INTRODUCTION:
It has been suggested that, within the carpal tunnel, injury to and subsequent dysfunction of the subsynovial connective tissue (SSCT) may cause idiopathic carpal tunnel syndrome. This study hypothesized that a novel image analysis approach based on speckle tracking can identify and track SSCT motion, and therefore assess its function noninvasively. Thus, the purpose of this study was to quantify the relative motion and the velocity of the flexor tendon and SSCT with speckle tracking and compare those to a previously reported method of tissue Doppler imaging.

METHODS:
This study protocol was approved by our Institutional Review Board. Ten normal human subjects (six male and four females) with the average age of 33.6 (±/− 6.5) years were recruited. Participants were given a brief description of the research and the testing procedures at the initial contact. Verbal consent was obtained from all participants. An ultrasound scanner (Acuson Sequoia C512, Siemens Medical Solutions, Malvern, PA) equipped with 15L8 linear array transducer was used.

Image Acquisition Procedure: A longitudinal ultrasound image of the middle finger flexor digitorum superficialis (FDS) tendon was obtained at the wrist crease level. To evaluate if the measurement method appropriately estimated the excursions, three different sizes of acrylic tubes, small, medium and large tubes with a diameter of 3.8, 5.1 and 6.4 cm, respectively, were used to limit tendon excursion. The participants were then asked to flex and extend with four fingers (index, middle, ring, little) from the range of full finger extension to the maximum flexion until lightly gripping each tube. The participants were asked to move repeatedly in 0.8 Hz cycles for each direction (flexion or extension).

For the speckle tracking method, the image was recorded for three flexion-extension cycles motion for each tube size. For the tissue Doppler imaging method, the velocity signals were obtained while placing a pulsed wave cursor at the flexor tendon and SSCT level during finger motion, while keeping the angle between the tendon and the cursor below 60 degrees. The Doppler velocity spectra were also recorded for three complete motion cycles for each subject for each tube.

Data Analysis: For the speckle tracking measurement, the images were analyzed with Syngo VVI software (Siemens Medical Solutions USA, Inc., Malvern, PA). By a point-click approach, three markers were placed on the FDS tendon tissue speckle perpendicular to the tendon motion direction at the radio-carpal joint level. For the SSCT motion analysis, the SSCT was defined as the highly echoic layer at the border of the tendon. Three markers were also placed lengthen this layer. The velocity time series data were then generated by the software. The maximum velocity for both flexion and extension were used for analysis. In addition, the tendon and SSCT excursions were calculated from the velocity/time series data.

For the tissue Doppler imaging measurement, Doppler velocity spectra of the three flexion and extension motions were analyzed. Doppler velocity spectra were interactively outlined, and the machine calculated maximum velocity. In addition, the area of the Doppler velocity spectra was measured using Image J software (National Institute of Mental Health, MD, USA) for the tendon and SSCT excursion.

The maximum velocity ratio was defined as the ratio of the SSCT maximum velocity to tendon maximum velocity. In addition, shear index, defined by the following equation, was calculated.

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\text{Shear index} = \frac{\text{Maximum velocity ratio}}{100}
\]

Tendon Excursion from Joint Angle: To provide a common frame of reference for the ultrasound measurements, the FDS excursion was selected to compare to the difference in shear index and maximum velocity ratio for different tube sizes, a two factor analysis of variance (ANOVA) followed by Scheffe’s post hoc test was selected. For the maximum velocity ratio, the difference in same direction motion (flexion or extension) was compared. The results were expressed as mean ± standard deviation (SD). P-values of less than 0.05 were considered statistically significant. All statistical analyses were conducted by SAS/STAT version 9.1 software (SAS Institute, Cary, NC).

RESULTS:
The correlation coefficient between the excursion from joint angle derivation and speckle tracking measurement was 0.642 (P=0.001). The correlation coefficient between the excursion from joint angle derivation and the tissue Doppler measurement was 0.506 (P=0.002). (Figure 1)

For the speckle tracking measurement, there were significant differences in the maximum velocity ratio between each tube size in the flexion direction. Also, there was a significant difference in velocity ratio between the small size tube and large size tube in extension motion. For the tissue Doppler measurement, there was no significant difference in velocity ratio between tube sizes.

For the speckle tracking measurement, there were significant differences between each tube size in the shear index. For the tissue Doppler measurement, there was no significant difference in the shear index between tube sizes. (Figure 2)

DISCUSSION:
Speckle tracking appears to be a potentially useful method to evaluate the relative motion of flexor tendon and SSCT in the carpal tunnel. In addition, we found that the maximum velocity ratio and shear index were distinguishable by this method. These may be useful indices to evaluate the pathomechanics of flexor tendons and SSCT in the carpal tunnel.

Figure 1. Correlations of the tendon excursions derived from joint angle and the ultrasound measurements.

Figure 2. Shear index (marks show significant difference, P<0.01).

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