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Electromyographic analysis of reverse total shoulder arthroplasties

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Background: Understanding how reverse total shoulder arthroplasty (RTSA) affects muscle activation may help refine it. This study evaluated deltoid and upper trapezius activity during shoulder abduction, flexion, and external rotation in RTSA recipients.

Methods: Fifty individuals were recruited for this study: 33 were ≥6 months postunilateral RSTA, and 17 comprised our control group. Control individuals easily performed all functional tasks and had no history of shoulder pathology or pain. RTSA participants were divided into 3 groups according to implant design. Participants performed weighted and unweighted abduction in the coronal plane, forward flexion in the sagittal plane, and unweighted external rotation. Electromyography activation of the anterior, lateral, and posterior aspects of the deltoid and the upper trapezius muscles was recorded bilaterally. Motion capture using passive reflective markers quantified 3-dimensional motions of both shoulders.

Results: During abduction and flexion, deltoid and upper trapezius activity was significantly increased in RTSA shoulders. Posterior deltoid activation was highest in shoulders with the medial glenosphere/lateral humerus implant. Medial glenosphere/medial humerus shoulders were most similar to the control group's anterior, lateral, and posterior deltoid muscle activation during weighted flexion.

Conclusions: RTSA increases muscle activation compared with normal shoulders. RTSA often restores stability and motion but not normal deltoid or upper trapezius activation. Increased muscle activation in shoulders with RTSA suggests less efficiency. RTSAs with lateral or medial glenosphere centers of rotation had mostly similar muscle activation. Average posterior deltoid activation did not exceed 20% of maximal voluntary isometric contraction for any group during unweighted external rotation, and differences between groups were <5% maximal voluntary isometric contraction.

Level of evidence: Basic Science, Electromyography.

Keywords: Reverse total shoulder arthroplasty; rehabilitation; implant design; surgical technique; muscle function; physical therapy

Reverse total shoulder arthroplasty (RTSA) is an effective treatment option for patients with symptomatic glenohumeral arthritis, and a deficient rotator cuff. RTSA has been reported to produce early satisfactory clinical outcomes in pain relief and restoration of active forward

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flexion and abduction.[16,17] However, associated deltoid tensioning and potential instability, scapular notching, and polyethylene wear may lead to significantly decreased functional outcomes and increased risk of RTSA failure.[2,3,20] Better knowledge of muscle activity after RTSA is critical to understanding how shoulders with RTSA function and how to address associated challenges to improve functional outcomes and longevity.

Most RTSA research has focused on improving the design and biomechanics of reverse prostheses.[2,5,10,14] Few studies have focused on the deltoid, which becomes the primary mover in the rotator cuff-deficient shoulder and RTSA.[21] We currently lack a fundamental understanding of how deltoid tension and activity relates to functional outcomes, such as range of motion (ROM), arm strength, and functional scores with RTSA. Insufficient deltoid tension may lead to prosthetic instability, whereas excessive deltoid tension may result in acromial fractures[10]; other factors may also play a role.[13] Deltoid tension is thought to directly affect the activation pattern and active force-generating ability of the muscle,[5,10,14] such that active ROM and shoulder function depend on the interplay between RTSA geometry and deltoid length and tension.

In a rotator cuff-deficient shoulder, muscle tension is required to dynamically stabilize the glenohumeral joint and to move the arm. RTSA provides conforming joint surfaces that may reduce the need for dynamic muscular stabilizers and allow for more efficient recruitment of shoulder muscles compared with the rotator cuff-deficient shoulder, but this has not been demonstrated in vivo. The purpose of this study was to determine shoulder muscle activation in patients with 3 RTSA implant designs. We studied deltoid and upper trapezius muscle activity in RTSA shoulders and normal shoulders in controls matched for age and sex during weighted and unweighted shoulder abduction and flexion and also unweighted external rotation. In this study, we compared muscle activation patterns of the deltoid and trapezius between shoulders with RTSA and shoulders in controls matched for age and sex.

Materials and methods

Fifty individuals (34 women and 16 men) aged between 60 and 85 years gave written informed consent to participate; of these, 33 (24 women, 9 men) with RTSA comprised the RTSA group. They were an average of 37 months after unilateral RTSA (range, 12-63 months) and were an average age of 73 years. Seventeen healthy individuals (11 women, 6 men; indicating no history of shoulder pathology or complaints), with an average age of 73 years, comprised the age- and sex-matched control group.

Patient evaluation

Patients undergo rigorous examination of their deltoid function both preoperatively and postoperatively. Any patients with a significant neurologic deficit were not included in the study and were not candidates for RTSA. None of the study patients had neurologic deficits postoperatively. No revisions were included in the study. Symptomatic rotator cuff arthropathy was the only indication for surgery. Each RTSA patient had at least 2 rotator cuff tendon tears that were deemed nonrepairable by the surgeon as well as secondary arthritis.

RTSA participants were divided into 3 groups according to implant design. Seven patients in group 1 received implants with a glenosphere center of rotation within 2 mm of the glenoid face and a medialized humeral design having a line of action within the humerus (Aequalis, Tornier, Edina, MN, USA; Fig. 1, *A*). Sixteen participants in group 2 received implants with a glenosphere center of rotation at least 6 mm lateral to the glenoid face and a medialized humeral design (Reverse Shoulder Replacement, DJO Surgical, Austin, TX, USA; Fig. 1, *B*). Ten participants in group 3 received implants with a medial center of rotation glenosphere and a lateralized humeral design (Equinoxe, Exactech, Gainesville, FL, USA; Fig. 1, *C*). Retroversion was implemented according to manufacturer recommendation: Exactech, 20°; Tornier, 20°; and Encore, −30°. Two surgeons performed the operations. Each variation of prosthetic shoulder geometry is intended to provide mechanical advantage to the deltoid. RTSA participants' average Constant-Murley Shoulder Score preoperatively was 18. The average RTSA patient-normalized Constant-Murley Shoulder Score at the time of the study was 73 (Table I).

Each participant's arm motions and muscle activities were recorded during weighted and unweighted abduction, weighted and unweighted flexion, and unweighted external rotation. Motions were performed so that 1 cycle required approximately 15 seconds. Weighted trials used a 1.5-kg hand-held weight. Participants rested for 2 minutes between activities to minimize the effects of fatigue. Each activity was repeated 2 times to test for repeatability. Repeatability in the activation curve was also seen between participants per activity.

A 12-camera motion capture system was used to record the motions of 15 skin-mounted retroreflective markers at 60 Hz (Fig. 2).[11,12] Skin surface electromyography (EMG) was collected simultaneously at 1200 Hz using bipolar electrodes placed bilaterally on the anterior, lateral, and posterior aspects of the deltoid and on the upper trapezius (Telemyo 2400, Noraxon USA Inc, Scottsdale, AZ, USA).[13] Maximal voluntary isometric contraction (MVIC) data were used to normalize the EMG signals.[14] A hand-held dynamometer was used to measure the maximum force generated at the wrist joint during MVIC trials.

Reflective marker kinematics were determined using EvaRT software (Motion Analysis Corporation, Santa Rosa, CA, USA) and filtered using a fourth-order, zero-phase-shift, low-pass Butterworth filter with a 12-Hz cutoff frequency. A custom program was used to compute shoulder abduction, flexion, and external rotation angles using an abduction-flexion-external rotation sequence.[1,4] EMG data were mean filtered,[13] and fitted spline curves were used to determine the EMG signal magnitude at specific arm angles.

Statistical methods

Comparisons between shoulders with RTSA and controls were performed using 2-way repeated-measures analysis of variance with the level of significance at 0.05. The Tukey honestly significant difference test was used to perform pair-wise post hoc comparisons.