	0.068
30° of internal rotation	7.6	± 5.1	17.1	± 22.9	0.168
Total	6.6	± 3.1	10.3	± 5.7	0.017

SD standard deviation

better than the proprioception of the arthroplasty groups (Fig. 5).

The comparison of pre- to postoperative deterioration of proprioception between TSA and HEMI subgroup showed significant greater deterioration of proprioception for the HEMI subgroup at 30° of external rotation of 9.8° (SD 10.1) as compared with the TSA group with 1.6° (SD 6.3)

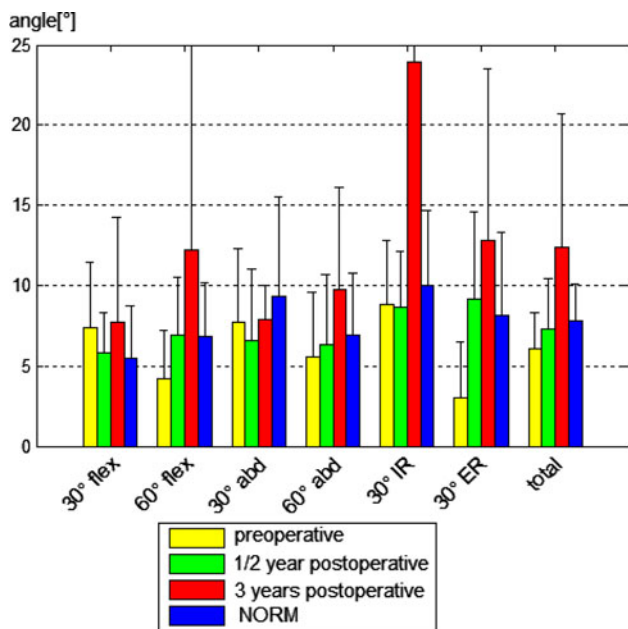


Fig. 3 The hemiarthroplasty (HEMI) group shows significant lower AAR at 30° of external rotation (30° ER) 3 years after surgery [3.1° (SD 3.5) vs. 12.8° (SD 10.7); ($p = 0.031$)]. Otherwise, there are no significances between pre- and postoperative AAR, although the total proprioceptive performance (total) almost reaches significance ($p = 0.063$). Graphically, there is deterioration in all movements

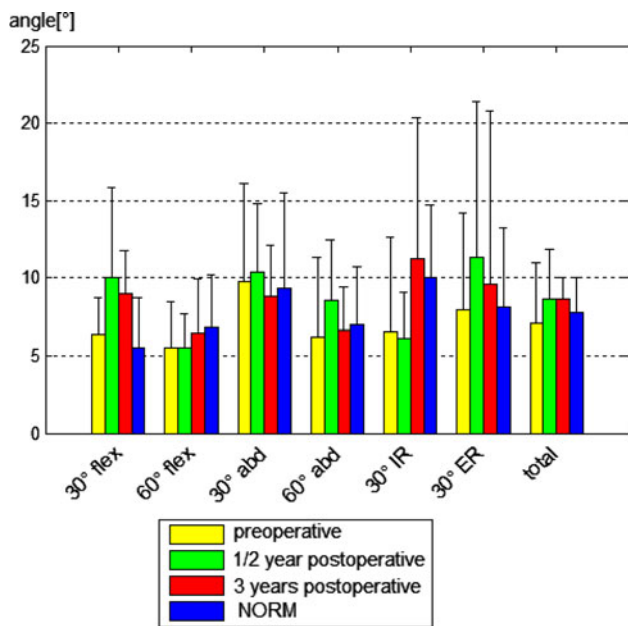


Fig. 4 The comparison of preoperative proprioception with 6-month and 3-year postoperative values after implantation of the total shoulder arthroplasty group (TSA) shows no significant differences between pre- and postoperative AAR. By trend, there is a deterioration of proprioception 3 years after surgery. The total proprioceptive performance (total) deteriorates by trend from 7.1° (SD 3.1) to 8.6° (SD 1.4)

($p = 0.046$; Table 2). Comparing the overall differences between pre- and postoperative AAR, by trend the deterioration of total proprioceptive performance (total) is more

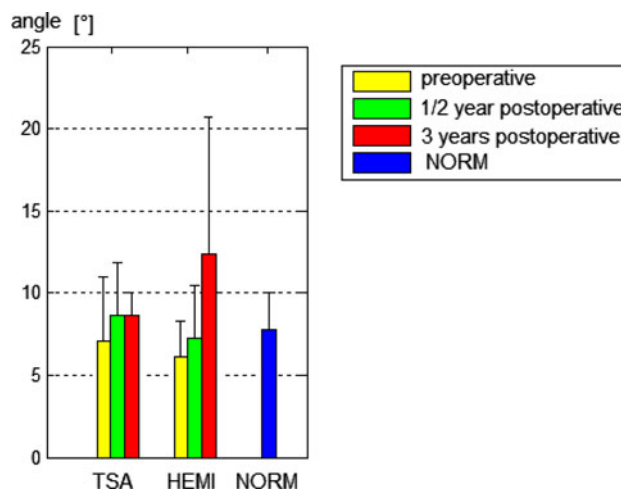


Fig. 5 Development of the total proprioceptive performance: preoperative, 6 months, and 3 years postoperative for the hemiarthroplasty (HEMI) group and the total shoulder arthroplasty (TSA) group in comparison with the control group (NORM). By trend, the deterioration of the hemiarthroplasty (HEMI) group is in the short-term follow-up (6 months), whereas the total shoulder arthroplasty group (TSA) deteriorates later in the middle-term follow-up. By trend, the 3-year postoperative proprioception of the control group is better than the proprioception of the arthroplasty groups

Table 2 Comparison of pre- to postoperative differences in the AAR test of the TSA and the HEMI subgroup

Movement	TSA		HEMI		p values
	Diff. (°)	SD (°)	Diff. (°)	SD (°)	
30° of flexion	2.7	±3.1	0.3	±7.5	0.116
60° of flexion	0.9	±5.7	8.0	±15.1	0.475
30° of abduction	-0.9	±4.3	0.2	±3.5	0.668
60° of abduction	0.3	±6.2	4.0	±6.7	0.775
30° of external rotation	1.6	±6.3	9.8	±10.1	0.046
30° of internal rotation	4.6	±11.5	15.1	±30.1	0.886
Mean values	1.6	±3.3	6.2	±8.7	0.253

Positive values indicate a deterioration of the AAR
 TSA total shoulder arthroplasty, HEMI hemiarthroplasty, Diff pre- to postoperative differences, SD standard deviation
 p values indicate whether there were significant differences between the groups TSA and HEMI

distinctive in the HEMI [6.2° (SD 8.7)] than in the TSA [1.6° (SD 3.3)] subgroup (Table 2).

Discussion

This study was performed to assess the 3-year results of proprioception measurement after shoulder arthroplasty. Our data demonstrate that proprioception remains unchanged or deteriorates 3 years after shoulder arthroplasty.

To our knowledge there are only two studies analyzing proprioception after shoulder arthroplasty [5, 13]. Both are short-term studies with a 6-month follow-up:

1. Cuomo et al. [5] performed a prospective analysis of 20 consecutive patients with unilateral advanced glenohumeral arthritis who underwent TSA. Shoulder proprioception testing for passive position sense and detection of motion was performed 1 week before surgery and 6 months after TSA. Six months after TSA, position sense and the sensitivity of detection of motion were significantly improved ($p < 0.05$) and did not differ significantly from the contralateral shoulder or the controls. Cuomo concluded that in patients with advanced glenohumeral arthritis after TSA there was a marked improvement in proprioception.
2. Kasten et al. [13] assessed proprioception 6 months after shoulder arthroplasty by the same *active* and unguided angle-reproduction test with 3D motion analysis as described in the present study. In contrast to the findings of Cuomo et al. the authors found out that 6 months after surgery proprioception remained unchanged or deteriorated. Due to the fact that this is completely different from the findings of Cuomo et al., it was concluded that this is either due to the different measurement methods (active versus passive) or the relatively short rehabilitation period of 6 months. Maybe an improvement would also be found in the mid-term follow-up.

However, the present study with the mid-term follow-up shows rather a deterioration of proprioception over the course of 3 years after shoulder arthroplasty. How can we explain that?

Cuomo et al. used a hydraulic machine that passively moved the arm. The patient had to indicate when he or she noted movement (“detection of motion”) and, in a separate approach, when he or she passively reassumed a joint position that was previously defined (“passive position sense”). Cuomo and colleagues thus measured two entities of proprioception separately. The AAR test that was used in our setting has more elements that can influence the outcome. The test person has to actively move the arm and is not limited regarding the direction of movement. Consequently, a more comprehensive concept of proprioception is tested, comprising the elements of position sense, motion sense, and the muscle strength that is necessary to reassume the position. We used an active and not a passive angle reproduction test to come up to this complexity of proprioception.

The AAR has been used to assess shoulder proprioception before, for example, in shoulder instability in which Pötzl et al. [16] examined the proprioceptive capabilities of 14 patients with recurrent anterior shoulder instability pre-

operatively and at least 5 years postoperatively using the AAR test. In their series the joint position sense improved on average about 4° in abduction, flexion, and rotation. They concluded that 5 years after surgical restoration of shoulder instability the joint position sense improved significantly to the same level as normal healthy shoulders. Having these results in mind we have to ask why proprioception measured with a comparable AAR deteriorates after shoulder arthroplasty, whereas it improves after surgery of shoulder instability. In shoulder arthroplasty, the operative approach for implantation of a TSA and hemiarthroplasty includes the cutting (and subsequent repair) of the subscapularis muscle and usually release of all glenohumeral ligaments. However, these structures contain afferent and efferent structures important for proprioception. Therefore, concerning the influence on proprioceptive structures, the surgical procedures for shoulder instability and shoulder replacement are distinct. Since the approach in TSA and hemiarthroplasty is identical, a comparison seems to be valid. Therefore, looking at the comparison of proprioceptive development after surgery between TSA and HEMI group (Fig. 5), we have to ask as to why deterioration in the TSA group seems to appear during the first 6 months, whereas in the HEMI group deterioration appears by trend between 6 months and 3 years. A possible explanation for this finding is that in the HEMI group the disease of osteoarthritis with its destruction of glenohumeral cartilage and the associated change in capsular structures and periarticular structures continues to progress in contrast to the TSA group. Maybe there is glenoid erosion in the HEMI group that deteriorates the accuracy of the angle reproduction test. However, the main aim of this study was to assess proprioception changes 3 years after shoulder arthroplasty. In order to evaluate if our findings have any clinical relevance, we have to take a closer look at the current understanding of proprioception: Proprioception is a specialized variation of the sensory modality and includes different qualities, such as active and passive joint position sense, kinaesthesia, movement replication, sensation of resistance, and appreciation of joint velocity [1]. Since the ground-breaking observations of Goodwin et al. [10] in 1972, we know that not joint receptors alone but rather muscle spindles make a major contribution for joint position sense. Today it is accepted that peripheral receptors which mostly contribute to joint position sense are muscle spindles and skin stretch receptors. A short time ago, Proske and Gandevia [17] showed that today’s data support the existence of two separate senses, the sense of limb position and the sense of limb movement. While limb position and movement can be signaled by both skin and muscle receptors, new evidence has shown that if limb muscles are contracting, an additional proprioceptive information is provided by centrally generated motor command signals.

Moreover, there is a study by Wise and Fallon [26] that suggests that there is a decreased position sense during muscle contraction. Wise assessed kinaesthesia acuity in human subjects, defining kinaesthesia as our conscious awareness of body position and movement. Interestingly, the results showed a reduced ability to detect limb movement and match limb position during co-contraction of elbow extensors and flexors compared with when these muscles were relaxed. They also report results from animal experiments showing a reduction in muscle spindle stretch sensitivity during fusimotor and skeletomotor activation, a factor that might contribute to the decreased kinaesthetic acuity observed during muscle contraction.

It can be assumed that if an active angle reproduction test for measuring of shoulder proprioception is used as it was done in this study, through contraction of shoulder muscles as the rotator cuff, deltoid, biceps and triceps muscles, we can also measure the additional proprioceptive information provided by centrally generated motor command signals as Proske described [17]. As Smith et al. [22] reported, these signals of motor command can bias joint position sense in the presence of feedback from proprioceptors.

What we observed in our study is the trend that the proprioceptive ability of the preoperative state of osteoarthritis (preoperative) is better than the proprioceptive ability of the controls (Fig. 2). This might be explained by nociceptive afferent inputs that might play an important role. During the repeat postoperative measurement, the patients mentioned that they were lacking the information input of pain sensation that they had usually during motion of the arm before surgery. The lacking of this afferent input might adversely influence the postoperative proprioceptive performance with the AAR.

Another issue is how we could diminish the loss of proprioception after shoulder replacement. Certainly we have to take a look at the surgical procedure. In the cases of TSA and HEMI the deltopectoral approach was used with detachment of the subscapularis tendon and release of all glenohumeral ligaments. In shoulder replacement different procedures exist for detachment of the subscapularis tendon. If the external rotation is $>20^\circ$, according to our concept the subscapularis tendon is divided 5–10 mm medial to its insertion at the lesser tuberosity. The lateral tendon stump will permit an end-to-end suture at the end of surgery. If the external rotation is $<20^\circ$, the detachment of the subscapularis tendon from the lesser tuberosity is recommended, because this allows to gain length by medializing the tendon insertion after implantation of the prosthesis. At the end of the surgery, the subscapularis tendon is repaired in slight abduction and external rotation of the arm either with an end-to-end suture or, in the presence of joint contracture, reattached with the help of previously mounted transosseous sutures [11, 20]. This refixation is important,

because otherwise it carries the risk of a later anterior instability of the prosthesis and loss of shoulder function.

This intraoperative soft tissue management could play an important role for the proprioceptive outcome according to a recently published study by Rokito et al. [21]. They investigated the degree to which surgical approach affects recovery of strength and proprioception. The recovery of strength and proprioception after open surgery for recurrent anterior glenohumeral instability was compared for two surgical procedures. Group 1 underwent an open inferior capsular shift with detachment of the subscapularis, and group 2 underwent an anterior capsulolabral reconstruction without detachment of the subscapularis. In group 2 the subscapularis was split horizontally at the junction of its upper two-thirds and lower one-third, and a glenoid-sided capsular shift was performed, followed by reapproximation of the split. At 6 months after surgery in group 1 patients there were still significant deficits in mean position sense and strength values. Rokito concluded that detachment of the subscapularis delays recovery of strength and proprioception. These findings can explain the deterioration of proprioceptive outcome in shoulder arthroplasty which usually implies the detachment of the subscapularis muscle. Another important issue is the release of the glenohumeral ligaments that play an important role in proprioception of the shoulder. Postoperative management with immobilizing in a Gilchrist sling or an abduction pillow, physiotherapy management including a temporary avoidance for rotational movements to allow for healing of the subscapularis muscle as well as proprioceptive neuromuscular facilitation exercises might play an important role for the individual proprioceptive outcome. In this connection, we have to ask if our finding of an average deterioration of 3.7° after shoulder replacement is at all clinically relevant. In the literature, to date there is no study analyzing the question of clinical relevance of a deterioration of shoulder proprioception after surgery. But there is one actual review by Gokeler et al. [9] analyzing the clinical relevance of a proprioceptive deficit after ACL injury. They even discuss proprioceptive deficits of 0.2° – 0.8° relative to their clinical relevance and conclude that proprioceptive deficits as measured with the current methods have only a low to moderate clinically relevant correlation with function. For shoulder proprioception authors like Cuomo et al. [5] found proprioception differences of 2° after shoulder replacement and adjudged them as clinically relevant also as reported Pötzl et al. [16] who found a proprioception change of 4° . In the present study on purpose we used an *active* and not a passive angle reproduction test to advance clinical relevance. But to fully answer the question of clinical relevance we require further studies with a prospective correlation between proprioception and clinical outcome parameters like the ability to perform activities of daily living.

Our study has some limitations. Within the treatment groups the standard deviations were relatively high, which made it difficult to reach the level of significance. Nevertheless, there was a clear trend and significant findings with deterioration of the AAR test after shoulder arthroplasty. Since the AAR data also had a high standard deviation in the healthy control group (Fig. 2), this seems to be related not to the different arthroplasty implants, but rather to the person performing the test. Most likely the high standard deviations are not related to any inaccuracy of the measuring because its accuracy has been demonstrated in previous studies [18].

Although proprioception deteriorates 3 years after implantation of shoulder arthroplasty, a pain-free increase of range of motion in activities of daily living, as we described in a previous study [14], is the main improvement for the patient after surgery.

Conclusion

Performing shoulder arthroplasty did negatively affect one component of shoulder proprioception that was measured by the active angle-reproduction test. This might be related to the surgical approach that includes divisions of the subscapularis muscle and the glenohumeral ligaments. In order to be able to diminish negative influences on postoperative proprioception, further prospective studies will have to evaluate pre- and intraoperative variables to improve proprioception after shoulder replacement.

Acknowledgments We thank the research fund of the Department of Orthopaedic and Trauma Surgery of the Hospital of the University of Heidelberg for the financial support of the study. Furthermore, we would like to thank the motion analysis team of the University of Heidelberg, especially Petra Armbrust and Waltraud Schuster, for the practical support during the study.

Conflict of interest All authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

References

- Blasier RB, Carpenter JE, Huston LJ (1994) Shoulder proprioception. Effect of joint laxity, joint position, and direction of motion. *Orthop Rev* 23(1):45–50
- Carman AB, Milburn PD (2006) Determining rigid body transformation parameters from ill-conditioned spatial marker co-ordinates. *J Biomech* 39(10):1778–1786
- Chiari L et al (2005) Human movement analysis using stereophotogrammetry. Part 2: instrumental errors. *Gait Posture* 21(2):197–211
- Constant CR, Murley AH (1987) A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res* 214:160–164
- Cuomo F, Birdzell MG, Zuckerman JD (2005) The effect of degenerative arthritis and prosthetic arthroplasty on shoulder proprioception. *J Should Elbow Surg* 14(4):345–348
- Deshmukh AV et al (2005) Total shoulder arthroplasty: long-term survivorship, functional outcome, and quality of life. *J Should Elbow Surg* 14(5):471–479
- Doorenbosch CA, Harlaar J, Veeger DH (2003) The globe system: an unambiguous description of shoulder positions in daily life movements. *J Rehabil Res Dev* 40(2):147–155
- Gamage SS, Lasenby J (2002) New least squares solutions for estimating the average centre of rotation and the axis of rotation. *J Biomech* 35(1):87–93
- Gokeler A et al (2012) Proprioceptive deficits after ACL injury: are they clinically relevant? *Br J Sports Med* 46(3):180–192
- Goodwin GM, McCloskey DI, Matthews PB (1972) The contribution of muscle afferents to kinaesthesia shown by vibration induced illusions of movement and by the effects of paralysing joint afferents. *Brain* 95(4):705–748
- Habermeyer P, Engel G (2004) Surgical technique for total shoulder arthroplasty. *Operat Orthop Traumatol* 16:339–364
- Jerosch J, Prymka M (1996) Proprioception and joint stability. *Knee Surg Sports Traumatol Arthrosc* 4(3):171–179
- Kasten P et al (2009) Proprioception in total, hemi- and reverse shoulder arthroplasty in 3D motion analyses: a prospective study. *Int Orthop* 33(6):1641–1647
- Kasten P et al (2010) Can shoulder arthroplasty restore the range of motion in activities of daily living? A prospective 3D video motion analysis study. *J Should Elbow Surg* 19(2 Suppl):59–65
- Orfaly RM et al (2003) A prospective functional outcome study of shoulder arthroplasty for osteoarthritis with an intact rotator cuff. *J Should Elbow Surg* 12(3):214–221
- Pötzl W et al (2004) Proprioception of the shoulder joint after surgical repair for instability: a long-term follow-up study. *Am J Sports Med* 32(2):425–430
- Proske U, Gandevia SC (2009) The kinaesthetic senses. *J Physiol* 587(Pt 17):4139–4146
- Raiss P et al (2007) Range of motion of shoulder and elbow in activities of daily life in 3D motion analysis. *Z Orthop Unfall* 145(4):493–498
- Rettig O et al (2009) A new kinematic model of the upper extremity based on functional joint parameter determination for shoulder and elbow. *Gait Posture* 30(4):469–476
- Rockwood CA Jr (1990) The technique of total shoulder arthroplasty. *Instr Course Lect* 39:437–447
- Rokito AS et al (2010) Recovery of shoulder strength and proprioception after open surgery for recurrent anterior instability: a comparison of two surgical techniques. *J Should Elbow Surg* 19(4):564–569
- Smith JL et al (2009) Signals of motor command bias joint position sense in the presence of feedback from proprioceptors. *J Appl Physiol* 106(3):950–958
- van de Sande MA, Brand R, Rozing PM (2006) Indications, complications, and results of shoulder arthroplasty. *Scand J Rheumatol* 35(6):426–434
- Walch G, Boileau P, Pozzi P (1999) Glenoid resurfacing in shoulder arthroplasty. In: Walch G, Boileau P (eds) *Shoulder arthroplasty*. Springer, Berlin, pp 177–181
- Walch G et al (1998) Primary glenohumeral osteoarthritis: clinical and radiographic classification. The Aequalis Group. *Acta Orthop Belg* 64(Suppl 2):46–52
- Wise AK, Fallon JB (2002) The effect of muscle contraction on kinaesthesia. *Adv Exp Med Biol* 508:87–94
- Wu G et al (2005) ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *J Biomech* 38(5):981–992