Surgical Technique and Implant Design Influence Muscle Activation Patterns During Functional Hand-to-Head and Hand-to-Back Motions After Reverse Shoulder Arthroplasty: An Electromyographic Analysis

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INTRODUCTION:
Reverse shoulder arthroplasty (RSA) is used to treat rotator cuff arthropathy and proximal humerus fractures in older patients. In vitro studies suggest that modifications in prosthesis design and surgical technique can improve range of motion and functional outcome after RSA. However, functional outcomes after RSA remain unfavorable with only 36.4% of patients able to wash their back with the affected arm at long term follow-up. The purpose of this study was to evaluate the impact of surgical technique and prosthesis design on muscle activation patterns after RSA. We hypothesized that humeral retroversion, change in humeral retroversion from native (Δretroversion), lateral humeral offset (LHO), change in LHO from native (ΔLHO), neck-shaft angle, and glenosphere lateralization, size, eccentricity, and tilt would be associated with muscle activation patterns during hand-to-head (H2H) and hand-to-back (H2B) functional movements.
METHODS:
Twenty-eight patients (14 males, mean age 73.0 years) underwent RSA 2±1 years prior to testing with one of two modular RSA designs (135° or 145° stems). EMG data from 8 muscles (trapezius major, anterior deltoid, middle deltoid, posterior deltoid, teres minor, pectoralis major, latissimus dorsi, and infraspinatus) were collected as patients performed 3 trials each of H2H and H2B. EMG values were normalized using Maximum Voluntary Isometric Contractions. Muscle activation on-times (OT) were determined manually using custom MatLab software. Total muscle activation (TMA) was calculated as the sum of the normalized EMG signal. Implant characteristics were extracted from operative reports or measured on CT. Linear regression assessed the relationship between implant characteristics and muscle TMA/OT, as well as between patient reported outcomes (Constant Murley Score (CMS), Disabilities of the Arm (DASH), American Shoulder and Elbow Surgeons (ASES)), clinical internal rotation (IR) scores, and muscle TMA/OT.
RESULTS:
The muscle OT in H2H and H2B indicate that H2H is initiated by the anterior deltoid and H2B is initiated by the trapezius. Qualitatively, H2H was dependent on the anterior deltoid, while H2B was posterior deltoid dependent (Figure 1).

In H2H, greater glenosphere size, glenosphere eccentricity, glenosphere tilt, LHO, ΔLHO, and glenosphere lateralization were associated with muscle activation patterns of the teres minor, anterior deltoid, middle deltoid, pectoralis major, latissimus, and infraspinatus (Table 1, Figures 2A and 2B). Lower TMA of the infraspinatus and anterior deltoid were associated with better CMS ($p=0.007$ and $p=0.042$, respectively). Later pectoralis major OT was associated with worse DASH scores ($p=0.039$).

In H2B, glenosphere lateralization, glenosphere eccentricity, neck shaft angle, Δretroversion, LHO, ΔLHO, and glenosphere tilt were associated with muscle activation patterns of the trapezius, posterior deltoid, pectorals major, infraspinatus, and teres minor (Table 1, Figures 2C and 2D). Later teres minor OT was associated with higher CMS ($p=0.025$). No associations between muscle activation and IR scores were identified in either movement.
DISCUSSION AND CONCLUSION: Specific implant characteristics and surgical technique influence muscle activation patterns after RSA. Improved understanding of these relationships may help surgeons optimize shoulder function in the primary setting, address specific functional deficits in the revision setting, as well as help guide pre- and post-operative rehabilitation.

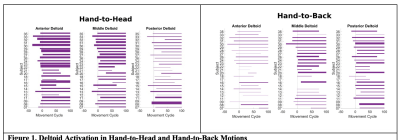

Figure 1. Deltoid Activation in Hand-to-Head and Hand-to-Back Motions
Muscle activation for each participant is displayed in relation to the percentage of the movement cycle. The height of each bar represents the integrated EMG, while the length of each bar represents the muscle on/off time.

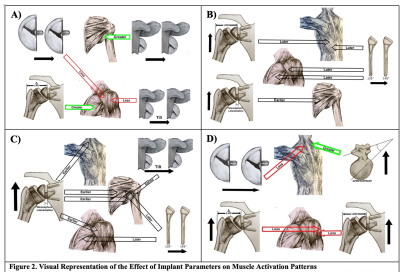

Figure 2. Visual Representation of the Effect of Implant Parameters on Muscle Activation Patterns
A) **H2H TMA:** Greater glenosphere size was associated with greater teres minor TMA, while eccentricity resulted in less anterior deltoid TMA. Greater ΔLHO was associated with more pectoralis major TMA. Greater glenosphere tilt was associated with less middle deltoid TMA.
B) **H2H OT:** Greater neck shaft angle was associated with later OT of the latissimus, anterior deltoid, and pectoralis major. Greater LHO was associated with later OT of the latissimus. Greater glenosphere lateralization was associated with earlier OT of the infraspinatus.
C) **H2B OT:** Greater glenosphere lateralization was associated with earlier OT of the trapezius, anterior deltoid, and infraspinatus. Greater neck shaft angle was associated with later OT of the infraspinatus and pectoralis major.
D) **H2B TMA:** Eccentricity was associated with less trapezius TMA, greater ΔretroversIon was associated with more trapezius TMA, and greater LHO and greater ΔLHO both were associated with less posterior deltoid TMA.

Table 1. Association Between Component Characteristics and Muscle Activation Patterns

Hand-to-Head (H2H)			
Parameter	**Muscle Activation**	**Beta**	**P**
Glenosphere Size	Teres Minor TMA	4.190	0.027
Eccentricity	Anterior Deltoid TMA	-11.613	0.017
Tilt	Middle Deltoid TMA	-0.426	0.037
ΔLHO	Pectoralis Major TMA	0.647	0.036
LHO	Latissimus OT	2.305[δ]	<0.001
Neck Shaft Angle	Latissimus OT	25.746[δ]	0.016
	Anterior Deltoid OT	12.050	0.040
	Pectoralis Major OT	14.645	0.047
Glenosphere Lateralization	Infraspinatus OT	-1.700	0.036
Hand-to-Back (H2B)			
Parameter	**Muscle Activation**	**Beta**	**P**
Eccentricity	Trapezius TMA	-3.015[*]	0.043
ΔRetroversion	Trapezius TMA	0.172[*]	0.026
LHO	Posterior Deltoid TMA	-0.385[ץ]	0.042
ΔLHO	Posterior Deltoid TMA	-0.426[ץ]	0.043
Neck Shaft Angle	Pectoralis Major OT	45.122	0.027
	Infraspinatus OT	28.573	0.031
Tilt	Teres Minor OT	-1.490[ץ]	0.045
Glenosphere Lateralization	Teres Minor OT	-5.325[ץ]	0.016
	Trapezius OT	-1.832	0.028
	Anterior Deltoid OT	-4.610	0.020
	Infraspinatus OT	-4.044	0.018

[*]Multivariate Model 1, [δ]Multivariate Model 2, [ץ]Multivariate Model 3, [ז]Multivariate Model 4