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Tendon and nerve excursion in the carpal tunnel in healthy and CTD wrists

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A B S T R A C T

Background: During hand and finger motions, friction between flexor digitorum superficialis tendon and the median nerve is thought to play a role in the development of cumulative trauma disorders. This study investigated three methods to determine excursions of the flexor digitorum superficialis tendon and median nerve using several motions.
Methods: Twenty-five participants (mean age 37.2 years SD 13.4) were classified as healthy ($n=16$), self-reported distal upper extremity cumulative trauma disorders (6), or wheelchair users (3). Static carpal tunnel measurements were taken and displacements of the index flexor digitorum superficialis tendon and median nerve were determined via the velocity time integral and post hoc integration of the Doppler ultrasound waveform using a 12–5 MHz linear array transducer, as well as using predictive equations.
Findings: Median nerves in symptomatic wrists were larger than healthy wrists by 4.2 mm^2 (left) and 4.1 mm^2 (right) proximally to less than 1.4 mm^2 distally. In healthy wrists, left–right tendon excursion differences ranged from 0.7 mm to 4.3 mm depending on the motion while left to right differences in symptomatic wrists ranged over 22.2 mm. Ultrasound measures of tendon excursion overestimated those determined using predictive equations and were poorly correlated.
The ratio of median nerve excursion to tendon excursion was lower in finger only motions compared to wrist motions with or without finger motion.
Interpretation: Spectral Doppler ultrasound imaging provided insights into tendon excursion that was not apparent with mathematical modeling. The difference in excursion between finger motions and wrist motions could be beneficial in therapeutic techniques.

1. Introduction

Tendinitis, tenosynovitis and carpal tunnel syndrome (CTS) are common cumulative trauma disorders (CTD) of the hand and wrist. The annual incidence of upper extremity CTDs has been reported to range from 21.1 to 25.3% in industrial and clerical occupations (Gerr et al., 2002; Kurppa et al., 1991; Werner et al., 2005). It is well established that high force, high repetition and deviated postures are risk factors for upper extremity CTDs with a greater risk when a combination of risk factors are present (Silverstein et al., 1986). Movement of the flexor tendons within the carpal tunnel (CT) has been related to tenosynovitis and tendinitis, and has been associated with development of CTS (Amadio, 2005; Gelberman et al., 1992).

Deviation of the wrist curves the paths of the flexor tendons allowing forces normal to the tendon paths to be imposed on the median nerve as well as other tendons and structures within the carpal tunnel (Keir and Wells, 1999). In addition, differential finger and wrist movement is also associated with relative motion between tendons, their sheaths and the median nerve creating frictional forces. Schuind et al. (1990) found evidence of frictional damage in idiopathic CTS wrists in which the synovium appeared similar to tissues degenerated by repetition. The combination of force and repetition increases the risk of developing tenosynovitis/tendonitis due to an increase in frictional work imposed on the sheaths (Moore et al., 1991) and tasks involving higher velocities of movement further increases friction on the tendon sheaths due to greater tendon forces (Marras and Schoenmarklin, 1993; Ugbolue et al., 2005). Frictional forces between tendon and sheath, or pulley, increase with finger flexion and tendon excursion (Uchiyama et al., 1995), which may pose a problem if maintained or repeated often (Amadio, 2005). With tenosynovitis or tendon repair, friction also increases (Zhao et al., 2002). Scar tissue and/or inflammation may increase the force to initiate tendon movement up to 6 N (Zhao et al., 2004).

Excursions of the finger flexor tendons have been assessed in cadavers (An et al., 1983; Armstrong and Chaffin, 1978; Ugbolue et al., 2005) and using ultrasound in vivo (Oh et al., 2007; Yoshii et al., 2009a). From their cadaveric study, Armstrong and Chaffin (1978) developed a

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regression model to predict tendon excursions and moment arms of flexors digitorum profundus (FDP) and superficialis (FDS) based on joint angles and thicknesses. Similar methods have been used to examine the index finger (An et al., 1983) as well as differential motion between the flexor tendons and median nerve (Ugbolue et al., 2005). The excursion model of Armstrong and Chaffin (1978) has been effectively used to evaluate injury risk during keyboarding (Treaster and Marras, 2000; Sommerich et al., 1996) and to determine muscle incursion into the carpal tunnel (Keir and Bach, 2000). Using the thickness and angle of each joint provides a linear relationship for tendon excursion which may change with health conditions and/or postural constraints. Understanding these differences will improve our models of tendon motion and to develop therapeutic and ergonomic techniques.

Ultrasound imaging techniques have been used to examine displacements of tendons (Cigali et al., 1996; Buyruk et al., 1998) and the median nerve (Erel et al., 2003; Nakamichi and Tachibana, 1992, 1995) in the hand and wrist. The median nerve is known to move in both longitudinal and transverse directions (Nakamichi and Tachibana, 1992) but may be adhered to the flexor retinaculum in patients with CTS (Nakamichi and Tachibana, 1995). Similar observations of fibrosis have been found around the subsynovial connective tissue (SSCT) (Gelberman et al., 1992), which loosely connects the finger flexor tendons and serves to reduce friction (Ettema et al., 2006a). Recently, speckle tracking (Yoshii et al., 2009a) and color Doppler imaging (Oh et al., 2007) have been shown to provide improved visualization and tracking of the tendons and nerve in the carpal tunnel. Determining the movement of the tendons and median nerve through the carpal tunnel in both symptomatic and healthy participants is needed to help prevent distal upper extremity CTDs in the workplace, as well as assist with rehabilitative nerve and tendon gliding protocols.

The purpose of this study was to use spectral Doppler ultrasound to determine excursions of flexor digitorum superficialis (FDS) tendons and the median nerve through the carpal tunnel in both healthy and self-reported hand/wrist CTD participants. A series of motions was used to compound finger motions and postures with wrist motion. Secondary aims were to compare ultrasound derived tendon excursions with those estimated using predictive equations and obtain static measurements of the carpal tunnel.

2. Methods

2.1. Participants

Twenty-five volunteers participated in the study, 16 in the healthy group (9 females and 7 males), 6 in the self-reported symptomatic group (4 females and 2 males), and a separate group of 3 wheelchair users (1 female and 2 males) that were included only for descriptive comparison and not included in statistical analyses. The mean participant ages in years for the healthy, symptomatic and wheelchair groups were 33.1 (SD 11.5), 46.3 (12.7), and 41.3 (18.5), respectively. Of the 25 participants, 23 were right-handed and 2 were left-handed.

2.2. Protocol

Participants completed a questionnaire to document general health, handedness, specific health conditions (diabetes, previous carpal tunnel surgery, rheumatoid arthritis, and pregnancy), work and sport history, and present or past hand/wrist injury status. After providing written informed consent, anthropometric measurements were taken followed by static and dynamic ultrasound measurements. The protocol was approved by the McMaster Health Sciences ethics review board and the sub-committee for Human Research at York University.

Anthropometric measurements of the wrist and hand were made using calipers and measuring tape and included *wrist width* (distance between the outer borders of radial and ulnar styloid processes), *wrist depth* (volar to dorsal distance at distal wrist crease), *wrist circumference* (at distal wrist crease), *hand length* (radial styloid process to tip of 3rd digit), *hand width* (distance between 2nd to 5th metacarpal heads), *metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joint thickness* (at joint line).

Gray-scale sonography examinations were performed by a registered medical sonographer with a broad bandwidth transducer and a 12–5 MHz linear array (HDI Philips 5000, Philips Canada, Markham, ON, Canada). Both wrists were scanned with static measurements performed first, followed by motion trials. Spatial compound imaging was used to obtain static measurements with an axial resolution of 0.5 mm, lateral resolution 0.5 mm, and a slice thickness of 1.5 mm.

All scans were taken from the volar aspect of the wrist with the participant seated comfortably in an adjustable chair, forearm supine on an adjustable table and the elbow comfortably flexed to 120°. The middle volar wrist crease was used as an initial external reference point, using carpal bony landmarks and other internal reference points during scanning. Static images in the transverse view were used to examine the carpal tunnel (CT) area, CT depth (deepest border of transverse carpal ligament to palmar border of carpal bones) (Fig. 1), CT width (hook of hamate medially to tuberosity of scaphoid laterally), cross-sectional area (CSA) of median nerve at the proximal wrist crease, at the CT inlet (within tunnel), and distal to the hook of hamate, and longitudinal distance between distal end of radius and base of 3rd metacarpal (distal end of radius articulating with lunate and scaphoid). The borders of the carpal tunnel were defined to ensure the proper scanning location. The palmar border of the carpal tunnel was located by the hyperechoic (bright) transverse carpal ligament (Beekman and Visser, 2003) and the dorsal border of the tunnel was considered the most palmar edge of the carpal bones (dark gray). The cross-sectional area of the median nerve was measured by tracing the margin of the nerve defined as the area between the outside of the hypoechoic nerve fascicles and the inside hyperechoic nerve sheath (Lee et al., 1999). Calipers within the ultrasound system were used to mark key landmarks on the static images and calculate linear distances and areas.

After completion of the static images, motions of the flexor digitorum superficialis (FDS) tendon bundle and the median nerve were measured using Spectral Doppler scanning during 3–5 cycles of the five motions for each hand. The system accuracy was reported as 0.4% of maximum velocity at an angle of 0°. Our data was corrected at 60° thus we expect an accuracy of less than ±3.5%, in line with ±0.7 mm as found by Hough et al. (2007). The 5 motions incorporated metacarpophalangeal and interphalangeal joint flexion, wrist extension and a three finger pinch (Table 1). Motions with wrist extension were used as it positions the median nerve palmarly between the flexor retinaculum and the 2nd FDS tendon, putting stress on both the tendon and median nerve (Zeiss et al., 1989) while allowing the transducer to maintain contact with the wrist throughout the range of motion. Prior to recording, participants practiced the 5 motions until the investigator deemed the motion and postures were repeatable (using a manual goniometer). The forearm and wrist were not constrained to allow for "normal" motion as would be seen in activities of daily living, work, or potential therapeutic motions. To ensure proper measurement of excursion, the ultrasound transducer was positioned parallel to the tendon/nerve (Soeters et al., 2004).

Three methods were used to measure displacement of the FDS tendons and median nerve: (i) velocity time integral (VTI) measured by the ultrasound machine, (ii) post-hoc tracing and integration of the velocity curves, and (iii) predictive equations to calculate displacement. For each motion, the location of the measurement was noted (FDS or median nerve, Fig. 2, top) and velocity of the tendon or nerve demonstrated a characteristic pattern of triangular velocity peaks (Fig. 2, bottom). FDS and median nerve movement were scanned separately for each motion consecutively. For each velocity curve there were 3–5 (positive and negative) excursion profiles. The VTI for both the FDS and median nerve were determined using the tracing