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Original article

Variation of the glenohumeral and scapulothoracic motion in progressive severity of glenohumeral osteoarthritis

David M. Spranz, Hendrik Bruttel, Jan M. Eckerle, Sebastian I. Wolf, Gregor Berrsche, Michael W. Maier*

Clinic for Orthopedics and Trauma Surgery, Heidelberg University Hospital, Schlierbacher Landstraße 200a, 69118 Heidelberg, Germany

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ABSTRACT

Introduction: The aim of this study is to investigate the variation of the glenohumeral and scapulothoracic motion in progressive severity of glenohumeral osteoarthritis using a 3-D-motion analysis. Moreover, the variation of the Constant Score is evaluated.
Hypothesis: The hypothesis is that the motion of the scapulothoracic joint may partly compensate for the loss of the glenohumeral joint movement in patients with increasing severity of glenohumeral osteoarthritis.
Material and methods: A total of 21 patients with primary osteoarthritis of the glenohumeral joint were clinically examined, divided in three groups (SP1-SP3) according to size of their caudal osteophyte. The contribution of the scapulothoracic (acromioclavicular and sternoclavicular) joint to the total arm (humerothoracical) elevation in sagittal and frontal plane was measured with 3D motion analysis and the Constant Score was evaluated.
Discussion: In sagittal plane elevation (anteversion) the contribution of the scapulothoracic joint to the total elevation was while arm raising 32.7% (SD 8.0%) in Group SP1, 36.6% (SD 11.0%) in Group SP2 and 49.6% (SD 9.0%) in Group SP3 ($p = 0.002$). The contribution of the scapulothoracic joint to the total elevation while arm lowering was 31.4% (SD 9.0%) in Group SP1, 39.0% (SD 13.0%) in Group SP2 and 49.7% (SD 12.0%) in Group SP3 ($p = 0.043$). In frontal plane elevation (abduction) the contribution of the scapulothoracic joint was while arm raising 33.7% (SD 8.0%) in Group SP1, 34.0% (SD 10.0%) in Group SP2 and 42.3% (SD 9.0%) in Group SP3 ($p = 0.071$). While arm lowering the contribution of the scapulothoracic joint was 30.8% (SD 10.0%) in Group SP1, 36.3% (SD 12.0%) in Group SP2 and 44.8% (SD 8.0%) in Group SP3 ($p = 0.022$). The group SP1 achieved a Constant Score of 78.00 (SD 9.823) points. The group SP2 achieved a Constant Score of 53.57 (SD 13.92) and the group SP3 38.64 (SD 10.40). There is a significant difference between the three groups ($p < 0.001$). Increasing severity of glenohumeral osteoarthritis leads to a reduced motion of the glenohumeral joint. Instead the magnitude of the scapulothoracic motion increases.
Level of Proof: V, Case Series.

1. Introduction

The movement of the arm in relation to the trunk results in the interaction between the glenohumeral (GH) joint and the scapulothoracic (ST) joint. The simultaneous interaction of the shoulder joints during arm elevation is called scapulohumeral rhythm (SHR) [1].

Degenerative GH osteoarthritis is characterized by the degeneration of articular cartilage and subchondral bone with the narrowing of the glenohumeral joint. It causes significant pain, functional limitation and disability [2].

The severity of GH osteoarthritis is commonly classified on the basis of typical alterations of the glenohumeral joint, which can be visualized by X-ray. In this study the severity is graduated into three groups as described by Samilson and Prieto [3].

The aim of this study is to investigate the variation of the GH and ST motion in progressive severity of GH osteoarthritis using a 3-D-motion analysis. The hypothesis is that the motion of the ST joint may partly compensate for the loss of the GH joint movement in patients with increasing severity of glenohumeral osteoarthritis.

The Constant-Murley Score (CS) [4] is a well-established method to determine the function of the shoulder joint. This study wants

* Corresponding author.
E-mail address: Michael.Maier@med.uni-heidelberg.de (M.W. Maier).

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to confirm that the result of CS decreases in progressive severity of osteoarthritis.

2. Patients and methods

A group of 21 patients with mean age 64.3 years (SD: 9.2, range 46–72) with primary GH osteoarthritis participated in this single-center study. Five patients were affected bilaterally, so that in total 26 shoulders were examined. Demographic data is summarized in Table 1. All participants were recruited from our upper extremity outpatient clinic. Patients with secondary GH osteoarthritis, history of shoulder surgery or cuff tear arthropathy were excluded. The study was approved by the local ethics committee (S-657/2015) and all participants signed written informed consent prior to participation.

The participants were divided in three groups according to the length of the caudal osteophyte measured as described by Samilson and Prieto [3] (Group SP1 < 3 mm, Group SP2 3-7 mm and Group SP3 > 7 mm). The latest available X-ray images of the shoulder joint in anterior-posterior projection were taken for measurements. We used the hospitals Centricity PACS Software (GE Healthcare, Little Chalfont, United Kingdom) for these measurements.

Group SP1 consisted out of 5 unilaterally affected subjects. Five subjects (3 unilaterally, 2 bilaterally affected) were selected for Group SP2 and 11 subjects (8 unilaterally and 3 bilaterally affected) were categorized in Group SP3 (Table 1).

All patients were clinically examined and CS [4] was evaluated prior to motion analysis. CS was used to grade pain (with 0 points indicating severe pain and 15 points indicating no pain), activities of daily living (ADL; with 0 points indicating no mobility and 20 points indicating full mobility), power (with 0 points indicating 0 kp [0 N] and 25 points indicating 25 kp [110.4 N]) and range of motion (ROM; max. 40 points).

After that, patients were equipped with retroflective markers (Fig. 1). An opto-electronic system with 12 T40-s infrared cameras (Vicon T40-s, Motions Systems, Oxford, United Kingdom) recording at 120 Hz was used. A marker cluster on the flat part of the acromion (AMC) was used to track scapular motion. The anatomical landmarks that were not directly tracked via markers, were digitalized in a technical coordinate system of the marker clusters with a pointing device. Anatomical coordinate systems for the segments thorax, clavicula, scapula, humerus and forearm were defined according to the ISB recommendations using the anatomical landmarks [5]. The GH center of rotation was located with the least squares method proposed by Gamage and Lasenby [6] and a bias compensation algorithm [7]. Elevation movements in frontal and sagittal plane were recorded for the calibration.

A three-dimensional method proposed by Robert-Lachaine et al. [8] was used to calculate contribution of the scapulothoracic joint (sternoclavicular plus acromioclavicular joint) to the total humerothoracical elevation. Humerothoracical elevation was calculated as an euler angle between the thorax and the humerus coordinate system with the rotation order Y-X-Y as recommended by the ISB [5]. A reference posture was recorded with the subject standing with arm hanging loosely by the side. In post-processing, the humerus coordinate system was aligned to the thorax coordinate system to represent 0° of humerothoracic elevation. In post-processing of the dynamic recordings, the GH joint's coordinate system was rotated back to its reference position and the resulting humerothoracic elevation was calculated. The resulting humerothoracical elevation was accounted for as the scapulothoracic contribution to the total humerothoracical elevation. The difference between both was attributed to the glenohumeral joint [8]. The advantage over the commonly used approach of using scapulothoracic upward rotation is that this method takes all three rotational degrees of freedom in account and the resulting elevation angle time series for each joint add up to the total humerothoracical rotation.

All subjects performed repeated elevation movements in sagittal and frontal plane. The accuracy of the AMC is limited for high elevation angles. Validity up to 90–120° was reported [9–12]. Since many patients had limited range of motion and due to the altered SHR, we decided to set the upper cut off for our analysis to 90° humerothoracical elevation. The lower cut off was set to 30° humerothoracical elevation since there is a lot of variability in this early phase of elevation. For participants with severely reduced ROM data was analyzed up to their individual maximum ROM. Differences were analyzed visually by angle-angle plots of ST elevation vs. humerothoracical elevation. For statistical analysis the total ST contribution was calculated by the area under the curve of the ST elevation divided by the by the area under the curve of the humerothoracical elevation over the individuals' ROM. The results of the four conditions (sagittal and frontal plane elevation and depression) and CS were tested for normal distribution with Shapiro-Wilk's test and for homogeneity of the variances with Levene's test. If both assumptions were met, one-way ANOVA with Bonferroni post-hoc testing was used for statistics. If one of the assumptions was not met Kruskal-Wallis' test and Dunn-Bonferroni post-hoc test was used.

Table 1
Demographic data of participants.

Group	SP1	SP2	SP3	Total
Subjects (n)	5	5	11	21
Sex (male)	3	3	7	13
Dominant (right)	4	4	11	19
Age [a]	61.8 (7.9)	62.2 (14.1)	65.7 (7.6)	64.3 (9.2)
BMI [kg/m^2]	26.6 (4.0)	28.1 (3.5)	29.1 (4.7)	28.7 (4.5)
Shoulders (n)	5	7	14	26
Dominant side affected	0	3	6	9

Values in brackets state standard deviation; BMI: body mass index.

3. Results

The angle-angle plots showed that ST contribution to the total humerothoracical elevation between 30 and 90° increased with severity of the glenohumeral OA in all four conditions (Fig. 2).

In sagittal plane (anteversion) the contribution of the ST joint to the total elevation was 32.7% (SD 8.0%) in Group SP1, 36.6% (SD 11.0%) in Group SP2 and 49.6% (SD 9.0%) in Group SP3 while arm raising. The one-way ANOVA showed a statistically significant difference ($p = 0.002$). Post-hoc tests showed a significant difference between Group SP1 and SP3 ($p = 0.007$) and between Group SP2 and SP 3 ($p = 0.019$).

While arm lowering the ST joints' contribution was 31.4% (SD 9.0%) in Group SP1, 39.0% (SD 13.0%) in Group SP2 and 49.7% (SD 12.0%) in Group SP3 (Fig. 1). The Kruskal-Wallis-Test showed a statistically significant difference ($p = 0.043$) (Fig. 3).

In frontal plane (abduction) the contribution of the ST joint was 33.7% (SD 8.0%) in Group SP1, 34.0% (SD 10.0%) in Group SP2 and 42.3% (SD 9.0%) in Group SP3 while arm raising. The one-way ANOVA showed no statistically significant difference between the groups ($p = 0.071$).

While arm lowering the contribution of the ST joint was 30.8% (SD 10.0%) in Group SP1, 36.3% (SD 12.0%) in Group SP2 and 44.8% (SD 8.0%) in Group SP3. The one-way ANOVA showed a statistically significant difference ($p = 0.022$). Post-hoc tests showed a significant difference between Group SP1 and SP3 ($p = 0.031$) (Fig. 4).

The group SP1 achieved a CS of 78.0 (SD 9.8) points. The group SP2 achieved a CS of 53.6 (SD 13.9) and the group SP3 38.6 (SD 10.4) (Fig. 5). ANOVA showed a significant difference between the three

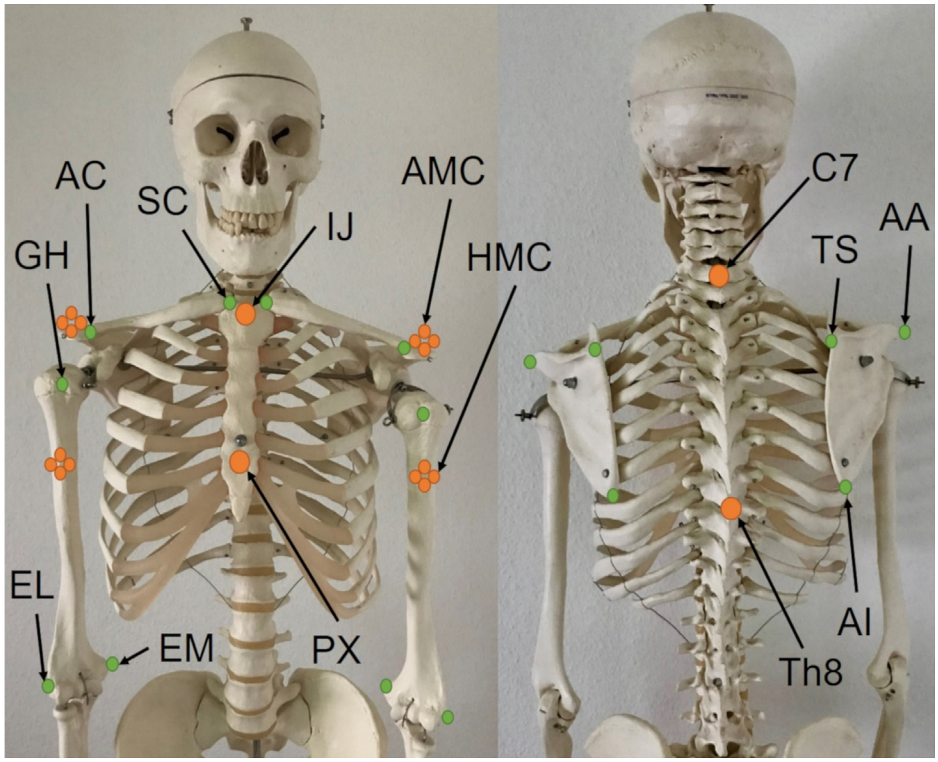

Fig. 1. It shows the anatomical landmarks used for the motion analysis. Orange markers were tracked by the camera system (four markers on the thorax, marker clusters on the humerus [HMC] and the acromion [AMC]) and green markers were virtually reconstructed from reference frames. Landmarks are named according to the ISB recommendations.

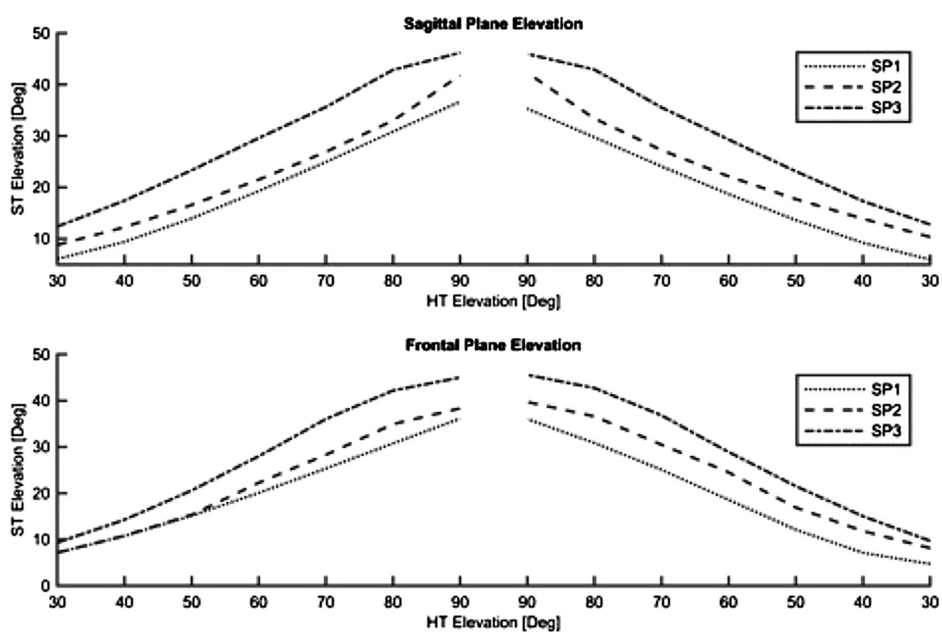

Fig. 2. ST elevation plotted against total humerothoracical elevation. Left half shows arm raising and right halt arm lowering.

groups ($p < 0.001$). Post-hoc test showed a significant difference between SP1 and SP2 ($p = 0.004$), between SP2 and SP3 ($p = 0.027$) and between SP1 and SP3 ($p < 0.001$).

4. Discussion

Knowledge about scapular movement under the influence of glenohumeral motion helps to understand the mechanism and pathology of the shoulder joint. Cathcart [13] was the first to recognize the contribution made by the scapulothoracic joint to normal shoulder complex kinematics and Codman termed this synchronous motion scapulohumeral rhythm (SHR) [1]. Inman et al. [14] reported a SHR of 2:1 in healthy subjects.

This present study is, to our knowledge, the first study to show changes in movement of the GH joint and the ST joint in progressive severity of GH osteoarthritis. The results show that in progressive severity of GH osteoarthritis the part of the ST joint increases to compensate the loss of GH joint movement.

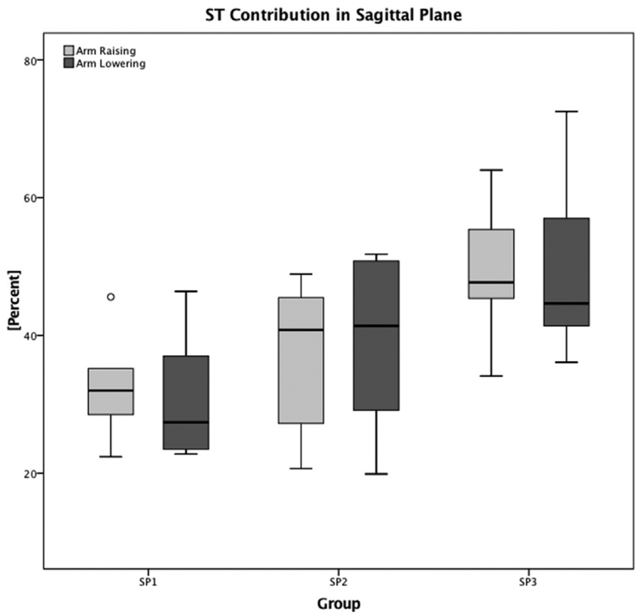

Fig. 3. Boxplots of ST contribution to the total elevation in sagittal plane while arm raising and lowering. Circles show values outside 1.5 times of the interquartile range.

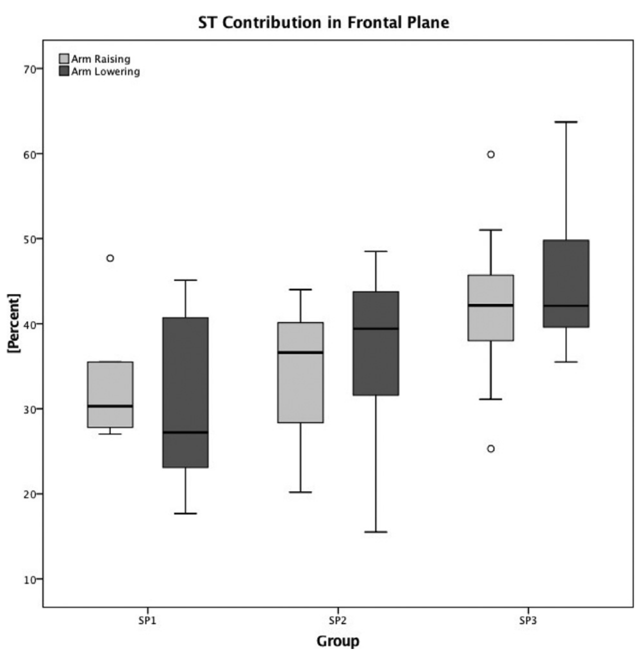

Fig. 4. Boxplots of ST contribution to the total elevation in frontal plane while arm raising and lowering. Circles show values outside 1.5 times of the interquartile range.

There are several studies available which investigated the movement of the ST joint after shoulder arthroplasty [15–17]. Roren et al. reported that for patients after total shoulder arthroplasty (TSA), the increased contribution of the scapula to arm elevation is accompanied by a compensatory mechanism for the reduced GH mobility [15]. Walker et al. reported that shoulder with reversed TSA use more ST motion and less GH motion to elevate the arm [17]. The same result is reported by Lee et al. [16]. Kim et al. reported a SHR of 2.4:1 on operated shoulders after reversed TSA and 4.1:1 on contralateral shoulders at 120 degrees of abduction [18].

The severity of GH osteoarthritis can be determined by using X-ray of the shoulder joint according to the length of the caudal osteophyte, measured and graduated into 3 groups (Group SP1 < 3 mm, Group SP2 3–7 mm and Group SP3 > 7 mm) as described by Samilson and Prieto. Our results show that the severity of GH osteoarthritis in X-ray correlates to the severity of GH osteoarthritis in motion and we conclude that this, all in all, is a suitable option to graduate the severity of GH osteoarthritis.

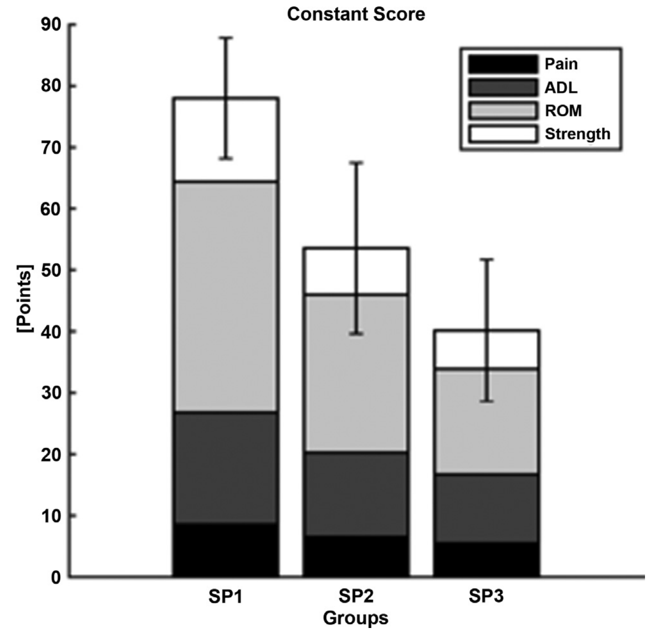

Fig. 5. CS for the three groups. Error bars state standard deviation of the total score.

The present study has some limitations. The most obvious is the small number of cases enrolled, especially in the group SP1. The reason for this is that these patients often do not have severe symptoms and hence they do not seek medical treatment. We would expect that with a higher number of subjects there would be a statistically significant difference in frontal plane elevation while arm raising and additionally significant differences between SP1 and SP2 in the post-hoc tests. Furthermore 5 subjects were affected on both sides and both their shoulders were included in this study. This is a violation the condition of independent observations. Although we like to mention that none of these subjects was included in two different groups. Another limitation is that some subjects, especially in Group SP3, had a limited ROM and were not able to reach 90° of humerothoracical elevation. This means that the analyzed ROM differs between subjects. Since this is normal for GH osteoarthritis, it does not make sense to exclude participants with limited ROM.

Nevertheless, our study was the first to investigate the variation of the GH and ST motion in progressive severity of GH osteoarthritis using a 3-D-motion analysis. Further studies should analyze GH and ST motion in comparison to the other joints of the upper extremity as Gielen et al. [19] showed. Furthermore, combination of 3D motion analysis with surface EMG would give more insight into the changes of muscle activation as Karst et al. [20] showed. In addition, future studies could investigate the influence of motor disorders on shoulder pathologies as Flash et al. [21] showed that movement of the upper extremity's joints is strongly dependent on the intended movement of the hand. It is possible that shoulder pathologies could alter the planning of motion and that this alteration is preserved after surgical treatment.

5. Conclusion

Increasing severity of GH osteoarthritis leads to a reduced motion of the GH joint. Instead the magnitude of the ST motion increases. A lower Constant Score indicates an increasing severity of GH osteoarthritis. The radiographic graduation of the severity of GH osteoarthritis by using the method described by Samilson and Prieto is a suitable option to graduate the severity of GH osteoarthritis.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contribution

David M. Spranz conceived the study and drafted the manuscript.

Hendrik Bruttel performed the statistical analysis.

Jan M. Eckerle performed the investigations.

Sebastian I. Wolf helped with the methodology and gave technical support.

Gregor Berrsche helped to draft the manuscript.

Michael W. Maier participated in the design of the study and its coordination.

All authors read and approved the final manuscript.

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