THE EFFECT OF VARIABLE MUSCLE LOADING RATIOS ON THE KINEMATICS OF GLENOHUMERAL ABDUCTION

Kedgley, A E; *Mackenzie, G A; *Ferreira, L M; *Drosdowech, D S; *King, G J W; *Faber, K J; +Johnson, J A
jajohnso@uwo.ca

INTRODUCTION: *In-vitro* biomechanical testing of the shoulder, with special interest in joint motion, is becoming increasingly prevalent. Due to the highly unconstrained nature of the glenohumeral joint, muscle loading has an important effect on joint kinematics. It has been shown that muscle loading influences the translations of the humeral head during abduction, however the influence of muscle loading on the motion pathways of the glenohumeral joint has not been reported. Electromyographic (EMG) studies have shown that muscle activation varies between muscles during abduction. Hence, we postulated that variable loading ratios should be assessed *in-vitro* to establish their influence on motion pathways. This study assessed the effects of four different loading ratios on active glenohumeral joint kinematics, with special interest in glenohumeral joint abduction.

METHODS: Five fresh-frozen cadaveric shoulders (mean age: 60.4 ± 12.0 years) were tested using a custom loading apparatus designed to simulate unconstrained motion. The scapula was constrained, allowing unrestricted motion of the humerus. Cables were sutured to the tendons of the supraspinatus, subscapularis and infraspinatus/teres minor. Three cables were attached to the deltoid tuberosity to replicate the anterior, middle and posterior thirds of the deltoid. Abduction was defined as elevation in the plane of the scapula. Computer-controlled pneumatic actuators were used to apply independent loads to each of the cables, using motion control on the prime mover (middle deltoid) and apportioned tone loads to the other muscles simulated.

The first simulation consisted of passive control of abduction by an investigator. Loads were then applied to simulate the muscles in four sets of ratios based on: (1) Equal loads to all cables (Constant-Constant); (2) Average physiological cross-sectional areas (pCSAs) of the muscles (Constant pCSA); (3) Constant values of the product of EMG data and pCSAs (Constant EMG); and (4) Variable ratios of the EMG data and the pCSA data which changed as a function of abduction angle (Variable EMG). An electromagnetic tracking device (Flock of Birds, Ascension Technologies, Burlington, VT) quantified motion. Kinematic data was transformed into coordinate systems, created on both the humerus and scapula from digitized anatomical landmarks. Repeatability was quantified from the maximum standard deviation of the plane of elevation during shoulder abduction based on five successive tests on the passive and active trials. The plane of elevation was quantified at 30, 50 & 70 degrees of abduction.

RESULTS: Figure 1 illustrates the repeatability of each loading ratio, quantified as the variation in the plane of the abduction angle (the standard deviation of the 5 trials) at 30, 50 & 70 degrees of abduction. There was greater repeatability in the active motions versus passive motions, significant for abduction angles less than 40 degrees (p<0.05). There was no significant difference in the repeatability of the active motions.

DISCUSSION & CONCLUSIONS: The use of constant muscle ratios throughout the motion of interest is the most common approach to model muscle activation *in-vitro*. It is unlikely, however, that these ratios remain constant throughout joint motions *in-vivo*. As shown in the current study, different loading scenarios generated distinctly different motion pathways. For the four simulated loading trials, the repeatability, as quantified by the standard deviation of 5 successive trials, was generally less than 2 degrees. This would suggest that active loading, as prescribed in these investigations, should be adequate for biomechanical investigations of this nature. Active loading produced more repeatable motion than passive motion, suggesting that this approach should be employed for *in-vitro* simulations of shoulder motion. While different loading ratios generated slightly different patterns of active motion, these pathways were highly repeatable, suggesting that any of these methods could be employed in laboratory based shoulder studies.

In summary, this is the first study to examine the relative influence of a number of different loading simulations on the kinematics of the glenohumeral joint. While an optimal testing approach for motion simulations is not yet defined, it is clear that forthcoming studies need to be cognizant of these findings.


Figure 1: Repeatability of each method of loading at 30, 50 and 70 degrees of abduction.

Figure 2 shows the motion pathways for one specimen, illustrating five trials for passive motion and the four different active loading ratios. The resultant plane of abduction for each test condition was variable between specimens, however the difference between the planes of abduction was significant for abduction angles less than 30 degrees (p<0.05). There was a trend for the EMG based loading ratios to produce a more posterior plane of abduction and the Constant-Constant and pCSA loading ratios to produce a more anterior plane of abduction.

Figure 2: Motion pathways of the distal humerus for passive and four methods of active motion are shown for one specimen.