Original article

How does reverse shoulder replacement change proprioception in patients with cuff tear arthropathy? A prospective optical 3D motion analysis study[☆]

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ABSTRACT

Background: Reverse total shoulder arthroplasty (RSA) can improve function in cuff tear arthropathy (CTA) shoulders, but limited data are available on the effect of RSA on proprioception. The purpose of this study was the evaluation of the proprioception after RSA.

Method: This study included fifteen consecutive patients ($n = 15$) who received an RSA. We measured an active angle reproduction (AAR) by a novel 3D motion analysis using the Heidelberg upper extremity model (HUX).

Results: The overall proprioception didn't change significantly from 6.2° preoperatively to 6.2° postoperatively.

Conclusion: We conclude that, the overall proprioception remained the same or deteriorated for different movements.

1. Introduction

Reverse total shoulder arthroplasty (RSA) is performed in patients with cuff tear arthropathy (CTA) of the shoulder, where the osteoarthritis of the glenohumeral joint is caused by a massive and irreparable tear of the rotator cuff.¹ The idea of the reverse arthroplasty is to re-establish the functionality of the shoulder, by using the musculus deltoideus to replace and overtake the function of the rotator cuff by increasing its lever arm.^{2,3} In addition, the RSA is used as a revision prosthesis after humerus head fracture or earlier arthroplasties.^{4–7} Postoperative, RSA can improve the function and relive pain in CTA shoulders⁸ but it is unclear if proprioception changes after RSA. Proprioception plays an important role in the stability of the shoulder and is a modality, that includes the joint position and kinesthesia, meaning the movement of the joint, in a complex system.⁹ Different receptors are included in the process of collecting the information for the central nervous system.^{10,11} Studies analyzing the evolution of the proprioception after shoulder arthroplasty are rare. Cuomo et al.¹² analyzed the proprioception for total shoulder arthroplasty, Kasten et al.¹³ for different shoulder implants, and Maier et al.¹⁴ for TSA and hemiarthroplasty. Cuomo et al. examined their patients one week before and six months after surgery. Proprioception was measured using a passive angle detection test. They found a significant improvement of the proprioception after the intervention. Kasten et al. is the only study which included patients with RSA, even though it only were five patients, with three different implant designs with a follow-up of six

months. They found a deterioration of the proprioception at 60° flexion and 30° external rotation. For the subgroup RSA, there were no significant changes in the active angle reproduction. Maier is the only study with a mid-term follow-up of three years. They only included TSA or hemiarthroplasty. They found that the overall proprioception decreased three years after surgery and was significantly worse than the control group.

2. Materials and methods

2.1. Subjects

The study included 15 Patients. The patients were divided into two subgroups with different indications for the implantation of the reverse shoulder arthroplasty. Nine patients were treated because of CTA. The other six Patients were treated with a reverse arthroplasty as a revision prosthesis. The group cuff tear (CTA) consisted of nine patients, seven women and two men, all of which underwent surgery of their right shoulder. Eight out of nine times, the treated shoulder was the dominant side, only one shoulder was the non-dominant side. The mean age was 73.4 years [standard deviation (SD) 4.5 years]. In all cases the deltopectoral approach was used, where the subscapularis muscle was detached and refixed afterwards, as well as the ligaments. The mean follow-up in this group was 7.8 months [SD 2.3 months], see Table 1.

The group revision (REVISION) consisted of six patients, five women and one man. In four cases, the RSA replaced an osteosynthesis

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Table 1
Patients treated with RSA for CTA.

	gender [m/w]	age [years]	Follow-Up	indication	treated shoulder	dominant side
1	w	77	7	CTA	right	right
2	w	75	7	CTA	right	right
3	m	69	6	CTA	right	right
4	w	70	4	CTA	right	right
5	w	74	10	CTA	right	right
6	w	77	10	CTA	right	right
7	m	73	9	CTA	right	left
8	w	80	6	CTA	right	right
9	w	66	11	CTA	right	right
MV		73.4	7.8			
SD		± 4,5	± 2,3			

Table 2
Patients treated with RSA as revision.

	gender [m/w]	age [years]	Follow-Up	indication	treated shoulder	dominant side
1	w	76	11	Revision after osteosynthesis	left	right
2	w	74	7	Revision after osteosynthesis	left	right
3	m	58	8	Revision after CUP-prosthesis	right	right
4	w	76	14	Revision after osteosynthesis	left	left
5	w	72	12	Revision after osteosynthesis	left	right
6	w	72	11	Revision after TSA	right	right
MV		71.3	10.5			
SD		± 6,8	± 2,6			

with plate after a humerus head fracture. One RSA was used as a revision prosthesis for a total shoulder arthroplasty (TSA), and one for revision in a patient with a CUP-prosthesis, whom had persisting pain and limited functionality of the shoulder. The surgery was performed on four left shoulders, and two right shoulders. The affected shoulder was three times the dominant side, and three times the non-dominant side. The mean age was 71.3 years [SD 2.6 year]. In these six cases the deltopectoral approach was used as well. The mean follow-up was 10.5 months [SD 2.6 months], see Table 2. The evaluation and analysis of the data was performed for the total of all patients as a group reverse shoulder arthroplasty.

2.2. Joint angle analysis

The approval of the ethics committee was obtained (S-305/2007). All patients consented to the study and were examined the day before the operation and at the abovementioned postoperative follow-up. All the surgeries were performed by one surgeon. The patients from the study were examined in the motion analysis lab, using a Vicon system (Vicon Motion System Inc., Lake Forrest CA, 92630 USA), which consists of 12 infrared-video cameras with a resolution of 1.3 megapixels, recording the motions of the reflecting markers. The recording frequency lies at 120 Hz, with a precision of ± 1 mm. Around each camera stroboscopes were placed, with emitted infrared light, which was reflected by the markers and recorded by the cameras. To get useful data from the markers, the reflection needs to be recorded by at least two cameras, so that a 3-dimensional model can be created from the 2-dimensional information. In this study the biomechanical model Plug in Gait constructed virtual marker positions from the real positions, creating the joint centers.¹⁵

Before every analysis, the system needed to be recalibrated, with a static and a dynamic calibration. With the calibration, the position of

Fig. 1. Patient with markers.

the camera and the relative position of the markers was established. The marker used in the study were small spheres with a diameter of 8 mm, with an infrared-reflective surface. There were single markers, consisting only of the sphere, which had 2 mm to the skin, and markers which consisted of two spheres linked with a 40-mm long stick. The markers were placed on anatomic landmarks per the beforehand established Heidelberg Upper Extremity Modell (HUX).^{16,15} 14 single and two double markers were used. The pelvis was marked with two markers, on the left and right spina iliaca anterior superior, for the trunk, four markers were used, according to the ISB, with one marker on the processus spinosus of C7, TH10, incisura jugularis of the sternum and the processus xiphoideus of the sternum.¹⁷ Furthermore, there was a marker on the acromion and one on the tuberositas deltoidea of the humerus. The forearm was traces with four markers, a double marker on the olecranon, and a normal marker on the processus styloideus of the radius and ulna, representing the hand wrist, see Figs. 1 and 2. After placement of the markers, the system needed to be calibrated for the patient. Therefore each patient performed one static and three dynamic calibration runs. For the static run, the patients were seated with a straight upper body, with the upper arms close to the body, and a 90° flexion in the elbow joint. The dynamic recordings consisted of a flexion/extension in the elbow joint, an abduction/adduction in the shoulder joint (performed once with both sides simultaneously, and on each side, individually), and an anteversion/retroversion in the shoulder joint. With these calibration trials the functional centers of the joint could be determined, by using the direct trajectory of the markers. The motion itself was set in relation to the coordination system, so that the axis and joint centers could be determined in each moment of the movement. The wrist joint center was determined as midpoint between the radial and ulnar marker in relation to the static calibration trial. The elbow joint was calculated from the double marker from the elbow, the humerus marker and the wrist joint. The axis of the elbow joint was calculated with the dynamic elbow flexion/extension calibration trial. The shoulder joint, glenohumeral joint, was determined from the dynamic calibration trials abduction/adduction and anteversion/

Fig. 2. 3-D image of the patient with markers.

retroversion and the elbow joint.

2.3. Angle reproduction test

The patients were seated on a chair and blindfolded, so the information of the position of the arm were reduced to the proprioception of the patient and the visual information were reduced to a minimum. The position of the arms which the patient was tested in were 30° and 60° anteversion, 30° and 60° abduction, and a 30° internal rotation and 30° external rotation with the arm being in 30° abduction. The arm of the patient was brought into the position by the examiner starting with the arms hanging by the side of the patient and using a manual goniometer to reach a precise position. The Patient then had 10 s to memorize the position, and the returned the arm in the starting position. From there, the patient had to bring the arm into the correct position by himself and hold for 10 s. Each position was examined twice. The difference of the requested angle to the actively reproduced angle was calculated, and the mean value of the two trials was determined. Adding up all six mean values a total proprioception value was determined.

Fig. 3. Proprioception of all patients: Preoperative and postoperative proprioception after RSA. Positive values mean deterioration of the proprioception. The amount “total” doesn’t change from pre- to post-operative. The 60° abduction proprioception significantly deteriorates from 2.9° to 4.6°.

2.4. Statistical analysis

The statistical analysis was performed using Microsoft Excel 2007 and SPSS Statistics Version 20 (SPSS GmbH Software, München, Deutschland). P values < 0.05 were acknowledged as significant. Using the Shapiro-Wilk Test, the allocation of the Data was evaluated, the Levene test served as test for the uniformity of the variances. The Wilcoxon-Test was performed to assess the change of the pre- and postoperative angle-difference of the required and reproduced angle of the shoulder joint.

3. Results

In the patients with reverse shoulder arthroplasty, including the cuff tear and revision group, the proprioception didn’t change considering the total proprioception values, which showed no significant change in the pre-op (6.2°) to the post-operative values (6.2°), 7.8 months post-operative. The amount total was the arithmetic mean of the six movements. Looking at the different motion for themselves, there was a significant deterioration ($p = 0.029$) of the proprioception for the 60° abduction movement, which changed from pre-op 2.9° to 4.6° post-operative. For the other movements, the change was not significant, but with a tendency for worsening in the anteversion (30° and 60°) and external rotation, and a slight improvement in the 30° abduction and internal rotation. For the anteversion of 30°, the angle changed from 8.4° to 9°, at 60° from 3.6° to 5°. The change in external rotation was 5.3° to 7.1°. For the abduction at 30° the angle improved from 5.9° to 5° and for the internal rotation from 11.2° to 6.1°, as shown in Fig. 3.

Looking at both groups themselves, there are no significant changes in the proprioception, except for the CTA group. Here, same as in the entire collective, the 60° abduction shows a significant deterioration from 3.1° to 5.4° ($p = 0.025$). In this group, the total proprioception improved insignificantly from 6.9° to 6.2°, and the other motions showed the same tendencies as the total group (Fig. 4). In the group REVISION, there are no significant changes. The total proprioception changed from 5.2° to 6° (Fig. 5).

When comparing the two groups, there are no significant differences in the total proprioception nor the different movements themselves, as shown in Table 3. The Group CTA shows a tendency of improvement of the total proprioception, whereas the REVISION group shows an insignificant deterioration.

4. Discussion

The Purpose of this study was to analyze the evolvement of proprioception in patients with a reverse shoulder arthroplasty in a 3D-motion analysis 7.8 months after arthroplasty. We found that the overall proprioception didn’t change at all, with a tendency of

Fig. 4. Proprioception in the CTA group: Comparison of the pre- and postoperative values of the proprioception in the CTA group. Total is the arithmetic mean of the 6 single proprioception values. Positive values mean deterioration, negative values mean improvement of the proprioception. There is a significant deterioration of 2.3° from 3.1° to 5.4° in the 60° abduction.

improvement in the cuff tear group and deterioration in the revision group, or deteriorated in the abduction movement. A bigger cohort study with a comparison between the posttraumatic RSA and the RSA for rotator cuff arthropathy might reveal the influence of a longer degenerative process of the joint on the proprioception.

There are no other studies evaluating the evolution of the proprioception after RSA. Cuomo et al.¹² found that 6 months after the implantation of a total shoulder arthroplasty the proprioception improved significantly. In their study, they used a different angle reproduction test, in which the patients arm was only moved in one dimension. The arm was fixed in a hydraulic machine, and passively moved to the tested angle. The patients then had to memorize the angle and in the second run, press a button to stop the machine at the angle they thought was the previously memorized one. The room for error therefor was smaller, considering the one-dimensional movement compared to our three dimensions. Also, the testing was a passive one, with an angle detection, our patients had to actively reproduce the required angle.

Kasten et al.¹³ analyzed the proprioception six months after implantation of total-, hemi- and reverse shoulder arthroplasty. They used the same angle reproduction test as in our study, enabling an active movement in three dimension, testing the proprioception by taking away the visual feedback of the blindfolded patient. They found a significant deterioration of the proprioception after the implantation of a prosthesis in 60° flexion and 30° external rotation for all groups. We found no significant change in the overall proprioception and a deterioration at 60° abduction. The tendencies of the two studies are similar though. Kasten et al. found a non-significant deterioration of 1.1° in the

Table 3

Comparison of proprioception between the groups CTA and revision: Comparison between the differences of the pre- and postoperative proprioception values between the groups CTA and revision. Positive values mean deterioration, negative values mean improvement of the proprioception.

movement	CTA		Revision		p-value
	difference [°]	SD [°]	difference [°]	SD [°]	
anteversion 30°	1.2	± 7,9	−0.2	± 4,9	0.556
anteversion 60°	0.9	± 2,6	2.1	± 2,8	0.908
abduction 30°	−2.4	± 3,3	3.5	± 5,6	0.136
abduction 60°	2.3	± 3,2	0.8	± 2	0.203
external rotation	3.8	± 14,1	−1.3	± 7,3	0.632
internal rotation	−8.6	± 5,6	0.2	± 5,8	0.074
total	−0.7	± 7,5	0.8	± 5,2	0.726

reverse arthroplasty group. In our study, there was a tendency for worsening in the AAR for the 30° and 60° flexion and external rotation, without a significant difference between pre- and post-operative. The limitation of Kasten et al. is, that the reverse group only consists of five patients with a short follow-up. Maier et al.¹⁴ analyzed the proprioception three years after the implantation of hemi or total arthroplasty. They found a significant impairment of the proprioception of 3.7°. They also argued that the post-operative missing nociceptive aspect of the proprioception could be responsible for the deterioration. Furthermore, they found that the operation and the surgical approach may be responsible. The damaging of the muscular structure and glenohumeral

Fig. 5. Proprioception in the REVISION group: Comparison of the pre- and postoperative values of the proprioception in the revision group. Total is the arithmetic mean of the 6 single proprioception values. Positive values mean deterioration, negative values mean improvement of the proprioception. There are no significant changes of the proprioception.

ligaments which are inevitable through the deltopectoral approach may play an important role. More specifically, the detaching and refixing of the subscapularis muscle may influence the functioning of the muscle spindle and the Golgi tendon organ, both of which play an important role in the proprioception. By changing the fixation point of the muscle and therewith the tension of the muscle, one may cause the Golgi and muscle spindle to function imprecise. To evaluate this, a study with the comparison of different operation techniques needs to be done, comparing the deltopectoral approach with an anterosuperior approach, in which the muscle fixation remains unchanged.

All in all, for our study the pain seems to play an important role in the proprioception. Several patients indicated that they used their pain preoperatively to reproduce the required angle. They were guided by the pain, trying to reach the same level of pain as in the demonstration run, and thus reaching the required angle. Maier et al. reported a similar observation.¹⁴ Especially in the patients with a revision arthroplasty this aspect of proprioception could play an important role, and hereby explaining the slight insignificant deterioration of the overall proprioception. Different influences on proprioception are known, with, to date some unknown factors.^{18,19} Nociception could well be one of those factors influencing the proprioception, or at least influencing our study and the angle reproduction test. This might also explain the different results of Cuomo et al. In their study, the movement was a passive one, hence, probably the patients experienced less pain, so the influence of the factor pain on the proprioception was diminished (pain as orientation), and the postoperative results improved. Due to the less pain after RSA, the afferent nociceptive influence is reduced and the central nervous system might be more susceptible to the proprioception of the joint. Pain played an important role in the reproduction of the angle, especially in the preoperative trial. An additional study with an extensive analgesia to eliminate the pain as a factor might give further information, hereby maybe reproducing the improving proprioception due to a restored and functioning shoulder joint.

The limitation of our study is, that there are no preoperative MRI images of the shoulders, so the exact tear of the rotator cuff is unknown, and the difference of the tear between the patients is not measurable. Furthermore, the patient group is not homogenic, with different indications for the implantation of the RSA. Different influencing factors may weigh more heavily for the different indications, such as pain. For the patients with a defect arthropathy, the long ongoing process of degeneration in the shoulder might additionally influence the proprioception of the shoulder.

5. Conclusion

In conclusion, the overall proprioception of the shoulder after RSA doesn't change, only the proprioception in one movement decreases after surgery. Having different influencing factors on the proprioception, further prospective studies analyzing the surgical approach and the different indication for RSA need to be conducted.

Disclosures

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.

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The local ethics committee approved the study (S-305/2007) and all patients consented to the study.

Conflict of interest

None.

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