Individual thenar muscle size is affected differently in carpal tunnel syndrome patients

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INTRODUCTION: The thenar muscles include the abductor pollicis brevis (APB), flexor pollicis brevis (FPB), and opponens pollicis (OPP), which are critical for thumb oppositional movement. Due to these muscles typically being innervated by the median nerve, thenar atrophy is often associated with carpal tunnel syndrome (CTS) [1]. Thenar atrophy and dysfunction are typically measured through clinical evaluation or electrodiagnostic tests, which are often subjective, invasive, or lack accuracy [2]. Ultrasound imaging is a non-invasive, safe, and inexpensive imaging modality that has been shown to be a reliable method for thickness measurements of the thenar and hypothenar muscles [3], as well as evaluation of the insertions and origins of the individual muscles [4]. 3D ultrasonography allows for accurate and comprehensive representation of anatomical structures, and has potential to provide objective assessment of thenar atrophy. The purposes of this study were to 1) establish methodology for 3D ultrasonographic reconstruction of the individual thenar muscles and 2) compare APB, FPB, and OPP size between CTS patients and healthy controls.

METHODS: Ten healthy adult women (age 48 ± 17 years) and ten adult women who had been diagnosed with CTS (age 52 ± 13 years) were recruited for this study. An ultrasound transducer (Acuson S2000, Siemens Medical Solutions USA, Mountain View, CA, USA) was rigidly fixed to a six-degree of freedom robot arm (Denso Corp., Kariya, Aichi, Japan) using a custom 3D-printed spacer attachment. The right hand of each subject was splinted in the supine position with the thumb radially abducted and submerged in water. Four series of images were captured of the thenar muscles, each imaging the muscles from a different angle. For each series, the probe was placed in a starting position approximately 1cm above the skin surface and translated linearly 50mm in 1mm steps. After each step, an image was captured and the robot recorded the corresponding probe position. The boundaries of the APB, FPB, and OPP were extracted from the ultrasound images using a custom Python program using thresholding, canny edge detection, and Lucas-Kanade feature tracking. The extracted points were transformed from the 2D image coordinate system to the 3D robot coordinate system using a series of transformation matrices to form 3D point clouds representing each muscle. A 3D triangulated mesh was reconstructed for each muscle from the respective 3D point cloud. The volume, length, and nominal cross-sectional area of each mesh was calculated using Python. Length was defined as the maximum length of the muscle along the major principal axis of the combined muscles. Nominal cross-sectional area was defined as muscle volume divided by muscle length. Statistical analysis was done using R. One-way ANOVA was performed to determine significant differences between volume, length, and nominal cross-sectional area of each muscle between the two groups. A significant difference was indicated at $P < 0.05$.

RESULTS: In some CTS subjects, flattening of the thenar eminence and increased muscle echogenicity were observed on the ultrasound images, and the flattening was reflected in their 3D meshes (Figure 1). APB, FPB, and OPP volume, length, and nominal cross-sectional area for each group are shown in Figure 2. APB and OPP volumes were 29.1% and 30.8% smaller in the CTS group than the control group, respectively. APB and OPP nominal cross-sectional areas were 24.9% and 26.1% smaller in the CTS group than the control group, respectively. There was no significant difference in FPB volume, FPB nominal cross-sectional area, or length of any of the muscles between the two groups.

DISCUSSION: In this study, we used 3D ultrasonographic reconstruction to compare individual thenar muscle volume, length, and nominal cross-sectional area between carpal tunnel syndrome patients and healthy controls. We found that APB and OPP volume and nominal cross-sectional area were significantly smaller in the CTS group than the control group, suggesting that these muscles atrophied due to CTS. The FPB appeared to be unaffected by CTS, most likely due to its deep head usually being innervated by the ulnar nerve, and the variable innervation of its superior head. While previous studies assessing thenar atrophy usually do so through visual inspection, our results suggest this may not be sufficient, as this method does not account for the deep OPP. Consideration of the OPP in addition to the APB can provide a more comprehensive evaluation of thenar atrophy, and quantification of both muscles could aid in CTS diagnosis. Future studies can use 3D ultrasonographic reconstruction to correlate individual thenar muscle size with severity of CTS, as well as assess its potential as a diagnostic tool for CTS.

SIGNIFICANCE/CLINICAL RELEVANCE: 3D ultrasonography provides an objective assessment of thenar atrophy, and our findings suggest that APB and OPP size can aid in predicting CTS.

REFERENCES: [1]Padua et al. *Lancet Neurol*. 2016;15(12):1273-1284. [2]Rubin, Dimberg. *J Clin Neurophysiol Off Publ Am Electroencephalogr Soc*. 2018;35(6):481-484. [3]Misirlioglu, Ozyemisci Taskiran. *Muscle Nerve*. 2018;57(1). [4]Grechenig et al. *J Ultrasound Med*. 2000;19(11):733-741.

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IMAGES:

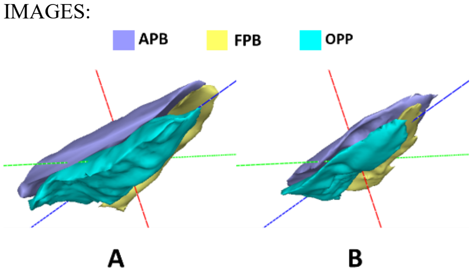

Figure 1. Dorsal view of 3D muscle meshes created for a healthy subject (A) and a CTS subject (B) to scale

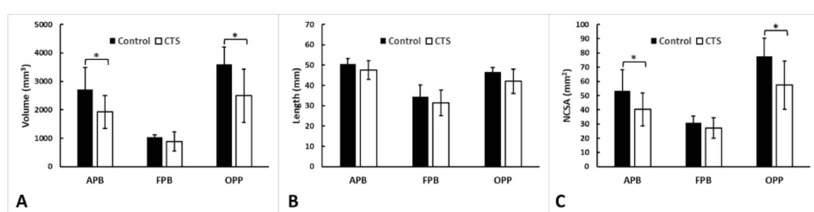

Figure 2. Volume (A), length (B), and nominal cross-sectional area (C) of APB, FPB, and OPP between control and CTS groups