THE INFLUENCE OF FIFTEEN MUSCLES ON DISTAL RADIOULNAR JOINT LOADING: A BIOMECHANICAL MODEL

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INTRODUCTION

Optimal management of fractures, post-traumatic arthritis and instability of the distal radio-ulnar joint (DRUJ) requires an understanding of the forces generated across this joint as a function of the activities of daily living; however, such knowledge is currently incomplete. Therefore, this study sought to quantify the three dimensional forces acting across the DRUJ during pronation (P) and supination (S) through use of an anatomically determined vector based mathematical model of DRUJ loading. It then sought to determine the role that each individual muscle played in DRUJ loading.

METHODS

The origin and insertion of 15 muscles were marked on the upper extremity of nine fresh cadaveric specimens. Muscles examined included biceps brachii (BB), brachialis (BRA), brachioradialis (BRAR), supinator (SUP), extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB), extensor indicis (EI), extensor policis longus (EPL), flexor carpi radialis (FCR), palmaris longus (PL), flexor carpi ulnaris (FCU), extensor carpi ulnaris (ECU), abductor policis longus (APL), abductor policis longus at the ulnar origin (APL), pronator teres (PT), and the pronator quadratus (PQ).

The positions of these muscles were digitally measured at various stages of P and S by using an electromagnetic 3D tracking sensor (Motion Star, Ascension Technologies, Burlington, VT). Data were collected for each of these fifteen muscles at each of 10° increments of simulated forearm pronosupination (PS) throughout the entire range of motion. Coordinates of the origin and insertion were used to determine the muscle's 3D vectoral orientation at each forearm position. A model consisting of 15 three-dimensional force vectors, one for each of the 15 muscles modeled, was created by combining two separate 2D models, one along the palmar-dorsal axis (shear force at the DRUJ), and a second along the radio-ulnar axis (transverse force at the DRUJ). Maximum muscle forces were determined based upon published tension fraction data [1] and physiological cross sectional area data [2]. Specimen motion ranged from 110° of pronation (P110) to 120° of supination (S120), but no single specimen exhibited that full range of rotation. A position was only analyzed if it was attained by at least 5 of the 9 specimens; therefore mean DRUJ forces were calculated only from the range of P80 to S90. A 3D transformation matrix was used to maintain a consistent set of anatomical reference axes for all angular positions. Forces at the DRUJ were calculated by summing the moments that each muscle provided to the forearm about the elbow. The resultant force acting at the DRUJ was determined from the shear and transverse forces.

The forces exhibited at each position were averaged for all specimens. The effect that each individual muscle had on DRUJ loading was found by removing that particular muscle from the model. Differences between the original model and the models with muscles removed were examined by using a paired t-test.

RESULTS AND DISCUSSION

The two muscles that exhibited the greatest increase in DRUJ loading at any one position and the two muscles that exhibited the greatest decrease in DRUJ loading were plotted against the original model (Figs. 1-3).

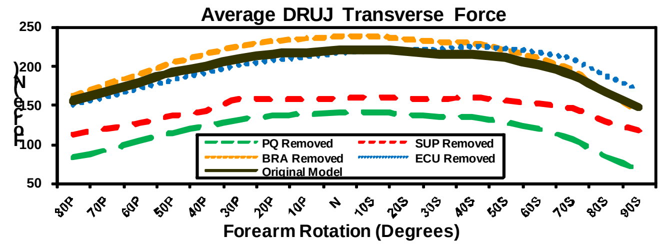

Figure 1: Effect of removing the PQ, SUP, BRA, and ECU on the average DRUJ transverse force during forearm rotation (n≥5).

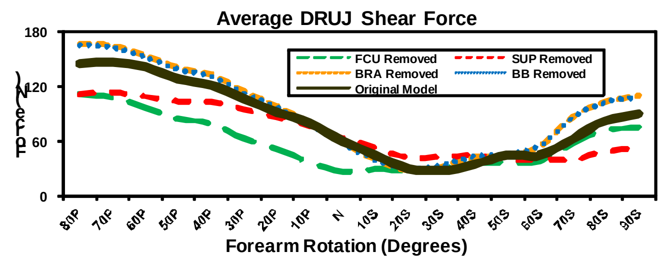

Figure 2: Effect of removing the FCU, SUP, BB, and BRA on the average DRUJ shear force during forearm rotation (n≥5).

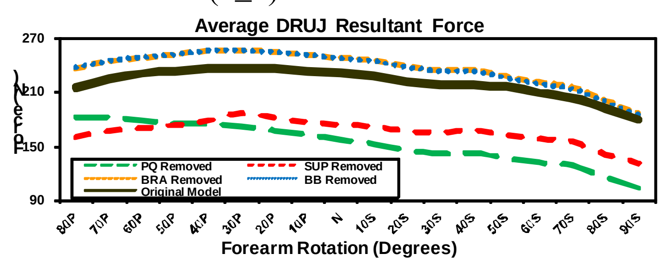

Figure 3: Effect of removing the PQ, SUP, BB, and BRA on the average DRUJ resultant force during forearm rotation (n≥5).

PQ and SUP caused the largest single position increase in transverse forces (82.4N and 62.1N) while BRA and ECU caused the greatest reduction in transverse forces (19.1N and 23.1N). FCU and SUP caused the largest single position increase in shear forces (44.6N and 38.2N) while BB and BRA reduced the shear forces the most (22.8N and 23.4N). SUP also had a significant reducing effect at 20S (p=0.0185) and at 30S (p=0.0428). The overall resultant DRUJ forces were increased the most by PQ and SUP (81N and 61.1N) while BB and BRA cause the greatest decrease in resultant DRUJ force (21.3N and 21.0N).

CONCLUSIONS

These results show that of all 15 muscles studied, the PQ was the greatest contributor to generating force across the DRUJ along the transverse axis, as well as to the resultant force. BRA contributed the most to offloading of the DRUJ along the transverse axis and 2nd most along the shear axis and resultant forces. BB contributed the most to DRUJ offloading along the shear axis and to resultant forces.

Removing a single muscle from the model does not seem to affect general trends of the model, only the magnitude. Along the transverse axis, all of the forces are greatest toward the middle of forearm rotation and decrease as the arm rotates in either direction. Along the shear axis, all forces are highest when the arm is in full pronation and the forces decrease toward their minimum around mid-supination before increasing. In the resultant plane, the forces were greatest in mid-pronation and decrease steadily to their minimum in full supination.

The data for BRA and BB is very similar for shear and resultant forces. This may be due to their similar axial placement on the proximal forearm. It may also be due to the fact that this was a maximal muscle force model and these are both large muscles with multiple roles in upper extremity movement. It is likely that the BB and BRA do not exert maximal muscle force during PS because this motion does not appear to be their primary function. It is worthy to note that simultaneous maximal contraction of all forearm muscles may not result in a maximal force across the DRUJ due to vectoral muscle force balancing. Collecting EMG data over the range of PS would help in scaling down the muscle forces during forearm rotation and help to create a more accurate model. However, the present study provides data that adds to our understanding of forearm muscle function and their cumulative result on distal upper extremity biomechanics.

REFERENCES

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ACKNOWLEDGEMENTS

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