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DIFFERENTIAL FINGER MOTION INCREASES SHEAR STRAIN BETWEEN THE TENDON AND SSCT

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SUMMARY

Non-inflammatory fibrosis of the subsynovial connective tissue (SSCT) is predominately found at the tendon-SSCT border and suggests an etiology of excessive shear forces. This study examined the relative motion between the flexor digitorum superficialis tendon and adjacent SSCT during two repetitive finger tasks. Twelve subjects performed cycles of flexion-extension for 30 minutes with the long finger alone (differential) and with all four fingers together (concurrent) while longitudinal motion was measured with colour Doppler ultrasound. Shear was represented with a shear strain index (SSI, a relative measure of excursion in flexion and extension) and maximum velocity ratio (MVR, the ratio of SSCT versus tendon during flexion and extension). The flexion SSI increased linearly by 20.4% from the first to the 30th minute, while MVR decreased 8.9% (flexion) and 8.7% (extension) at a linear rate in the differential finger condition alone ($p<0.05$). This study shows that repetitive differential finger tasks may increase the risk of shear injuries in the carpal tunnel. The data suggest a mechanism of cumulative trauma for pathological fibrosis of the SSCT.

INTRODUCTION

A characteristic finding with carpal tunnel syndrome (CTS) is non-inflammatory fibrosis of the subsynovial connective tissue [1]. It is composed of layers of collagen bundles that interconnect the median nerve and flexor tendons within the carpal tunnel. SSCT fibrosis is most apparent in layers closest to the tendons [1], which suggest that differential gliding between the tendons and SSCT may be involved in the etiology. This study used colour Doppler imaging to examine the relative motion between these structures and the effect of time during repetitive finger movements.

METHODS

Twelve healthy male volunteers (mean age 22.7) performed 30 minutes of two repetitive tasks including both concurrent (four fingers) and differential (long finger) finger flexion-extension movements at a rate of 1 per second. Longitudinal motion of the long finger flexor digitorium superficialis (FDS) tendon and the SSCT were measured using a sonographic scanner (Vivid Q; GE Healthcare, Milwaukee, WI). At the proximal wrist crease, a high-frequency linear array transducer (12L; GE Healthcare) was positioned in line with the tendon. Ten-second cineloops were collected at 29.5 frames per second at the end of each one-minute interval over a 30-minute time-span. Images were analyzed using dedicated software (EchoPAC, GE Healthcare, Milwaukee, WI).

Three markers were positioned on the longitudinal axis of the FDS tendon and the adjacent SSCT to obtain tissue velocity information. A mean velocity profile of the FDS and SSCT markers were calculated for each cineloop and low pass filtered (4.0 Hz). Velocity was integrated to obtain displacements. Relative shear between the FDS and SSCT was quantified using the shear strain index (SSI) and maximum velocity ratio (MVR) [2]. SSI was calculated as the difference in excursion between the tendon and SSCT during flexion and extension, expressed as a percentage of tendon excursion. MVR was defined as the ratio of maximum SSCT versus tendon velocity for flexion and extension. SSI characterized the potential for shear over the entire finger movement, while MVR expressed an instantaneous shear potential.

A two-way repeated measures ANOVA was used to test exertion time (0 - 30 minutes) and movement type (concurrent versus differential). Dependent variables in flexion and extension included time, SSI and MVR. Significant main effects and interactions were examined with post-hoc trend analysis at a level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The time to complete finger flexion and finger extension within each flexion-extension cycle did not change over the 30-minute finger tasks. There was also no significant difference in movement times between the concurrent and differential movement conditions.

The relative difference in excursion was examined using the shear strain index (SSI) in flexion and extension (Figure 1). There was a significant movement type X time interaction on flexion SSI ($F_{(29,319)}=1.665$, $p=0.019$) and no effect on extension SSI. A post-hoc trend analysis revealed a significant linear increase in SSI over 30 minutes in the differential finger movement condition only ($F_{(1,11)}=7.343$,

$p=0.020$, $\eta^2=0.400$). With differential finger motion, SSI in flexion increased by 20.4% from the first to the 30th minute. Flexion SSI did not change with concurrent finger motion.

The differences in velocity were examined with MVR (Figure 1). A significant movement type X time interaction was also found for MVR in both flexion ($F_{(29,319)}=1.615$, $p=0.026$) and extension phases ($F_{(29,319)}=1.628$, $p=0.024$). In differential motion, a significant linear effect of time was found to decrease MVR in flexion ($F_{(1,11)}=18.036$, $p=0.001$, $\eta^2=0.621$) by 8.9% and MVR in extension ($F_{(1,11)}=11.806$, $p=0.006$, $\eta^2=0.518$) by 8.7% through the 30 minutes of exertion. Likewise, no significant effect on MVR was found during concurrent finger motion.

The goal of this study was to determine the effect of exertion time with repetitive finger motions on carpal tunnel mechanics. We reported significant linear increases in tendon-SSCT shear for the differential finger movement alone. This indicates the potential for greater shear forces between the flexor tendon and SSCT that may increase the risk of shear damage over time. CTS is associated with the repetitive use of the hands and wrists [3]. While there are many factors that may be involved, if shear increases in the carpal tunnel in repetitive work, over the course of a worker's career this might play a role in injury and explain the accumulation of fibrosis. It is especially noteworthy that this was observed in only 30 minutes of low force exertions of a single-digit. The implications in the workplace may be even greater given longer work schedules and more intensive efforts.

Ettema et al. [1] found atypical tendon gliding patterns with CTS, including a lag in SSCT motion after tendon motion was initiated suggesting disrupted function of the tendon-SSCT connections. This differential motion has been quantified by higher shear magnitudes (SSI and MVR) in CTS patients compared to healthy controls [4]. Our shear values at the end of 30-minutes of continuous differential motion were comparable to the clinical population [4]. This may suggest that prolonged exertions could predispose to shear forces that are associated with the development of pathological fibrosis found in CTS patients.

The increase in flexion SSI was echoed by increases in tendon excursions over time and stable SSCT excursions. Likewise, the smaller MVR values were associated with greater tendon velocities over time and steady SSCT velocities. These changes were not expected to be from biomechanical factors. Participants performed the tasks in a consistent manner throughout the 30-minute trials, as evidenced by no changes in flexion or extension time for either differential or concurrent movement trials. However, changes in the mechanical properties of the tendon tissue might be involved in the development of shear. Goldstein et al. [5] reported peak strains of 0.8 - 1.5% in cadaver flexor tendons after 500 loading cycles. A 1% increase in tendon strain could potentially explain the increases in tendon excursion (2-3 mm for some participants) over 1800 loading cycles in the current study.

There were a few limitations with this study. While joint angles were not measured, subjects performed consistent finger motions by contacting movement end ranges marked by our apparatus. Subjects tended to have more difficulty reaching end ranges due to fatigue, which made increases in tendon excursion and velocity even more notable. The force associated with flexing and extending the fingers was also not monitored. However, there were no force requirements and movement times remained unchanged throughout the study, strongly suggesting that this was not an issue. We also might expect significant changes to occur in concurrent finger motion with faster repetition rates or longer durations. However, we selected a finger movement frequency that fit the definition for high repetition of work [3].

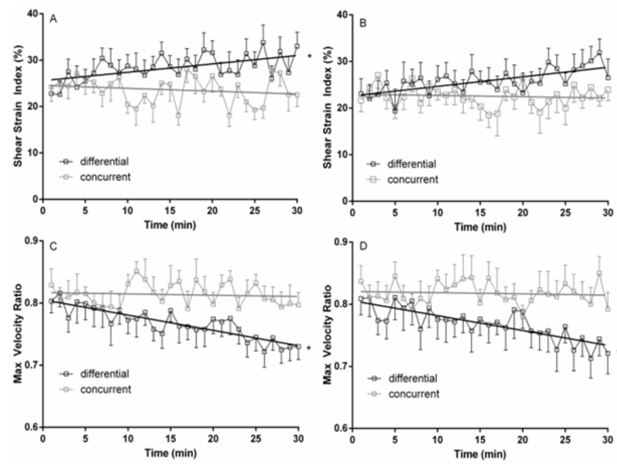

Figure 1: Shear for differential and concurrent finger motion. a) flexion SSI b) extension SSI c) MVR in flexion d) MVR in extension. *Significant ($p<0.05$).

CONCLUSIONS

We observed an increase in tendon-SSCT shear with repetitive differential tendon motion that might suggest an increased risk of shear damage over time. While many factors may affect shear, this was likely associated with larger tendon excursions. These findings indicate a potential mechanism of cumulative trauma with exertion time that could explain the development of fibrosis characteristically found in CTS patients.

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