In Situ Needle Insertion to the Transverse Carpal Ligament Using Robot-Assisted Ultrasound

Jocelyn Hawk, Hui Zhang, David Margolis, Zong-Ming Li
Hand Research Laboratory, Departments of Orthopaedic Surgery and Biomedical Engineering, University of Arizona, Tucson, AZ
Email: lizongming@arizona.edu

Disclosures: Jocelyn Hawk (N), Hui Zhang (N), David Margolis (N), Zong-Ming Li (N)

INTRODUCTION: Carpal tunnel release is the most commonly performed surgical procedure for carpal tunnel syndrome and consists of transecting the transverse carpal ligament (TCL). However, this surgery can result in post-operative complications such as pillar pain and hand weakness [1]. A potential alternative treatment for carpal tunnel syndrome is to inject enzymes into the TCL to decrease its stiffness and alleviate pressure off the median nerve. Because the transverse carpal ligament is such a small anatomical target with a thickness ranging from 1.3 to 3.0mm [2], great accuracy is needed in order to avoid damage to surrounding structures. Therefore, the purposes of this study were to 1) determine injection sites on the TCL using 3D reconstructed anatomy, and 2) accurately insert a needle in situ to the TCL using robot assistance.

METHODS: Six fresh-frozen cadaveric hands were used in this study. For imaging of the carpal tunnel, an ultrasound transducer (18L6, Siemens Medical Solutions USA Inc.) was rigidly fixed to the end effector of a 6-DOF robot (VM-G Series 6-axis, DENSO Robotics). Using programmed robot motion, the probe was translated along the length of the carpal tunnel, capturing images in 1mm steps. For each image, the robot recorded the position of the probe in the robot's 3D coordinate system. The pisiform, hamate, trapezium, and scaphoid bones were segmented from the ultrasound images and reconstructed in the robot's 3D coordinate system using a series of transformation matrices. The volar most points of each bone were used to establish an anatomical coordinate system with the origin in the center of the four points, the x-axis pointed proximally, and the y-axis pointed ulnarly. The ulnar edge of the thenar muscle and a portion of the TCL were reconstructed from ultrasound images to determine 5 injection points in the center of the TCL thickness 1mm ulnar to the thenar muscle attachment. For the needle insertion, a 27-gauge needle was rigidly fixed to the end effector of the robot. The needle was inserted into the wrist at a 45-degree angle to the xy-plane of the anatomical coordinate system until its tip reached the targeted injection site. Ultrasound images were taken of the needle inserted into the wrist, and the needle tip was transformed from the 2D image coordinate system to the 3D anatomical coordinate system to determine accuracy.

RESULTS: The needle was inserted into the TCL at 30 targeted injection points across six specimens. For each specimen, the hamate, trapezium, scaphoid, and pisiform bones were successfully reconstructed and used to define an anatomical coordinate system. Ultrasound imaging was used to verify that the needle was inserted into the TCL for each injection (Figure 1) by identifying the volar and dorsal boundary of the TCL and the needle tip. The average error in the x, y, and z direction were 0.37mm, 0.44mm, and 0.47mm, respectively, and the total needle deviation from the intended target was 0.83mm (Figure 2).

DISCUSSION: Methodology was established for robot-assisted needle insertion to the TCL. 3D ultrasonographic reconstruction was used to determine injection sites in the center of the TCL thickness, and robot-assistance allowed for positioning of the needle tip to the intended target with sub-millimeter accuracy. Accuracy is crucial for injection to the TCL to ensure the needle does not interfere with the thenar muscle attachment or pierce through the TCL and damage the carpal tunnel contents. The ulnar edge of the thenar muscle was used to determine the injection points in order to avoid disruption of the biomechanical function of the TCL as an anchor for the thenar muscle. The average total needle deviation from the intended target was sub-millimeter, but could still pose some risk of piercing through the TCL and damaging the carpal tunnel contents. Further refinement would be needed to increase accuracy to a clinically acceptable level.

SIGNIFICANCE/CLINICAL RELEVANCE: With further refinement to increase accuracy, this methodology can be used in the future to deliver collagenase to the TCL to decrease TCL stiffness and alleviate pressure off the median nerve.

REFERENCES: [1] Karl et al., *Orthop Clin North Am. 47(2),* 2016. [2] Pacek et al., *Hand (NY) 5(2),* 2009.

ACKNOWLEDGEMENTS: NIH/NIASM R21AR075402A1

IMAGES:

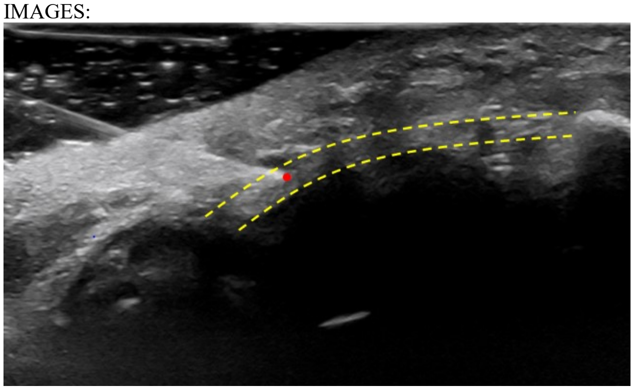

Figure 1. Needle tip (red) inserted into TCL (volar and dorsal boundary outlined in yellow).

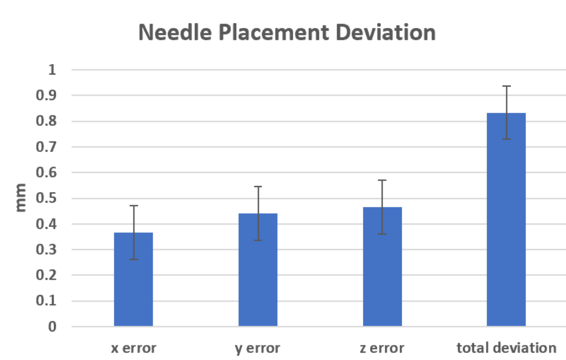

Figure 2. Graph showing the needle placement error in the x, y, and z directions, as well as the total deviation from the intended target.