INTRODUCTION:

The transverse carpal ligament (TCL) forms the palmar boundary of the carpal tunnel, supports the volar migration of the underly-
ing nerve and flexor tendons, and plays a critical role in regulating carpal tunnel mechanics. Knowledge of the TCL is necessary to facilitate further investigation into the TCL morphology related etiology of carpal tunnel syndrome (CTS). TCL morphology has been studied with varying techniques, including caliper, micrometer, histology, silicon casing with digitization, computed tomography (CT), and magnetic resonance imaging (MRI). Though these studies provide information regarding the TCL thickness, they are either expensive, time consuming, or require a relatively cheap, non-invasive methodology proper for clinical assessment of the TCL morphology is needed, such as ultrasound imaging. The purposes of this study were (1) to develop a methodology to measure the TCL thickness using ultrasound imaging and (2) to test the reliability and validity of this methodology since ultrasound is considered the most operator-dependent imaging modality.

METHODS:

Ultrasound Examination

Eight fresh frozen human cadaveric hands were thawed overnight. The hands were stabilized in a custom-made thermoplast split using Velcro straps in a supine posture with the thumb and fingers fully extended. A Siemens Acuson S2000 ultrasound system with a 18L6 HD wide band linear array transducer was used for this study. The machine settings were kept identical across all examinations with a frequency of 12 MHz. The main challenge of ultrasound examination was to standardize the location where TCL thickness would be measured. First, we located a desired plane of view, in which the trapezium, the hook of hamate, the TCL, and the thenar muscles were easily identified. Second, the transducer was held in place while the outline of the transducer was traced on the cadaver with a permanent marker. Third, using clear Transpore breathable surgical tape, we affixed a metal rectangular-shaped reference marker on the radial aspect of the hand. The short sides were ~16 mm apart, about the width of the transducer. The long sides were ~5 mm apart and oriented crossing the transducer, which created interference patterns visible on the ultrasound image and allowed tracing the transducer location in the radial-ulnar direction. Finally, we replaced the transducer on the previously delineated carpal tunnel location. Three operators conducted ultrasound examinations of each specimen in two sessions. Each operator collected three images during each session.

Measuring TCL Thickness from the Ultrasound Images

Each operator performed image analysis on his/her own ultrasound images. The surface projection of the thenar muscle attachment site (TMAS) and the interference pattern created by the reference marker were marked on the top of each image (crosses in Fig. 1). The distance between these two locations was measured by on-screen calipers and used for later identification of the location where the TCL thickness should be measured on the dissected TCL. Each operator manually outlined the volar and dorsal boundaries of the TCL using ImageJ. All images were processed using a customized MATLAB function to measure the TCL thicknesses at the TMAS (arrow in Fig. 1). Third, we made a 20 mm (radial-ulnar) × 30 mm (proximal-distal) rectangular incision on the skin with the superficial TMAS as the center. Fourth, we carefully removed skin, fat, muscles, and fascia to expose the TCL. The TCL was identified by its bone insertion sites and fiber orientation. Fifth, we aligned two threads along the two lines marked superficially outside the rectangular incision. The TMAS was marked by tissue ink at the intersection point of the threads. Afterwards, the TCL was dissected out of the cadaveric specimen. The thickness of the dissected TCL was measured by a linear variable differential transducer (LVDT) three times at the TMAS.

RESULTS:

Both intra-operator and inter-operator reliabilities were examined using intra-class correlation coefficients (ICC) and the standard error of measurement (SEM). Pearson’s correlation coefficient (r) was used to investigate the linear relationship between the TCL thicknesses measured from the ultrasound images and from the dissected specimens.

**Table 1 Intra-operator reliability for TCL thickness measurement.**

<table>
<thead>
<tr>
<th>TCL thickness</th>
<th>ICC3,2 (95% CI)</th>
<th>SEM (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>operator 1</td>
<td>1.3 ± 0.3</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>operator 2</td>
<td>1.4 ± 0.2</td>
<td>1.3 ± 0.3</td>
</tr>
<tr>
<td>operator 3</td>
<td>1.3 ± 0.3</td>
<td>1.5 ± 0.2</td>
</tr>
</tbody>
</table>

**DISCUSSION:**

To our knowledge, this is the first reliability and validity study of quantitative ultrasound measures of the TCL thickness. The results demonstrated that ultrasound imaging of the TCL has good inter-operator reliability (ICC3,2 = 0.87) and moderate to good intra-operator reliability (ICC3,1 in the range of 0.74-0.85). While the 95% CIs for inter-operator reliability were narrow, the 95% CIs for intra-operator reliability were large, indicating that the study was underpowered. The high Pearson’s correlation coefficient (r = 0.90) indicated that though the TCL thickness measured from the dissected specimens was larger than that measured from the ultrasound images (potentially due to incomplete removal of surrounding soft tissues), the trend was consistent. In summary, the ultrasound imaging methodology developed in this study was reliable and valid for measuring TCL thickness.

The SEM was relatively small, (0.10-0.18 mm), compared with the TCL thickness measured from the ultrasound images (mean thickness range: 1.0-1.8 mm). The SEM provides a guideline for interpreting changes within a single subject as real or due to measurement error. It will be useful in future studies that monitor TCL thickness changes in CTS-prone populations. Furthermore, the hypertrophy of the TCL in CTS patients has long been observed during surgeries. A clinical study showed TCL hypertrophy in 61 CTS patients, with the TCL thickness in the range of 2-10 mm and a mean of 4 mm, which was larger than the TCL thickness measured in this study. Therefore, the ultrasound imaging methodology developed in this study may be used to detect the TCL thickness difference between healthy subjects and CTS patients, which may serve as an alternative diagnosis method for CTS.

**SIGNIFICANCE:**

This study provides information on TCL thickness. This information gives insight into the TCL morphology related etiology of CTS and will help develop an ultrasound-based diagnosis method for CTS.

**ACKNOWLEDGEMENT**

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**REFERENCES:**

2. Yamagami et al., No Shinkei Geka 22, 617 (Jul, 1994).