The Effect of Muscle Loading on Elbow Joint Forces

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Introduction: An understanding of joint loading has important implications with regards to biomechanical modeling, developing rehabilitation protocols and implant design. Load transfer across the elbow has been previously explored using isolated bone-ligament specimens with the conclusion that 60% of force is exerted through the radiocapitellar joint and 40% through the ulnohumeral joint [1]. Also, computational models have shown that during certain activities forces can reach up to 3kN in both joints [2]. The objective of this study was to measure axial loads across the elbow joint in a cadaver-based study, through the radiocapitellar and ulnolhumeral articulations, during simulated muscle activation.

Methods: Nine upper extremity specimens were prepared and mounted onto an elbow motion simulator. The tendons of the biceps (BIC), brachialis (BRA), brachioradialis (BRD) and triceps (TRI) were attached to pneumatic actuators allowing for simulation of muscle loading. Axial load cells were implanted into the proximal radius and ulna. The specimen was oriented at both 0º and 90º flexion while the forearm was positioned in supination, neutral and pronation. Loads from 0 to 80N were applied individually to each muscle tendon in increments of 10N every 5 seconds. A three-way repeated measures ANOVA was conducted on both the radiocapitellar and ulnolhumeral joints, where the joint, flexion angle and forearm rotation were defined as independent variables.

Results: Across all three forearm positions and flexion angles similar linearity trends were observed, in which increasing muscle loads produced increasing axial joint loads (Figure 1A). Specifically at 50N loads in supination, the greatest compressive joint load at the ulnolhumeral joint was 49.0±8.1N, observed during TRI activation at 0º flexion, while the radiocapitellar joint produced the largest load of 19.7±22.3N at 90º flexion during BIC loading (Figure 1B). When examining muscle groups and comparing flexion angle and joints it was found that loading of the BIC resulted in no significant differences between the three factors (p<0.05), while BRD showed similar results, except interaction occurred between joint and flexion angle (p=0.0001) for BIC. Loading of the BRA only resulted in differences across the joints (p=0.004) whereas the TRI showed significant differences across the joint (p=0.011) and flexion angle (p=0.0001) with interactions between joint and flexion angle (p<0.05).

Discussion: The different muscles had varying influence on the radiocapitellar and ulnolhumeral joints at 50N loads, likely due to the anatomy and line-of-action of each muscle. For the BIC, interestingly, the ulna received the greatest joint load at 0º flexion whereas it would have been predicted radial loading would be greater, as in 90º flexion, due to the muscle’s line of action. Though the BIC inserts at the radius, load sharing across the interosseous membrane in the forearm could be a factor as well as radiocapitellar partial subluxation resulting in higher ulnar loading. The insertion point of the BRA muscle is at the proximal ulna, so as results would prove, ulnar loading was greatest at 0º flexion compared to radial loading. However, at 90º there was less load difference between the joints due to the position of the arm. During BRD activation, small differences were noted between the two joints at 0º flexion, however, during 90º flexion radial loading was greater possibly due to the mechanical advantage the muscle with its insertion on the distal radius. During TRI loading, the ulnar loads were much greater at 0º than 90º flexion, which may be related to the TRI inserting at the ulna’s olecranon and its line of action at the specific flexion angle.

The findings from this study provides a better understanding of joint loading at the elbow. Though the 40/60 relationship between ulnar and radial loading, respectively, was previously reported [1], the current study shows that the loading ratio between the two sides, in all probability, changes markedly throughout flexion, rotation, and during activities of daily living due to fluctuations in muscle loads.

Significance: The muscle-joint loading relationships established herein provide important new information that improves the understanding of the biomechanics of the elbow. This has implications for experimental studies, computational modeling, and design of fixation devices and implant systems.

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Figure 1. A. Ultrasound and radial loading at 0° flexion with the forearm in supination. B. Ultrasound and radial loads at 90° during supination for 0° and 90° flexion.

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