Introduction: Idiopathic carpal tunnel syndrome (CTS) is one of the most common peripheral neuropathies. While it is commonly agreed that the neurologic findings are due to increased pressure in the carpal tunnel, the etiology of the pressure elevation is unknown. The most characteristic histologic finding in patients with CTS is non-inflammatory fibrosis of subsynovial connective tissue (SSCT). It has been suggested that repetitive motion might be a cause of CTS, and that these changes in the SSCT might be the result of a shearing injury. Since it is known that work in certain wrist positions is associated with an increased risk of CTS, it would be helpful to know the normal shear strains between tendon and SSCT in various wrist positions before and after carpal tunnel release. The purpose of this study was to measure the effect of wrist position and carpal tunnel release on the relative motion of middle finger flexor digitorum superficialis (FDS) tendon, SSCT, and median nerve.

Materials and Methods: Ten fresh frozen human cadaver upper extremities specimens were used. A custom designed external fixator was used to position the wrist in the required position. A skin incision was made longitudinally to expose middle finger FDS tendon from the muscle tendon junction to the proximal end of finger flexor sheath, with the flexor retinaculum and bursa intact. A small window (5mm diameter) was made in the flexor retinaculum to expose the middle finger FDS tendon, median nerve and SSCT. Two metal markers (9291K12, McMaster-Carr, Chicago, IL) were inserted into the middle finger FDS tendon and median nerve. A third marker was glued on the surface of SSCT. The specimen was mounted in a custom fixture. The proximal ends of finger FDS tendons were fixed with sutures to a Dacron cord and connected to a mechanical actuator. A 100g weight was attached to each of fingertip to maintain tension in the system.

Testing was randomly performed in intact carpal tunnel with five different wrist positions, namely, neutral (0 degrees extension), 30 and 60 degrees of flexion (Flex 30, Flex 60), and 30 and 60 degrees of extension (Ext 30, Ext 60). The four FDS tendons (index, middle, ring, little finger) were pulled together proximally by the actuator against the weight at a rate of 2.0mm/s for 20 seconds (simulated fist). The motion of the three markers was recorded by lateral view fluoroscopy (BV 25, Scopofix MDPM, Philips) using a digital video camcorder (DCR-TRV350, Sony, Japan). Each of the marker movements was digitized with Analyze Software (Biomedical Imaging Resource, Mayo Clinic, Rochester, MN). After testing with intact carpal tunnel, flexor retinaculum was cut with a scalpel. Then the same procedures were repeated for each position.

Digitized coordinate data (X, Y) for the tendon, SSCT, and nerve were processed using a custom Matlab program (The Mathworks, Inc, Natick, MA). All X and Y coordinate data were converted from pixels to millimeters using the scale factor conversion obtained from the imaged ruler. The coordinates for tendon, SSCT, and nerve were normalized relative to the external fixator to correct for any translational or rotational motion of the image or specimen during data collection.

Finally, the coordinates of tendon, SSCT, and nerve were transformed to a new coordinate system such that the transformed X axis was aligned with the motion direction of tendon, as defined by a linear polynomial fit to the tendon time series data. Proximal and distal motions were defined as positive and negative motion, respectively, along the motion direction of tendon excursion. For the tendon, SSCT, and nerve, the distance along the motion direction of tendon excursion were calculated. To estimate shear strains between structures, the relative motions of tendon, SSCT and nerve were compared using a shear strain index (SSI), defined as the ratio of the difference in motion along the direction of tendon excursion between two tissues divided by tendon excursion, expressed as a percentage. Thus for example the tendon-SSCT SSI would be defined as:

\[
\frac{\text{tendon excursion} - \text{SSCT motion in the direction of tendon excursion}}{\text{tendon excursion}} \times 100\%
\]

Statistical Analysis

Marker motion was compared for different wrist positions and for before and after carpal tunnel release. The generalized linear model was used to analyze the variables. All results were expressed as mean ± standard error of the mean (SEM). The wrist position or carpal tunnel release factors were considered statistically significant when the p-value is less than 0.05. A post hoc pairwise comparison was adapted using the Scheffé's test criteria for ten combinations for wrist position factor (Neutral vs. Flex 60... Flex 60 vs. Ext 60), when carpal tunnel release factor is controlled. Thus, p-value of less than 0.005 (0.05/10) was considered statistically significant for each wrist position combination. All the analyses were conducted using SAS version 9.1 STAT software GLM procedure (SAS Institute, Cary, NC).

Results: Table 1 illustrates the shear strain index (SSI) for tendon-SSCT, tendon-nerve, and SSCT-nerve. With intact carpal tunnel, the tendon-SSCT and tendon-nerve SSI were significantly increased in the Flex 60 position compared to all other positions. The SSCT-nerve SSI was significantly decreased in the Flex 60 position compared to the neutral, Ext 30 and Ext 60 positions.

After carpal tunnel release, although there were still significant increases in the tendon-SSCT and tendon-nerve SSI in the Flex 60 position compared to neutral, Flex 30 and Ext 30 positions, the difference among wrist positions were reduced. Especially, tendon-SSCT SSI was significantly decreased compared to the intact carpal tunnel in the Flex 60 position.

Discussion: This study assessed the relative motion of SSCT, tendon and nerve in different wrist positions. We demonstrated that 60 degrees of wrist flexion maximizes the SSI between tendon and SSCT, and minimizes the SSI between SSCT and nerve. After carpal tunnel release, it was significantly reduced in 60 degrees of wrist flexion. Thus, this result suggests that the SSCT may be predisposed to shear injury from activity done in 60 degrees of wrist flexion. In addition, carpal tunnel release may reduce the risk of shear strain.

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Table 1. Results of shear strain index.