INTRODUCTION
Computational [1,2] and experimental studies [3] have found increased deltoid abduction moment arm with reverse shoulder arthroplasty when compared to anatomic shoulders [1,3] and natural prostheses [2]. Similarly, rotator cuff abduction moment arms are decreased when the humeral implant is positioned superiorly [4]. Despite marked variability in glenoid [5] and humeral head inclinations [6], their effects on muscle moment arms have not been previously measured. The objective of this study was to measure glenohumeral scapular plane abduction moment arms of rotator cuff and deltoid for normal shoulders and with altered glenoid and humeral head inclinations.

METHODS
 Embalmed cadaver shoulders (N=10) were abducted in the scapular plane while data were collected with a Qualisys Oqus 6 camera motion analysis system from markers attached to the specimen and weights attached to cords sutured to muscle-tendons (Figure 1). Sample size was determined with moment arm variance (S.D.=5 mm) from [7] and a desire to detect a mean difference in moment arms of 3.3 mm (α=0.05, β=0.20). Specimens were tested initially with an anatomic glenoid and humeral head, and then a glenoid or humeral head osteotomy was performed and specimens were retested. Osteotomy order was randomly determined. The glenoid was osteotomized 5mm medially from the articular surface and a 10° plastic wedge was inserted to incline the glenoid inferiorly. A similar osteotomy and wedge altered humeral head inclination both superiorly and inferiorly. The 10° wedge approximates three standard deviations of inclination variability for glenoid [5] (S.D.=3.2-4.4°) and humeral head, e.g. [6] (S.D.=2.9-3.6°).

RESULTS
Inclining the glenoid 10° inferiorly tended to cause an increase in supraspinatus moment arm (5.3 and 1.6 mm, 22% and 6%) at 0 and 10° of abduction. Similarly, for middle deltoid during the initial 40° of abduction, there was a tendency for the moment arm to be increased up to 6.7 mm (or 34%). However, these differences were not statistically significant. Downward glenoid inclination caused
significant (but small) changes in infraspinatus and subscapularis moment arms (both p < 0.02) that varied with abduction angle (Figure 2).

Middle deltoid moment arm increased on average 13.9 mm and 10.5 mm over the initial 10° abduction for increased and decreased humeral head inclination, respectively (both p < 0.05) (Figure 3). For supraspinatus, there was a trend toward an increased moment arm for the initial phase of abduction, but the change was not significant. Altering humeral head inclination resulted in significant changes in moment arms for infraspinatus (p < 0.02) and subscapularis (p<0.01); these changes varied with abduction angle and were generally smaller than middle deltoid or supraspinatus.

DISCUSSION

Computational studies of single specimens have found increases in moment arms of middle deltoid [8] and supraspinatus [9] with an inferiorly oriented glenoid. This study, which decreased glenoid inclination by approximately 3 S.D. of measured variability, found similar trends, but the results were non-significant. Moment arms for these muscles are likely most influenced by medial-lateral position of the muscle-tendon insertion relative to joint center of rotation [3], and superior-inferior humeral head location [4], respectively. Increases were found for middle deltoid moment arms when humeral head inclination was altered inferiorly and superiorly, suggesting that both procedures medialized center of rotation in a manner similar to reverse shoulder arthroplasty [3]. Taken together, these results indicate that supraspinatus moment arm is more likely influenced by inferior-superior insertion on the greater tubercle, the position of the humeral head relative to the insertion [4], and head diameter as the tendon wraps around the head, rather than inclination of articular surfaces. These results have implications for understanding variations in inclination angle and component placement in healthy subjects and arthroplasty patients, respectively.

REFERENCES


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