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ASSESSING FLEXOR TENDON AND SUBSYNOVIAL CONNECTIVE TISSUE (SSCT) EXCURSION WITH COLOUR DOPPLER ULTRASOUND

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SUMMARY
Patients with carpal tunnel syndrome present with fibrosis of the subsynovial connective tissue next to the flexor tendons, which is that shear forces play a role in injury development. To better link ergonomic factors with underlying pathomechanics, we used ultrasonography to measure relative motion of the long finger flexor digitorum superficialis and the adjacent subsynovial connective tissue during repetitive finger tasks. Sixteen participants completed three cyclical finger movements (metacarpophalangeal, proximal and distal interphalangeal joints, and full finger flexion/extension) in three wrist postures (30° flexion, 0°, 30° extension) with full motion analysis of the long finger and wrist. Relative displacements between the flexor tendon and subsynovial connective tissue increased linearly (by 32.3%) from 30° wrist extension to 30° wrist flexion ($F_{(2,30)} = 16.2$, $p < 0.01$). This shows that the wrist may be more prone to shear injuries in wrist flexion. We are currently integrating the data into an analytical model that predicts flexor tendon and subsynovial connective tissue motion as well as risk of injury in the workplace.

INTRODUCTION
The most common findings in patients with carpal tunnel syndrome are fibrosis and thickening of the subsynovial connective tissue (SSCT) surrounding the flexor tendons in the carpal tunnel [1]. These pathological changes are seen in the SSCT layers adjacent to the flexor tendons indicating that shear forces are involved in injury development. SSCT fibrosis also affects tendon gliding, resulting in either increased adherence or dissociation between the flexor tendons and the SSCT [1]. Frictional forces increase even further, giving rise to a vicious cycle of degradation [1, 2].

Researchers are utilizing sonography more often to assess musculoskeletal dynamics due to advances in image resolution. A recent ultrasound study found that flexor tendon excursions were greater compared to a time-honoured cadaveric model of tendon-joint interaction [3]. Differences were most pronounced during complex movement patterns involving concurrent wrist and finger motion. These results challenge traditional cadaver models that consider each joint independently. However, there is a need to quantify flexor tendon and SSCT displacements (*in vivo*) using ultrasound while measuring joint angles with motion capture to better assess carpal tunnel shear due to repetitive wrist and finger movements.

METHODS
Sixteen healthy participants (8 ♀ and 8 ♂) were seated at an adjustable table with the right forearm immobilized in a mid-prone posture using a thermoplastic splint (Figure 1a). A custom handgrip fixed the index, ring, and little fingers in a mid-flexed position, allowing only the long finger to move (Figure 1b). Flexor tendon excursions of the long finger were assessed as participants completed three cyclical finger movements (metacarpophalangeal, proximal and distal interphalangeal joints, and full finger flexion/extension) in three wrist postures (30° flexion, 0°, 30° extension).

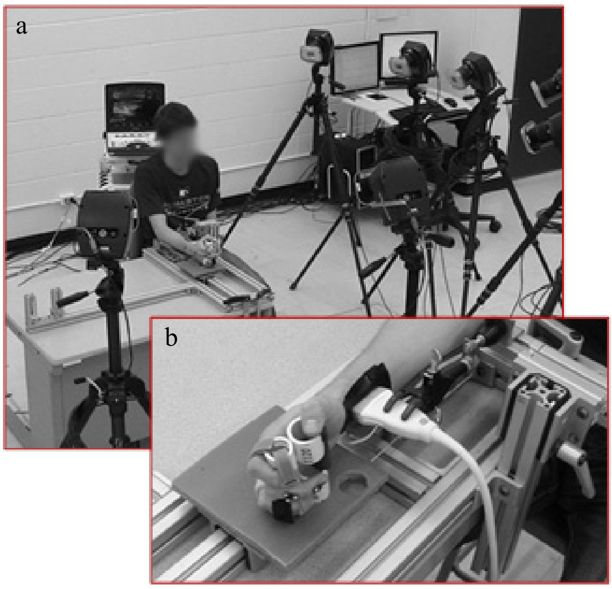

Figure 1: Experimental setup showing (a) the participant with the forearm immobilized in the apparatus, and (b) the custom handgrip used to perform long finger movements.

An ultrasound scanner (Vivid Q, GE Healthcare) equipped with a high-frequency probe (12L) was used to scan the proximal wrist with colour Doppler imaging (CDI) at 30 frames per second. Velocity-time data of the flexor digitorum superficialis (FDS) tendon and the adjacent SSCT were obtained from colour maps superimposed on the grayscale wrist images using dedicated software (EchoPac, GE Healthcare). Velocity profiles were integrated to determine displacements of the FDS and SSCT.

Twelve cameras (Raptor-4, Motion Analysis Corporation) recorded twenty-six reflective markers at 120 Hz, which fed into a kinematic model to calculate wrist and finger joint angles (Visual 3D, C-Motion Incorporated). Wrist and finger joint angles were calculated with an x-y-z Cardan sequence (flex/extension-ab/adduction-pro/supination).

Repeated measures ANOVAs were used to test the effects of finger movement (metacarpophalangeal, proximal and distal interphalangeal, full finger) and wrist posture (30° flexion, 0°, 30° extension). Dependent variables were FDS and SSCT excursions as well as the shear strain index (FDS excursion - SSCT excursion / FDS excursion × 100%).

RESULTS

Long finger FDS excursions were similar across wrist postures (Figure 2a). Full finger (FF) movements produced larger excursions than metacarpophalangeal (MCP) and interphalangeal (IP) motions ($F_{(2,30)} = 79.3$, $p < 0.01$; FF – 21.7 ± 1.0 mm; MCP – 14.0 ± 0.7 mm; IP – 11.9 ± 0.6 mm). SSCT displacements were smaller than the FDS by 32.5 % (on average). There was a main effect of wrist posture on excursions of the SSCT ($F_{(2,30)} = 9.9$, $p < 0.01$). SSCT displacements increased linearly, by 22.1 %, from 30° wrist flexion to 30° wrist extension (Figure 2b). There was also a main effect of finger movement ($F_{(2,30)} = 41.8$, $p < 0.01$), with FF producing larger excursions than MCP and IP.

The shear strain index (a measure of relative motion between the FDS and SSCT) was influenced by wrist posture ($F_{(2,30)} = 16.2$, $p < 0.01$). The highest shear strain index occurred at 30° wrist flexion (38.9 ± 1.9 %) and decreased in the neutral (32.4 ± 2.3 %) and extended (26.3 ± 2.0 %) wrist positions (Figure 2c). Type of finger movement (MCP, IP, FF) did not significantly affect shear strain.

DISCUSSION

We investigated the effects of finger movement and wrist position on absolute and relative displacements of the FDS and SSCT. Both flexor tendon and SSCT excursions were similar to previous cadaver studies [1, 2]. However, the current results differed from ultrasound assessment of complex and simple movement patterns by Lopes et al. [3]. In this study full finger motion did not result in larger FDS excursions compared to the sum of the simple movement components (metacarpophalangeal and interphalangeal joint flexion/extension). FF actually resulted in 16.1% less FDS excursion than MCP and IP added together. However, this discrepancy is likely due to differences in joint kinematic profiles. We are currently incorporating motion capture data from this study into a regression model that predicts displacements of both the FDS and SSCT.

This study also showed that the shear strain index increased with wrist flexion, largely due to increased SSCT motion. This indicates that the wrist may be more prone to shear injuries in wrist flexion. Yoshii et al. [3] found a similar trend in cadavers; however, significant changes only occurred with greater wrist flexion (> 60°).

CONCLUSIONS

This study represents an important first step into better understanding wrist and hand disorders during repetitive work tasks. FDS and SSCT excursions from this study showed the value of finger movement and wrist posture as occupational risk factors. An improved understanding of how work factors influence underlying pathomechanics will ultimately lead to the development of research-driven ergonomic tools based on tendon motion and shear.

ACKNOWLEDGEMENTS

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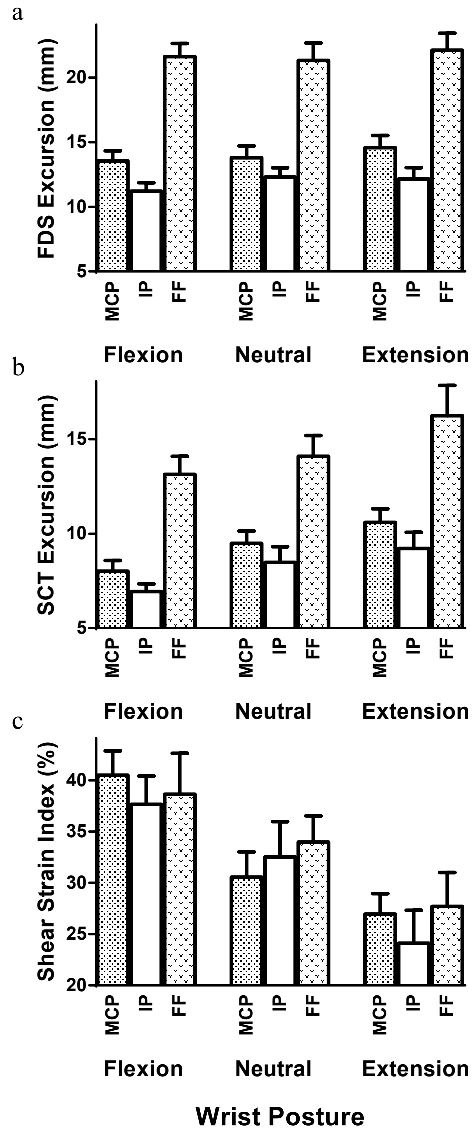

Figure 2: Displacements of the (a) FDS, (b) SSCT, and (c) the Shear Strain Index (a measure of relative motion between the FDS and SSCT). MCP – Metacarpophalangeal; IP – Interphalangeal; FF – Full flexion.