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A COMPARISON OF *IN VIVO*, *IN VITRO*, AND *IN SILICO* WRIST MUSCLE ACTIVITY

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INTRODUCTION

Understanding how the muscles that act on the wrist achieve different motions would have the potential to provide insight into the pathology of neuromuscular diseases, improve rehabilitation protocols, and enhance prosthetic design. However, most previous research into wrist muscle activity has focused on gripping or tendon forces via *in vitro* study [1]–[3]. The aim of this study was to investigate *in vivo* muscle activity of the wrist and compare results to *in vitro* and *in silico* data to determine how appropriate the two models are for predicting muscle activity patterns during motion.

METHODS

Synchronized kinematic and muscle activation data of 19 participants performing flexion-extension (FE), radial-ulnar deviation (RUD), and dart throwing motion (DTM) were collected using an eight-camera optical motion tracking system (Qualisys, Gothenburg, Sweden) and surface electromyography sensors (Delsys, Natick, MA, USA). The motions were performed with the elbow in a fixed location and the hand pointing upward against gravity. The muscles monitored were extensor digitorum communis (EDC), extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), flexor digitorum superficialis (FDS), flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), and pronator teres (PT). Muscle activities during the motions were normalized by activations recorded during nine resisted maximum voluntary contraction tasks.

The tendon forces of six forearm muscles during pure – motion with one degree of freedom – FE, RUD, and functional DTM were measured as reported by Shah et al [3] and the *in silico* results were produced via the model developed by Goislard de Monsabert et al. [4].

RESULTS AND DISCUSSION

Although it was not possible to make direct comparisons of the magnitudes of the measurements, identifying which muscles are active during each task provides insight into the motor control. Figure 1 shows the representative *in vivo* muscle activity and the *in silico* muscle forces during RUD.

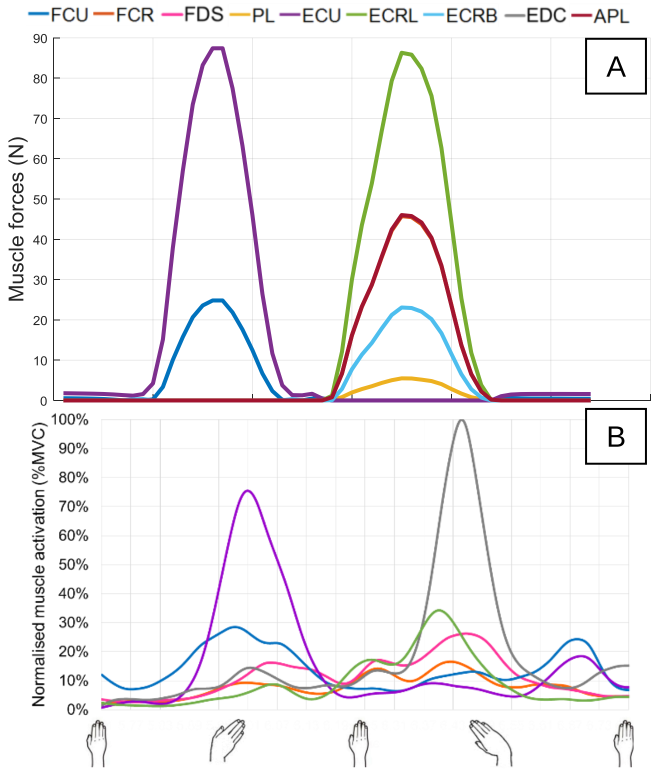

Fig 1: The computed muscles forces (A) and the recorded muscle activity (B) of a radial-ulnar deviation motion.

Both plots show that the ECU and FCU are active during ulnar deviation, the first part of the motion, and the ECR and FCR are active during radial deviation, the second part of the motion. There are also differences in which muscles are active. The recorded muscle activity shows EDC being active during radial deviation and the FDS is somewhat active throughout. In the computed results, however, we see the abductor pollicis longus (APL) and palmaris longus (PL) being activated during radial deviation.

Figure 2 shows the muscle activity and muscle forces for an FE motion. As expected, FCU and FCR are active during flexion and the ECRB, ECRL, and ECU active during the extension phase. Again, there are differences between the two plots. APL is shown to be active during flexion in the computed results whereas FDC is active in the recorded muscle activity. Also, the EDC is active during extension.

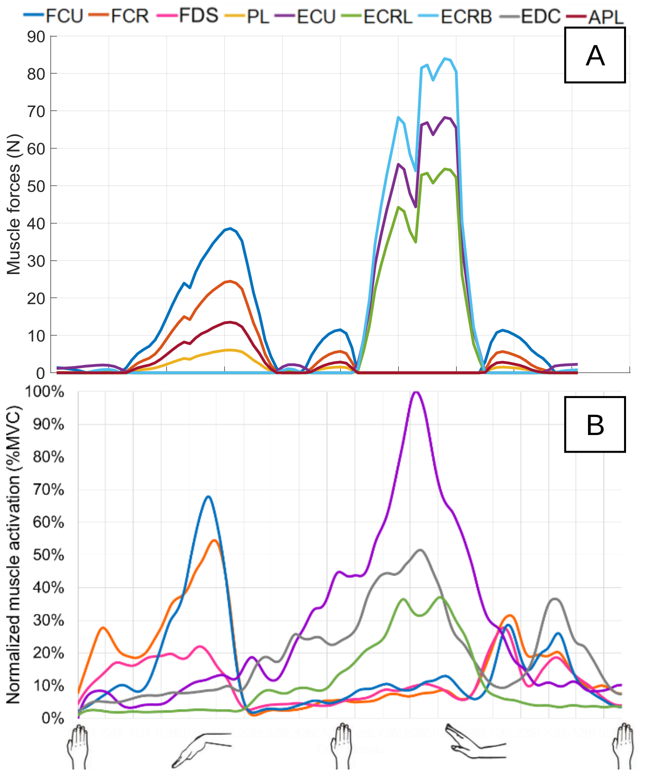

Fig 2: The computed muscles forces (A) and the recorded muscle activity (B) of a flexion-extension motion.

Figure 3 shows the muscle activity and muscle forces for a DTM motion. Again, the ECR, ECU, FCR, and FCU muscles are active in the same parts of the motion and the APL and PL are active when the FDS is shown to be active. The EDC is active towards the end of the motion.

These patterns of muscle activity were also found in the cadaveric study. The corroboration of the results across the three methods of analysis allows us to conclude that we have correctly identified the muscles employed to produce the desired motions. It also further validates the two models used in this study, supporting their use in investigating the biomechanics of the wrist.

A limitation of this study is that different muscles were included across the three data sets. The FDS and EDC muscles didn't feature in either the cadaveric or computational studies. Equally the PL and APL were not monitored during the *in vivo* data collection. Furthermore, the computational model currently doesn't feature the co-contraction observed in the cadaveric and *in vivo* study. This, however, does explain differences in the results across the data sets, as motion driven by the EDC and FDS would have to be resolved via other muscles in the cadaveric and computational studies. We observed activity in the APL and PL in the computed results whenever we see activity in the EDC and FDS in the EMG data. We also observed activity in the muscles throughout the motions in the EMG data, which is not present in the computed results, suggesting some level of co-contraction. Previous research has found that co-contraction may be a strategy used by the body to stabilize motion [5]. This highlights the importance of including the finger muscles and co-contraction in models of the wrist as the exclusion has resulted in muscle activity differences when compared to the *in vivo* results.

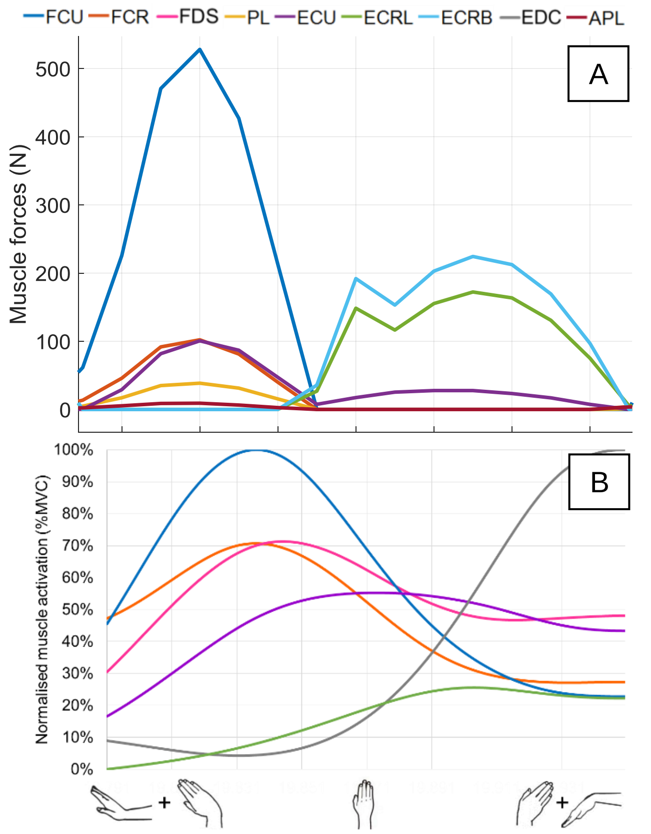

Fig 3: The computed muscles forces (A) and the recorded muscle activity (B) of a dart throwing motion.

CONCLUSIONS

This study provides insight into the motor control of the wrist during pure and functional motions. We have demonstrated that the modeled behaviour of the muscles of the wrist matches the activation exhibited *in vivo* for muscles included in the models and confirmed the necessity of including the finger muscles in models of the wrist to produce patterns that better match *in vivo* muscle activity. Further development of the musculoskeletal wrist model would enable the simulation of wrist motions and provide insight into pathology and rehabilitation.

REFERENCES

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