

Kinematic evaluation of patients with total and reverse shoulder arthroplasty during rehabilitation exercises with different loads

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ARTICLE INFO

Article history:

Received 26 January 2012

Accepted 25 April 2012

Keywords:

Shoulder

Arthroplasty

Kinematics

Scapulohumeral rhythm

ABSTRACT

Background: Following shoulder arthroplasty, any well-planned rehabilitation program should include muscle strengthening. However, it is not always clear how different external loads influence shoulder kinematics in patients with shoulder prostheses. The objective of this study was to describe shoulder kinematics and determine the contribution of the scapulothoracic joint to total shoulder motion of patients with total and reverse shoulder arthroplasties and of healthy individuals during rehabilitation exercises (anteflexion and elevation in the scapular plane) using different loading conditions (without external load, 1 kg and elastic resistance).

Methods: Shoulder motions were measured using an electromagnetic tracking device. A force transducer was used to record force signals during loaded conditions using elastic resistance. Statistical comparisons were made using a three-way repeated-measures analysis of variance with a Bonferroni post hoc testing.

Findings: The scapula contributed more to movement of the arm in subjects with prostheses compared to healthy subjects. The same applies for loaded conditions (1 kg and elastic resistance) relative to unloaded tasks. For scapular internal rotation, upward rotation and posterior tilt no significant differences among groups were found during both exercises. Glenohumeral elevation angles during anteflexion were significantly higher in the total shoulder arthroplasty group compared to the reverse shoulder arthroplasty group.

Interpretation: Differences in contribution of the scapula to total shoulder motion between patients with different types of arthroplasties were not significant. However, compared to healthy subjects, they were. Furthermore, scapular kinematics of patients with shoulder arthroplasty was influenced by implementation of external loads, but not by the type of load.

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1. Introduction

Shoulder arthroplasty constitutes a form of treatment for osteoarthritis in the shoulder and is currently widely used (Buck et al., 2008). The procedure is generally recognized as successful in terms of pain relief, while providing an improved, but nevertheless limited range of motion (RoM) (Bergmann et al., 2008, Veeger et al., 2006). Although

improvement in terms of RoM and function have been reported, it is not yet clear why optimal results are not always achieved or which factors influence these functional outcomes (Magermans, 2004).

There are different types of shoulder arthroplasty. Total shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA) are considered to be the most common in use (Buck et al., 2008). TSA provides reliable pain relief and improves function in most arthritic shoulders with an intact or reparable rotator cuff (Wiater and Fabing, 2009). However, TSA results are less satisfactory in patients with glenohumeral arthritis combined with severe rotator cuff deficiency or in patients with a failed primary arthroplasty in whom the rotator cuff is deficient or absent. For these shoulder conditions, for which reconstruction was previously considered unobtainable, RSA is a powerful new tool (Wiater and Fabing, 2009). Following this line of reasoning, the indication for each type of arthroplasty varies: TSA is usually performed on patients with an intact rotator cuff

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whereas RSA is performed on patients with primary cuff tear arthropathy or those who need a revision arthroplasty involving a deficient rotator cuff.

Optimizing a patient's response to arthroplasty is the combination of a correctly performed surgical procedure and a well-planned post-operative rehabilitation program. The challenges lie in reestablishing normal motion, as well as dynamic stability and strength, which requires an adaptive and progressive system of rehabilitation consisting of appropriate applications of range of motion and strengthening (Basti, 2005, Boardman et al., 2001, Brems, 1994).

Various exercises have been prescribed by physiotherapists focusing on shoulder muscle strengthening during rehabilitation of patients with shoulder injuries (Andersen et al., 2010, Hintermeister et al., 1998, Hughes and McBride, 2005, Hughes et al., 1999). Two commonly implemented methods of training involve exercises using machines or free weights and exercises involving elastic resistance (Hughes and McBride, 2005). Elastic resistance is commonly used for therapeutic exercise due to its low cost, simplicity, portability, versatility and non-reliance on gravity for resistance (Hughes and McBride, 2005, Hughes et al., 1999). Despite the popular use of the elastic resistance method during the management of shoulder rehabilitation, few studies have investigated the effect of such a tool on shoulder function. Most available literature with regard to elastic resistance, focuses on muscle electromyography (EMG) activity (Andersen et al., 2010, Hughes and McBride, 2005), without taking shoulder kinematics and especially scapular and glenohumeral motion into account.

A few studies have investigated three-dimensional (3D) upper-extremity motion patterns in patients with shoulder arthroplasty during movements without external load. Bergmann et al. (2008) studied patients with RSA and found that their glenohumeral elevation contributed roughly two-thirds of the total thoracohumeral elevation, which is comparable to healthy subjects. However, these patients were not able to actively use the full RoM provided by the prosthesis. Veeger et al. (2006) studied patients with TSA and hemi shoulder arthroplasty during a specific hair combing task. Both patient groups showed considerable limitations in glenohumeral RoM, when compared to controls, but between patient groups only axial rotation RoM was different. Alta et al. (2011) compared the kinematics of the arm in patients with a primary placed reverse prosthesis and those with a revision and concluded that active range of motion is better in primary placed prosthesis and that this difference is most noticeable mainly in the glenohumeral joint.

Since shoulder motion is a precise balance between mobility and stability (Veeger and van der Helm, 2007), attention must be paid to the joint kinematics while resistance is applied during the rehabilitation program to avoid possible injury causing factors. For example, research has demonstrated that alterations of scapular motion and position are associated with a wide variety of shoulder injuries (Ludewig and Cook, 2000, Ludewig and Reynolds, 2009). Moreover, Pascoal et al. (2000) also reported differences in the scapular kinematics of healthy subjects caused by external load, despite seemingly be unaffected by different load magnitudes. For this reason, the patient should not experience pain caused by possible kinematical alterations during strengthening exercises and shoulder dyskinesias should be avoided (Kibler and Sciascia, 2010). To ensure that strengthening exercises are indeed beneficial, it is important to understand the kinematics of the glenohumeral (GH) and scapulothoracic (ST) joints during rehabilitation exercises using these external loads. This certainly applies to patients with a shoulder replacement in which mechanical and proprioceptive changes are inevitable. Rehabilitation programs for these specific patients need even greater attention.

The main purpose of this study is to describe 3D scapular and glenohumeral kinematics for two patient groups and a healthy pilot group during two RoM tasks using different loads. The patient groups consist of patients with a total shoulder arthroplasty (TSA) and patients with a reverse shoulder arthroplasty (RSA). Kinematics are

reported during anteflexion and elevation in the scapular plane using different load situations (without external load, with 1 kg dumbbell and with elastic band resistance). We hypothesized that the contribution of the ST joint to arm elevation would be higher in patients with shoulder arthroplasty when compared to healthy pilots, whereas patients with a TSA would show a larger GH contribution than the RSA group, due to the different biomechanical principles between the two types of prostheses and a functional or non-functional rotator cuff. This means that to compensate for this loss in GH motion, more ST motion in the RSA group will be needed to be able to obtain the same thoracohumeral elevation angle. Furthermore, we hypothesized for all groups that loaded conditions would have a larger ST contribution to arm elevation than without load, while differences between the two load conditions are likely to be small.

2. Methods

2.1. Participants

Forty individuals participated in the study. Seventeen subjects (twenty shoulders/none revision) had a total shoulder arthroplasty (TSA group), eight subjects (nine shoulders/three revisions) a reverse shoulder arthroplasty (RSA group) and fifteen subjects had no problems (pain or injury) in the shoulder (pilot group). The average time between measurements and surgery, mean age, height, body mass of the patients and affected side are listed in Table 1. According to a clinical evaluation, all patients could perform their everyday activities independently, but when the activities implicated the involved arm, the activity level became restricted. The patients did not have other serious pathologies, which would otherwise be considered a contraindication for this kind of surgery. In the TSA patients the rotator cuff muscles were intact and in the RSA patients in nearly all cases only the supraspinatus and infraspinatus were absent. The indications for the reverse prosthesis were: primary cuff tear arthropathy, arthritis following a massive cuff tear (a painful condition which also entails a considerable limitation of range of motion) or revision of an earlier failed shoulder prosthesis. The protocol was approved by the medical ethics committee and all subjects provided written informed consent before commencement of the experiment.

2.2. Data collection

A six degree-of-freedom electromagnetic tracking device, the Flock of Birds (Ascension Technology Inc., Burlington, Vermont, USA) was

Table 1
Demographic, anthropometric and clinical data of the subjects.

	Pilot group (n = 15) (n = 15 shoulders)	TSA group (n = 17 patients) (n = 20 shoulders)	RSA group (n = 8 patients) (n = 9 shoulders)	Differences among groups (p)
Age (years)	25.1 (3.7)	72.1 (10.3)	73.3 (9.4)	<0.001*
Height (cm)	182.3 (12.2)	166.9 (10.0)	166.5 (9.1)	<0.001*
Body mass (kg)	73.1 (12.5)	83.9 (21.7)	70.5 (11.1)	0.118
Affected side	–	10–right 10–left	6–right 3–left	
Revision	–	–	3	
Time between measurements and surgery (months)	–	33 (18)	57 (24)	

Values expressed as mean (standard deviation). TSA: total shoulder arthroplasty. RSA: reverse shoulder arthroplasty.

* Statistical differences ($P < 0.05$) between pilot group and both patient groups.

used to collect the kinematic data. According to the manufacturer, the system specifications regarding measurement accuracy are 0.76 cm and 0.5° RMSE for position and orientation, respectively. This device consists of one extended-range transmitter that creates a 3D magnetic field. Electromagnetic sensors were attached to the sternum, humerus, forearm, and acromion (Johnson et al., 1993). The sensor in the sternum was located at the upper extremity of the sternum, the humeral sensor was located at the middle part of the arm, the sensor in the forearm was located at the middle part of the forearm and the sensor on the acromion was placed in the flattest part of the acromion. The sensors on the sternum and acromion were attached to the skin with double-sided adhesive tape and covered with a Fixomull stretch self-adhesive bandage (Beiersdorf AG, Hamburg, Germany) and the arm and forearm sensors were fitted on a cuff. An additional sensor was attached to a pointer and used to digitize 13 bony landmarks relative to their sensors (Meskers et al., 1998). The pointer is a non-metal object with a fine point upon which a kinematic sensor can be secured and that assists in locating segment endpoints and other bony landmarks with greater precision. The local vectors from bony landmarks to sensors were calculated and were used to construct anatomical local coordinate systems for thorax, humerus scapula and forearm using the *MotionMonitor* software (Innovative Sports Training, Inc., Chicago, Illinois, USA) and following the ISB standardization proposal for the upper extremity (Wu et al., 2005). For the humerus, the proximal landmark was assumed to be in the glenohumeral rotation center estimated by the rotation method (Veeger, 2000).

A 1-degree-of-freedom force transducer (FUTEK Advanced Sensor Technology, Inc., Irvine, California, USA) with a sample frequency of 1000 Hz, capacity of 445 N, and precision of 0.4 N was used to record force in the RoM tasks using the elastic resistance band. The force transducer was attached to the floor and to the bottom component of the elastic device (Fig. 1).

The net moment was calculated for all tasks with external load and it was defined as the sum of the segment's weight moment and the external load moment. The weight of the segment was obtained from anthropometric tables (Dempster, 1955) with inertial effects not being taken into account because of the low execution speed. The dumbbell moment was defined as the cross product of the dumbbell's weight and moment arm, and the elastic band moment was calculated by the cross product of the elastic band force (expressed by the force transducer) and the moment arm of the force direction. To determine the elastic band force direction, the base of the force transducer was pointed/digitized and the direction was determined as the vector between this base and the midpoint between the *styloideus ulnaris* and *styloideus radialis* landmarks (that were digitized beforehand). The elastic resistance device used is a Theraband® (yellow) with an initial length of 70 cm. To realize the same initial length for everybody, all subjects were asked to stand on a 35 cm high platform during the data collection of RoM tasks with the elastic resistance band and a rope between the elastic band while the force transducer was used to adapt to each subject's height, when necessary, and maintain the same 70 cm of initial length for all participants. During the other load situations (without external load and with 1 kg dumbbell) the subjects seated in a chair.

Two actively performed RoM tasks were measured in three different load situations (without external load, with 1 kg dumbbell and with elastic band resistance). The RoM tasks consisted of elevation in the sagittal plane (anteflexion) and elevation in the scapular plane (at an angle of 30° anterior from the frontal plane). Since it is quite common for patients to have a severely limited RoM, subjects were instructed to reach up to 90° elevation with both arms during the RoM task and these angles and the plane of elevation were maintained by using a semicircular board that subjects could follow as a reference. The data collection order was always the same for all subjects: 1) anteflexion without external load, 2) anteflexion with 1 kg, 3) elevation in scapular plane without



Fig. 1. Elastic band resistance and force transducer. The reference board for indication of the requested arm elevation has been temporarily removed for clarity purposes.

external load, 4) elevation in scapular plane with 1 kg, 5) anteflexion with elastic resistance, 6) elevation in scapular plane with elastic resistance. Dynamic tracking of the scapula is difficult, but up to 90° of elevation it is still possible using an acromion sensor (van Andel et al., 2009). The subjects were asked to perform each task three times without load and twice with loads. All patients were instructed to stop the task if they experienced any pain during the data collection.

Scapular and humeral motions were calculated relative to the thorax (scapulohumeral and thoracohumeral motion) and scapula (glenohumeral motion). The motions of the humerus were also calculated as scapulohumeral or glenohumeral motions, i.e. the humerus relative to the scapula. Joint angles were defined based on the International Society of Biomechanics standardization proposal of the International Shoulder Group (Wu et al., 2005) and data from left shoulders were mirrored to the right before further data processing. All angles were defined using a fixed sequence of rotations (each related to a principal plane), also known as *Euler* angles. The sequence of rotations for thoracohumeral and glenohumeral angles was YXY, which means that the plane of elevation is determined first, elevation angle second and axial rotation last. For scapulohumeral motion the sequence was YXZ, which represents internal/external rotation followed by upward/downward rotation and anterior/posterior tilt (Doorenbosch et al., 2003).

The contribution of the ST joint was expressed by the scapulohumeral rhythm calculated by the ratio of the glenohumeral elevation angle over the scapular upward rotation (slope of the regression line). Glenohumeral elevation angles and all scapulohumeral angles were selected for further analysis. All trials from each patient were used for further processing.

From the dynamic motions, kinematic measures are presented for 15, 30, 45, 60, 75 and 90° of thoracohumeral elevation.

2.3 . Statistical analysis

The Shapiro–Wilk test indicated that the overall data were normally distributed. Comparisons of mean age, height and body mass between pilot group and both patient groups were performed with a one-way analysis of variance test. Comparisons of the kinematic data were completed by means of a $3 \times 3 \times 6$ three-way repeated-measures analysis of variance for each separate Euler angle with the factors “load” (without load, 1 kg dumbbell and elastic band resistance), “group” (pilot, TSA and RSA), and thoracohumeral elevation angle (15, 30, 45, 60, 75, and 90). In the presence of significant interactions, one-way analysis of variance was calculated at each level of the interacting factor. Comparisons of net moment at 90° of thoracohumeral elevation were done by means of a one-way analysis of variance with the factor “group”. Bonferroni post hoc testing was used where appropriate to adjust for multiple pairwise comparisons across groups and loads. The significance level was set at 0.05.

3 . Results

3.1 . Net moment

The net moment values for all groups during anteflexion and elevation in the scapular plane with 1 kg dumbbell and elastic band resistance are shown in Fig. 2. Net moment presented the lowest value at the beginning of the RoM and the peak value at 90° of shoulder elevation. A significant main effect of group was detected for both exercises and loads. The net moment at 90° of thoracohumeral elevation was higher in the pilot group compared with the TSA group during anteflexion and elevation in scapular plane with 1 kg dumbbell and during anteflexion with elastic band resistance. No significant differences were found between either patient groups.

3.2 . Effect of groups on scapulohumeral rhythm, scapulothoracic and glenohumeral motion

A statistically significantly smaller average ratio was found between glenohumeral elevation and scapular upward rotation for TSA and RSA groups than for the pilot group in all load situations, showing that the scapula contributes more to movement of the arm in subjects with a shoulder arthroplasty compared with healthy subjects (Fig. 3).

For scapular internal rotation, upward rotation and posterior tilt no significant differences among groups were found during anteflexion or during elevation in the scapular plane. On the other hand, the glenohumeral elevation angle was significantly higher during anteflexion in the TSA group than in the RSA group ($49^\circ \text{SD } 1.5^\circ$ versus $42^\circ \text{SD } 2.1^\circ$, $P = 0.038$), while only a tendency towards a main effect of group was detected for glenohumeral elevation during elevation in the scapular plane ($P = 0.06$).

3.3 . Effect of loads on scapulohumeral rhythm, scapulothoracic and glenohumeral motion

The scapula contributed more to externally resisted movements of the arm compared with movements using just arm's weight (Fig. 3). This was visible as a lower and statistically significant average ratio for situations with 1 kg dumbbell and elastic band resistance for all groups than for movements without external load.

For scapular internal rotation, significant differences were found among loads during anteflexion ($P = 0.04$) and elevation in the scapular plane ($P = 0.04$). Across all thoracohumeral elevation angles, the scapula relative to the thorax was significantly more internally rotated during anteflexion with 1 kg dumbbell (an average of $33.5^\circ \text{SD } 1.4^\circ$) when compared with no external load (an average of $32.7^\circ \text{SD } 1.3^\circ$).

No main effect of load for upward rotation during anteflexion ($P = 0.66$) and elevation in the scapular plane ($P = 0.18$) was detected.

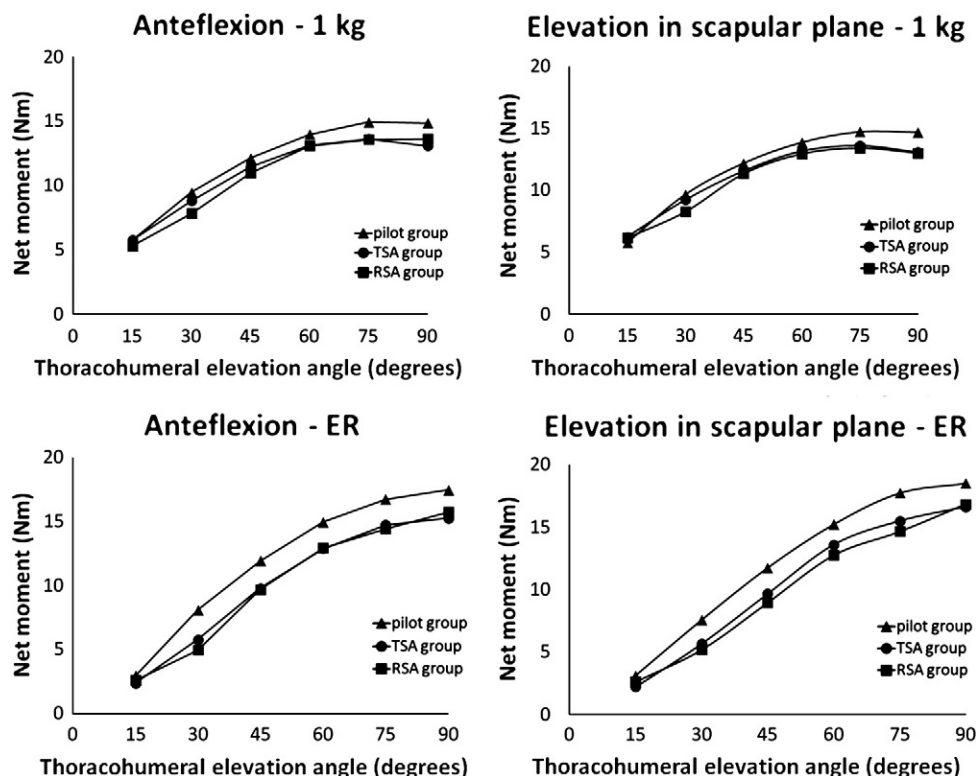


Fig. 2. Net moment calculated for both exercises using 1 kg dumbbell and elastic band resistance (ER) for all groups. TSA: total shoulder arthroplasty. RSA: reverse shoulder arthroplasty.

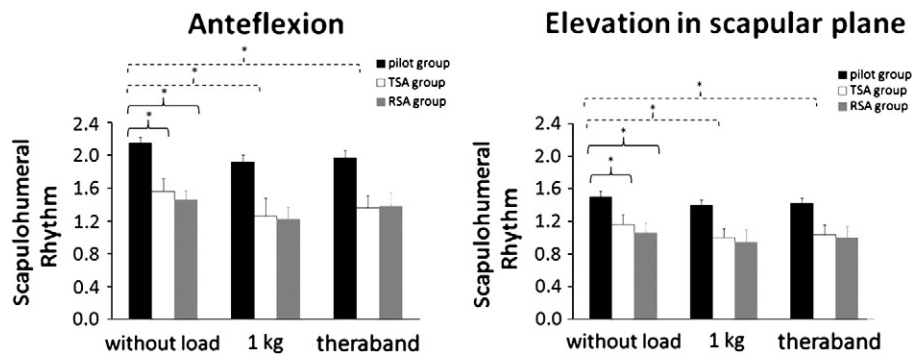


Fig. 3. Scapulohumeral rhythm during anteflexion and elevation in the scapular plane. *Significant differences ($P < 0.05$). Dotted curly brackets represent differences in load situations and solid curly brackets represent differences among groups. TSA: total shoulder arthroplasty. RSA: reverse shoulder arthroplasty.

(Fig. 4). On the other hand, two interaction effects during anteflexion were significant: angle \times group ($P < 0.001$) and angle \times load ($P < 0.001$). In the pilot group, the scapula was more upwardly rotated in the without load situation compared with 1 kg dumbbell at 30° and 45° of thoracohumeral elevation. In the same group, the scapula was also more upwardly rotated in the without load situation compared with elastic band resistance at 15° and 30° of thoracohumeral elevation.

In some thoracohumeral angles for the TSA group the opposite occurred: greater upward rotation was seen with 1 kg dumbbell compared with the without load situation at 45°, 60° and 75° of thoracohumeral elevation. No differences were detected among the three loads across all thoracohumeral elevation in the RSA group. All these results for upward rotation can be seen in Fig. 4. No significant differences among loads during anteflexion ($P = 0.18$) and elevation in the scapular plane ($P = 0.27$) were detected for posterior tilt.

No main effect of load ($P = 0.46$) was detected for glenohumeral elevation angle during elevation in the scapular plane. Other than that, one interaction was significant: load \times group ($P = 0.03$). At 90° of thoracohumeral elevation with elastic band resistance, the GH elevation angle was higher in the pilot group (mean of -64.6° SD 5.9°) compared with RSA group (mean of -52.8° SD 12.3°) and also higher in the TSA group (mean of -63° SD 7.6°) compared with the RSA group (mean of -52.8° SD 12.3°). The RSA group showed more GH elevation during the without load situation when compared with 1 kg dumbbell at 30°, 45°, and 60° of thoracohumeral elevation. The other groups did not show this load influence on GH elevation angle (Fig. 5).

4. Discussion

The hypotheses of the present study were that the contribution of the ST joint to arm elevation would be higher in patients with shoulder arthroplasties when compared to healthy pilots. Furthermore, the loaded conditions were expected to make a larger ST contribution to arm elevation than without load, while differences between the two load conditions were expected to be minimal.

Our results showed that patients with a shoulder arthroplasty indeed presented a smaller GH elevation angle compared to healthy subjects. Between patient groups, the TSA group presented higher GH elevation angles compared to the RSA group in some load conditions (for example at 90° of elevation in the scapular plane with elastic band resistance), which was in accordance with our expectation. The GH elevation angles in our patients were similar to the RoM presented by a group of patients with hemi and total shoulder arthroplasties (35°–55°) (Veeger et al., 2006). During anteflexion, the TSA group presented an average GH elevation angle of 49° SD 1.5° and the RSA group of 42° SD 2.1° . Furthermore, when compared to the results of our pilot group, GH elevation angles were lower for both patient groups in accordance with this same study that showed a GH angle of 85° for the pilot group and 35–55° for patients with a

shoulder arthroplasty (Veeger et al., 2006). Based on these results, it may well be worthwhile paying more attention to training the rotator cuff muscles in TSA patients to increase GH mobility. In most cases, the arthritis was chronic which will lead to non-functional rotator cuff muscles. For RSA patients on the other hand, rehabilitation should focus mainly on the deltoid muscle as this muscle compensates for the deficient rotator cuff muscles (Boileau et al., 2005).

Bergmann et al. (2008) also calculated scapular contribution for patients with RSA. Their results for maximal active unloaded anteflexion are 1.7 and for abduction 1.6. Comparing this data with our study, it is possible to recognize differences: we found a ratio of 1.4 for anteflexion and 1.1 for the scapular plane. Furthermore, the authors stated that the reverse arthroplasty seems to enable a scapulohumeral rhythm during arm elevation similar to that found in healthy subjects (Groot et al., 1998) in contrast to the standard total shoulder arthroplasty. Our findings conflict with this statement because we did not find differences between both groups of patients regarding scapulohumeral rhythm up to 90° of elevation. However, it is not possible to compare these results directly, since the ratio calculation is different: in our study we calculated the ratio between the GH elevation angle and scapular upward rotation and Bergmann et al. (2008) calculated the ratio between peak thoracohumeral elevation angles and peak GH elevation angles. Even when calculating in a similar way for comparison, we found a ratio of 1.3 for anteflexion without external load for both patients group, which again showed different results from those presented by Bergmann et al. (2008).

With regard to the effect of different loads, our results showed that there is no difference in kinematic motion patterns between 1 kg dumbbell and elastic band resistance, but there are differences relative to unloaded tasks. One study analyzed muscle activation during resistance exercise with elastic tubing and dumbbells and our main finding was the comparable high level of muscle activation, also indicating that both types of exercise can be implemented equally during rehabilitation (Andersen et al., 2010). As in clinical practice the use of elastic band resistance is a very common alternative method; the results of our study suggest that it could be used when dumbbells are not feasible, without having any disadvantages for the rehabilitation process. Specific protocols and methods have been described which advocate exclusive use of elastic bands in strengthening the rotator cuff muscles (Hughes and McBride, 2005). For this reason, it must be taken into consideration as a very important tool in shoulder rehabilitation programs.

The present results also showed that the load influence is different for each group, depending on thoracohumeral elevation angle. In the TSA and RSA groups, for example, greater upward rotation was seen in the 1 kg situation compared with the without load situation, indicating more upward rotation in extra-load situations in some thoracohumeral elevation angles. Conversely, in the pilot group there was more upward rotation during without load situation compared to 1 kg dumbbell and elastic band resistance in some

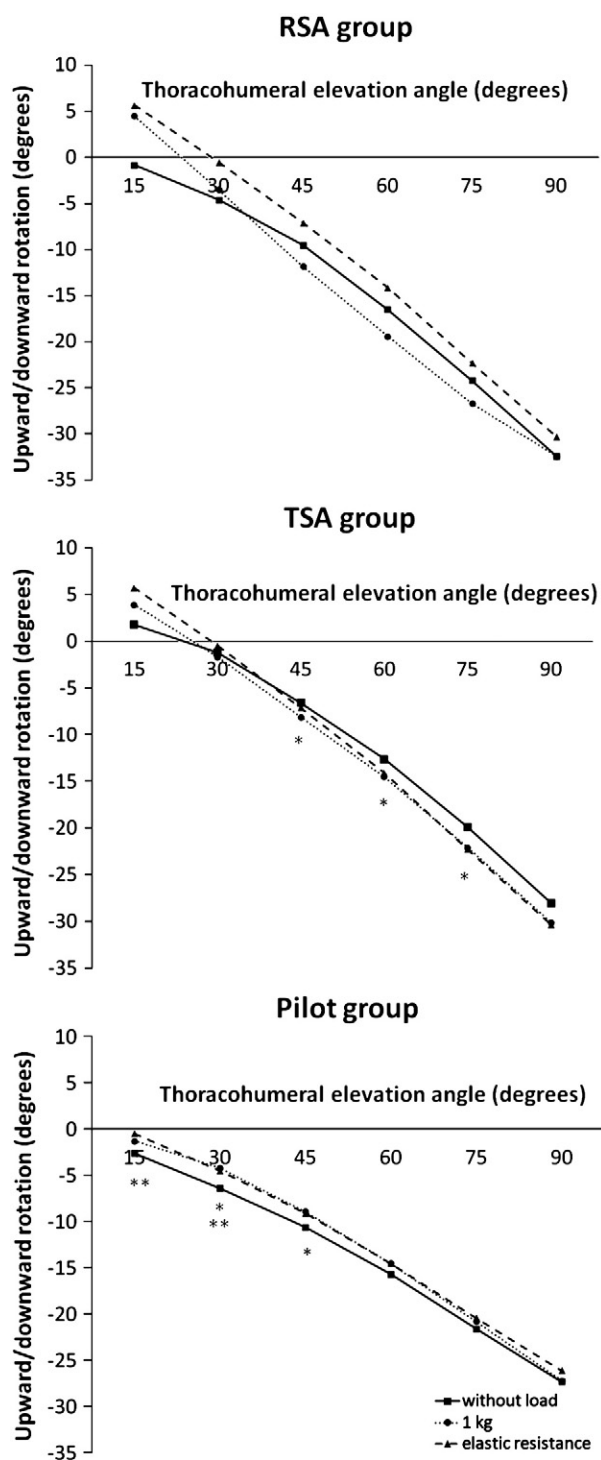


Fig. 4. Scapular upward rotation (mean values) during ante flexion for all groups and load situations. Load legends are equal for all groups. * Significant difference between without load situation and 1 kg dumbbell ($P < 0.05$). ** Significant difference between without load situation and elastic band resistance ($P < 0.05$). TSA: total shoulder arthroplasty. RSA: reverse shoulder arthroplasty.

thoracohumeral elevation angles. One study has found the same behavior in healthy subjects: greater upward rotation when the external load (5% of subject's body mass) was applied at 60° and 90° of shoulder abduction (Forte et al., 2009). On the other hand, de Groot et al. (1999) concluded that there is no meaningful influence of external load on scapular orientation in different humeral abduction positions in healthy subjects. Such differences could be explained by the different ways scapular kinematics is analyzed: both studies have

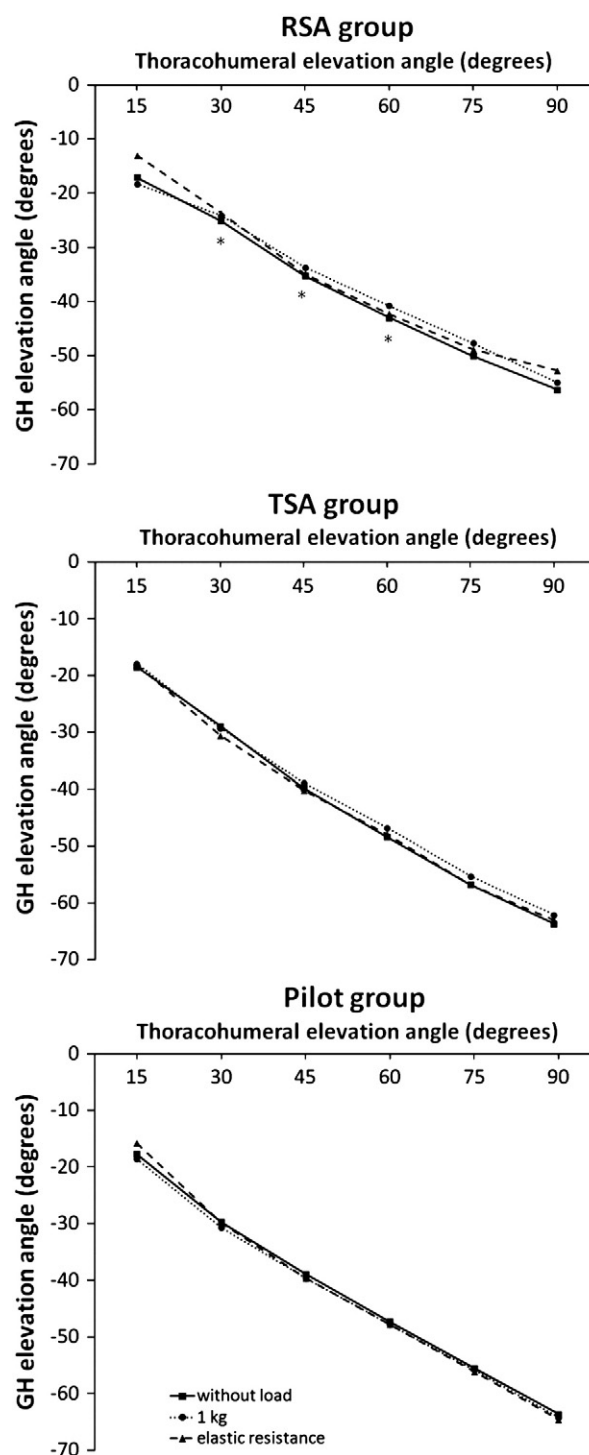


Fig. 5. Glenohumeral elevation angle (mean values) during elevation in the scapular plane for all groups and load situations. Load legends are equal for all groups. * Significant difference between without load situation and 1 kg dumbbell ($P < 0.05$). TSA: total shoulder arthroplasty. RSA: reverse shoulder arthroplasty.

used the quasi-static method and the present study used dynamic tracking of the scapula.

The contribution of the GH and scapular motion is not well documented in patients with a shoulder arthroplasty. Furthermore, the influence of external loads on GH and scapular kinematics of these patients has also not been well discussed in the literature. The present study showed similarities between 1 kg dumbbell and elastic band resistance with regard to scapular kinematics during ante flexion and elevation in the scapular plane. Although not specifically investigated in this study,

some differences may still exist. Whereas the 1 kg situation provides constant downward force and inertia, elastic resistance increases linearly with elongation of the material without any inertia effects (Patterson et al., 2001). Nevertheless, joint torque curves of elastic band resistance training mimic joint torque curves of training with free weights, depending on the angle of pull (e.g., torque is increased similarly during shoulder abduction from 0° to 90° due to elongation of the material and increased lever arm length, respectively) (Andersen et al., 2010). The results of the present study confirmed this torque behavior, showing that both types of load situations increase their net moment up to 90° of shoulder elevation. Furthermore, a higher torque was found in the pilot group, which can probably be explained by the differences in arm lengths of the subjects. As the RoM of this study was only up to 90°, this range may have had some influence on our results since the results would probably be different in higher movements where the torque of free weights would decrease after 90° of elevation and the torque of elastic band resistance would further increase.

It was clear that the literature has demonstrated different results for shoulder elevation tasks, sometimes showing this elevation as a complete thoracohumeral motion and at other times as GH and ST motions. For this reason, our objective in this discussion was only to compare our data with arm movements measured and analyzed in a similar setup. No study has been found with patients with shoulder arthroplasties and exercises using external loads.

This study presents some limitations. The patients and pilot subjects were of different ages, which results in variations in muscle strength, proprioception and even the presence of osteoarthritis might have influenced the results. Ideally, it would be better to have a pilot group with a mean age close to that of the patients. However, it is difficult to select people without a history of shoulder complaints above 70 years of age. Moreover, it is also unclear how aging affects shoulder kinematics. One study that has investigated the relationship between aging and scapulohumeral motion showed that one of the effects of aging on the shoulder is a decrease of posterior tilt and upward rotation angle at 90° of abduction (Endo et al., 2004). However, seeing as these authors have not found similar data to compare their results, the effects of aging on shoulder kinematics are not well-marked. Furthermore, the same load used for all groups certainly represented different challenges for each individual subject, but it facilitates the comparison with the literature that usually use the same load applied in different subjects. Additionally, the task range restricted to 90° of elevation made the comparison of our results with literature difficult. On the other hand, this range facilitated the dynamic scapula tracking during the data collection and was a range that was feasible for our patient group, whereas higher elevation angles would likely be too challenging (Bergmann et al., 2008). Furthermore, the methodology used to register shoulder kinematics also has limitations but it is considered suitable and precise for dynamic recordings of scapular rotations only when the acromion sensor is not replaced and in lower elevation angles (Meskers et al., 2007). Moreover, the results of this study indicated significant but small differences for glenohumeral elevation angles between groups and conditions. The clinical value of these differences is as yet unknown and difficult to interpret. On a more general level, our results should probably be read as general indications that load does influence motion pattern in patients with shoulder arthroplasty, irrespective of the type of prosthesis, but that type of loading is of lesser importance. Also, the differences in kinematic alterations due to conditions between the pilot group and our patients are likely more indicative of a different scapular role. Finally, it should be noted that the data presented represent average values across all subjects of each group. Substantial variability was noted among individual subjects, and not all subjects demonstrated these average patterns. For this reason, it might be possible to find different kinematic patterns in specific patients during the clinical practice compared to our average results.

5. Conclusion

The present study suggests that for a same shoulder RoM, patients with a shoulder arthroplasty will have a higher scapular motion compensating for a loss of glenohumeral motion (prosthesis) even at low angles (i.e. 90° of elevation). Furthermore, scapular kinematics of patients with shoulder arthroplasty is also influenced by the implementation of external loads, but not by the type of load (1 kg dumbbell or elastic band resistance). For this reason, in both types of load subjects would be expected to present a higher scapular contribution during arm movements in a shoulder rehabilitation program.

Conflict of interest statement

The authors confirm that there are no financial and personal relationships with other people or organizations that could inappropriately influence (bias) the present work.

Acknowledgments

This project was supported by grants from CAPES—*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* and Tornier SA France.

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