Kinematics and EMG activity in Reverse Total Shoulder Arthroplasty

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ABSTRACT

Introduction: Patients undergoing a Reverse Total Shoulder Arthroplasty (RTSA) often have functional limitations that affect the range of motion of the shoulder. These limitations are not mechanical in nature, but instead linked to a reduced ability to generate muscle force. The specific aims of this study was to offer a comparison between the muscle activity generated by a post-operative RTSA shoulder in a patient to that of their contralateral shoulder during a series of functional activities.

Material & methods: A convenience sample of 10 subjects between the ages of 50–75 years of age were recruited. EMG and kinematic data were concomitantly collected while subjects completed tasks that included common activities of daily living.

Results: The main findings of this study were that all sub regions of the deltoid functioned as abductors, versus the native shoulder where the middle deltoid primarily works in abduction. For the scapular elevation activity there was a significant difference in flexion between the surgical and contralateral shoulder ($p < .001$), with the surgical shoulder having nearly 30° less range of motion.

Conclusion: Anticipating limitations in functional outcomes and range of motion for patients after RTSA may inform patient decision-making and improve clinical evaluations. The finding of increased mid deltoid function during lifting activity has implications for rehabilitation and encouraging protocols that strengthen the deltoid in concentric motions. Additionally, the decreased scapular elevation found in this study may guide rehabilitation focusing on regaining range of motion post-operatively.

1. Introduction

Patients undergoing a Reverse Total Shoulder Arthroplasty (RTSA) anticipate the ability to more comfortably perform their activities of daily living (ADL). Yet after RTSA, there are functional limitations that affect the range of motion of the shoulder. These limitations are not mechanical in nature, but instead linked to a reduced ability to generate muscle force. The deltoid muscle is indicated as the key to functional outcomes.^{1–5} In the anatomy of the native shoulder, the anterior deltoid is mainly a flexor, the middle deltoid an abductor, and the posterior deltoid an extensor. In the RTSA shoulder all 3 deltoid sub regions demonstrate primarily abductor function.³ Compared with the native anatomy, the abduction moment arm of the deltoid in a RTSA shoulder fluctuates to a much greater extent and shows significant increases in the abductor moment arm of the anterior and middle deltoid sub regions in the coronal plane.^{6–8} At 90° abduction in a native shoulder, the

weight of the arm generates its largest adducting moment. In this position, the deltoid muscle force in the native shoulder is approximately 50% of the body weight, compared to 36.8% in the RTSA shoulder. This indicates that the RTSA shoulder reduces the deltoid muscle force required to produce sufficient torque to abduct and flex the shoulder, which occurs at the cost of changes to the deltoid's axial rotation moment and changes in the center of rotation of the joint.^{3,9}

Prosthetic designs and surgical installation consider the change in forces placed on the musculature of the arm and the center of rotation that varies throughout the arc of motion, as these factors can impact post-operative complications, shoulder stability, and functional outcomes for patients.^{3,7,10,11} An evaluation of the forces generated in the muscles of a patient's post-operative RTSA during a series of functional activities may advance clinicians' understanding of post-operative functional limitations. The purpose of this work was to compare the upper extremity kinematics and EMG activity in a patient's post-

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operative RTSA to that of their contralateral shoulder during a series of functional activities to understand patient outcomes and to improve the clinically relevant evaluation of patients who undergo RTSA.

2. Material and methods

2.1. Human subjects

A convenience sample of 10 subjects between the ages of 50–75 years of age were recruited for participation in this study. All subjects were within the same post-operative time frame of 6–24 months post-surgery and had had their RTSA procedure performed by the same board certified orthopaedic surgeon using an Arthrex Reverse and Universe Revers (Arthrex Inc, Naples, FL) 155- or 135-degree stem inclination implant. Of the ten subjects, 6 were female. Eight subjects had a unilateral (five on the left and three on the right) and 1 a bilateral RTSA. Two subjects had an RTSA using a 155-degree stem, and 8 subjects using a 135-degree stem inclination angle. The 155-degree stem was indicated in these 2 subjects based on clinical evaluation by the surgeon because the subjects were walkers and frail, and the surgical shoulder was their dominant arm; neither required glenoid augmentation. This study considered all stem types. Subjects were excluded from the study if they were unable to complete the study protocol, biomechanical analysis, or if they were allergic to adhesive tape.

2.2. Procedures

Upon obtaining informed consent, all subjects completed a questionnaire ascertaining their sex, implant type and angle, brief medical history and the presence of any neuromuscular pathology that would make them ineligible for participation in this study. The subjects' height and weight were then recorded. The skin overlying the anterior, middle and posterior subdivisions of the shoulder were then prepped by removing any hair that was present and vigorously scrubbing the skin overlying these areas with an alcohol impregnated gauze pad. A pair of Ag–Ag Cl surface electrodes were attached over the mid points of the above muscles. The locations of the electrodes were confirmed by applying an electrical current using a handheld neurostimulator and observing for the occurrence of an isolated muscle twitch. Once the placement of the electrodes was confirmed, the electrodes were connected to preamplifiers, which were connected to a data transmission box (Motion Lab Systems, Baton Rouge, LA). The electrodes were then connected to differential pre-amplifiers. The locations of the electrodes were again confirmed by having the subject perform a series of sub maximal isometric muscle actions consisting of shoulder abduction, flexion and extension and adduction. Once the locations of the electrodes were confirmed, the electrodes and electrode leads were secured to the subjects' upper arm using foam pre-wrap.

At this time a series of three maximal voluntary contraction (MVC) isometric trials were performed by the subject while concomitantly collecting EMG data from the surface electrodes. The trials consisted of isometric shoulder horizontal adduction and abduction, respectively with the shoulder in 90° of frontal plane elevation and neutral horizontal abduction and rotation.

Subjects were then instructed on performance of the testing protocol and afforded an opportunity to practice the protocol. Retro reflective markers were placed over specific bony landmarks located on the subjects' upper extremities and trunk bilaterally using double-sided adhesive tape. The subjects then commenced and completed the testing protocol while EMG and kinematic data were concomitantly collected at 2400 and 120 Hz, respectively using a 10-camera motion analysis system (Motion Analysis Corp, Santa Rosa, CA).

2.3. Testing protocol

Subjects were asked to move the shoulder through a series of active

range of motion (AROM) activities. The first motion was anterior flexion to 180°, or the patient's maximum available range. The second motion was abduction in the scapular plane to 180° or patient's maximum available range. The third motion was horizontal abduction to 180° or patient's maximum available range. The fourth motion was abduction with a 90° flexion at the elbow to 180° or patient's maximum available range, and the fifth and final motion was external rotation, with the elbow at their side.

The next sequence of motions consisted of a series of functional activities. The motions evaluated included lifting a 2.27 kg weight from a shelf located at height of the subjects' waist to a shelf located at the subjects' eye level returning the weight to the lower shelf, running a comb through the top of their hair, using a fork to simulate the motion of taking food off of a plate and bringing the utensil to their mouth.

2.4. Data analysis

A commercially available software package (Cotex 6.X, Motion Analysis Corp, Santa Rosa, CA) was used to obtain and filter the coordinate histories of the markers using a 4th order, zero lag, Butterworth filter with a 6 Hz cutoff frequency. The upper extremities and trunk were modeled as a 5-segment rigid body system. Using this model, the filtered coordinate data and a commercially available software package (KinTools, Motion Analysis Corp, Santa Rosa, CA) the angular displacements of the shoulder were obtained. The maximum, minimum, and range of three-dimensional motion of the shoulder were then obtained for each motion trial.

Using a custom-made software package (MatLab, The Mathworks, Natick, MA) the EMG data was filtered using a band pass 4th order, zero lag Butterworth filter with an upper and lower cutoff frequency of 6 and 350 Hz. The root mean square (RMS) of the filtered EMG data was then obtained using a 250 ms window. The peak RMS value of each MVC trial was determined and used to amplitude normalize the RMS data (NEMG) of the motion trials by the dividing the RMS of the motion trials data by the peak RMS value of the respective MVC trials and multiplying by 100. Using the coordinate data, the onset and relative timing of the anterior, middle, and posterior deltoid during the different motions and the mean amplitude of the NEMG of each muscle were obtained for the motion trials.

Descriptive statistics were used to describe the kinematics range of motion, and EMG output. For the kinematics range of motion outcomes a multivariate linear mixed model with a two level within subjects factor (shoulder: RTSA shoulder and contralateral shoulder) and a two level between subjects factor (group: 135°, 155°) was used to test for differences between shoulders and groups on maximum flexion, rotation, and horizontal abduction by activity performed (elevation of scapula, lifting, and eating). For the EMG a multivariate linear mixed model was used to compare groups on concentric and eccentric deltoid muscle output by activity performed. For the mixed models fixed effects included shoulder and group, and an unstructured covariance matrix was used for the random effects to model the correlation among outcomes measures. Statistical analyses were conducted in SPSS v24 and the alpha level for statistical significance was set at 0.05.

3. Results

There were 10 subjects of whom 4 (40%) were male. Seven (70%) had RTSA on the left shoulder, 2 (20%), on the right shoulder and 1 (10%) had bilateral surgery. Eight (80%) had the 135-degree stem, 1 (10%) had the 155-degree stem, and the one bilateral subject had the 135-degree stem on the left and 155-degree on the right.

Table 1 shows the means and standard deviations of the kinematic range of motion angles by movement, activity, and shoulder. The operative shoulder displayed 27° less flexion during scapular elevation as compared to the native, contralateral shoulder ($p < .001$). There was

Table 1Mean ($\pm$ SD) of maximum range of motion angle by shoulder.

Activity	Flexion	Rotation	Hor. Abduction
Elevation Scapular			
Surgical	106.3 $\pm$ 23.7	-1.7 $\pm$ 24.6	84.0 $\pm$ 5.3
Contralateral	133.3 $\pm$ 6.9	8.2 $\pm$ 17.3	81.6 $\pm$ 9.1
Lifting			
Surgical	86.8 $\pm$ 20.3	10.2 $\pm$ 14.1	89.1 $\pm$ 5.5
Contralateral	94.0 $\pm$ 11.6	17.7 $\pm$ 21.8	86.3 $\pm$ 7.2

Table 2Mean ($\pm$ SD) of maximum range of motion angle by stem group.

Activity	Flexion	Rotation	Hor. Abduction
Elevation Scapular			
135	104.2 $\pm$ 27.8	-5.8 $\pm$ 28.8	86.6 $\pm$ 2.4
155	111.3 $\pm$ 13.5	8.5 $\pm$ 3.8	77.6 $\pm$ 5.5
Lifting			
135	79.1 $\pm$ 21.0	3.8 $\pm$ 11.3	90.8 $\pm$ 3.1
155	102.2 $\pm$ 3.8	23.2 $\pm$ 10.2	85.8 $\pm$ 9.6
Eating			
135	50.1 $\pm$ 15.4	-18.3 $\pm$ 30.5	82.9 $\pm$ 6.1
155	71.3 $\pm$ 3.8	13.9 $\pm$ 2.5	81.5 $\pm$ 11.4

no difference between shoulders on rotation or maximum horizontal abduction. For lifting there were no significant difference between shoulders on flexion, rotation, or horizontal abduction.

Table 2 shows the mean kinematic range of motion of the operated shoulders by stem group. There were no significant differences between groups on any of the three scapular movements, lifting movements, or eating movements.

Table 3 shows the mean concentric and eccentric EMG output by muscle, activity and stem group. Fig. 1 shows the mean and standard error of the concentric movements. There were no significant differences between stem groups on any of the three concentric deltoid movements during the scapular activity, lifting activity, or eating activity. Fig. 2 displays the mean eccentric EMG by muscle, activity and stem group. There were no significant differences between stem group on any of the eccentric deltoid movements during the three activities. However, the 135-degree stem produced a higher EMG output (20.9) compared to the 155-degree stem (11.2) in the middle deltoid during eccentric lifting, which is near significant ($p = .077$).

4. Discussion

As mentioned, the functional limitations affecting the range of motion after RTSA are primarily due to a lack of generated muscle force

and not mechanical limitations.^{2,3} In contrast to the anatomy of the native shoulder, in which the anterior deltoid region is mainly a flexor, the middle deltoid sub region an abductor, and the posterior deltoid subregion an extensor, all 3 deltoid sub regions demonstrate primarily abductor function after RTSA.³ The main findings of this study were that all sub regions of the deltoid in the RTSA shoulders functioned as abductors, whereas in the native shoulders the middle deltoid primarily works in abduction. Between the RTSA and contralateral shoulders, there were no significant differences on rotation, maximal horizontal abduction, and flexion during the scapular elevation and lifting activities. Of particular note, the surgical shoulder performed 27° less when elevating the scapula than the contralateral shoulder during maximum range of motion testing ($p < .001$). This diminished range of motion highlights a significant reduction in the functional outcome for the surgical shoulder. Among the RTSA shoulders, there were no differences during scapular movements, lifting or eating between those with a 155-degree stem and those with a 135-degree stem.

Elevation and abduction above 90° creates the largest adducting moment in the arm.⁷ Compared with the native anatomy, the deltoid's abduction moment arm in an RTSA shoulder has greater fluctuation.⁷ RTSA has been shown to result in significant increases in the abductor moment arms of the anterior and middle deltoid sub regions, occurring in the coronal plane.^{6,8} In this study, there was no difference between the 155- or the 135-degree stem groups on any of the functional motions, but there was a difference in the mid deltoid EMG activity between the 135- and 155-degree stem during the eccentric lifting activity. The 135-degree stem generated more muscle activity than the 155-degree stem. This touches on the idea that there are differences in the functional outcomes of RTSA shoulders and alterations in the level of muscle activation. While this difference may be linked to pre-operative factors or variations in post-operative recovery, the theme remains unchanged that muscle activation is altered after RTSA, which impacts functionality of the joint specifically in patients' ADLs.

5. Conclusion

Given that functional outcomes influence patient centered results and that limitations in range of motion after RTSA have been cited to be largely due to lack of generated muscle force, anticipating these factors may guide post-operative care. Providing accurate anticipatory guidance in the pre-operative planning stages and during rehabilitation will help patients to make informed decisions about their treatment options and to set realistic recovery goals. This work offers a comparison between the muscle activity generated by a post-operative RTSA shoulder in a patient to that of their contralateral shoulder during a series of functional activities. The finding of increased mid deltoid function during lifting activity has implications for rehabilitation and encouraging protocols that strengthen the deltoid in concentric motions. Additionally, the decreased scapular elevation found in this study

Table 3Mean ($\pm$ SD) of EMG reading by muscle and stem.

Activity	Concentric			Eccentric		
	Ant Delt	Mid Delt	Post Delt	Ant Delt	Mid Delt	Post Delt
Scapular						
135	99.6 $\pm$ 43.4	68.4 $\pm$ 62.1	24.4 $\pm$ 16.6	48.1 $\pm$ 14.2	36.3 $\pm$ 37.8	14.9 $\pm$ 11.5
155	67.1 $\pm$ 53.5	30.6 $\pm$ 0.5	33.0 $\pm$ 31.8	34.3 $\pm$ 30.5	13.8 $\pm$ 3.4	11.0 $\pm$ 8.1
Lifting						
135	39.8 $\pm$ 9.5	22.9 $\pm$ 13.0	59.1 $\pm$ 76.7	39.4 $\pm$ 11.9	20.9 $\pm$ 5.4	40.3 $\pm$ 50.2
155	42.4 $\pm$ 33.2	14.6 $\pm$ 1.0	12.5 $\pm$ 8.0	30.6 $\pm$ 20.0	11.2 $\pm$ 1.1	11.4 $\pm$ 8.4
Eating						
135	35.0 $\pm$ 12.3	16.2 $\pm$ 14.9	5.8 $\pm$ 4.5	31.8 $\pm$ 8.1	17.0 $\pm$ 15.1	5.5 $\pm$ 4.9
155	31.0 $\pm$ 18.9	8.8 $\pm$ 1.0	7.1 $\pm$ 3.8	24.9 $\pm$ 19.5	6.6 $\pm$ 1.1	5.3 $\pm$ 1.6

Fig. 1. Mean ($\pm$ SEM) of EMG Concentric Output by Muscle Stem. The mean EMG data for a series of activities of daily living for concentric deltoid activation are reflected for the 135-degree stem group and the 155-degree stem group.

Fig. 2. Mean ($\pm$ SEM) of EMG Eccentric Output by Muscle Stem. The mean EMG data for a series of activities of daily living for eccentric deltoid activation are reflected for the 135-degree stem group and the 155-degree stem group.

may guide rehabilitation focusing on regaining range of motion post-operatively.

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Declaration of competing interest

The authors declare that they have no competing interests or personal relationships that would influence the work reported in this manuscript.

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