ULTRASONOGRAPHIC 3D RECONSTRUCTION OF AND ROBOT-ASSISTED INJECTION TO THE TRANSVERSE CARPAL LIGAMENT

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Introduction

Transection of the transverse carpal ligament (TCL) is commonly performed as a surgical treatment of carpal tunnel syndrome. The carpal tunnel release surgery disrupts the anatomy, structure, and biomechanics of the carpal tunnel, causing post-operative complications such as pillar pain and hand weakness [1]. A potential alternative approach for median nerve decompression is to enzymatically regulate TCL stiffness by collagenase injection. One major challenge of injection to a small anatomical target like the TCL is inaccurate needle placement that could cause damage to surrounding structures. The purposes of this study were to develop methods for 1) reconstruction of the TCL using robot-assisted ultrasound imaging and 2) robot-assisted delivery of injection to a targeted location defined by the reconstructed TCL.

Methods

One freshly frozen cadaveric hand (Male, left hand, BMI 20 kg/m^2, age 54 years) was used for the methodological development. The TCL was exposed by removing volar tissues of the hand to allow for attaching echogenic beads. The carpal tunnel was evacuated and pressurized at 24 mmHg with a medical balloon to maintain carpal arch morphology.

An ultrasound probe (18L6, Siemens Medical Solutions) was rigidly attached to the end-effector of a Denso robot arm. The TCL was scanned by translating the ultrasound probe using programmed robot motion (Figure 1A). For data collection, ultrasound images and the corresponding probe position were recorded.

After TCL scanning, eight echogenic beads (Φ = 1.5 mm) were adhered to the TCL, one to each of four TCL bony attachments and four to the TCL midline in the longitudinal direction. Then, the beads together with the TCL were scanned using the same robot motion program.

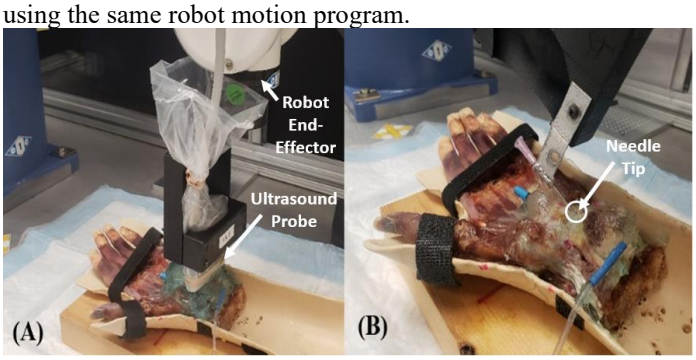

Figure 1: Robot assisted ultrasound scanning (A) and needle injection (B)

To reconstruct the TCL, the ligament was segmented from the 2D images and reconstructed as a 3D point cloud by a series of coordinate system transformations. The TCL point cloud was further separated into volar and dorsal subsets, which were then fit to polynomial functions to reconstruct the surfaces. One injection site was determined by first taking the center point of the four midline beads and then projecting the point 1 mm dorsally inside the TCL thickness.

For injection, an 18-gauge needle was fixed to the end effector of the robot arm, which allowed for programmed needle motion. The needle was positioned at a 45-degree angle and approached along the needle line to deliver the needle tip to the defined injection site in the TCL (Figure 1B). At the end of needle insertion, ultrasound images were manually taken to determine injection accuracy by measuring the distance between the needle tip and injection target.

Results and Discussion

Ultrasound images were automatically segmented for the TCL based on its echogenic pattern for collection of point clouds and reconstruction of TCL surfaces (Figure 2). TCL thicknesses (calculated in the center 10 × 10 mm region of the TCL) ranged from 1.81 mm to 2.41 mm, with an average of 2.04 (± 0.15) mm. The distance between the needle tip location and target injection site was 0.68 mm, as measured on the manually collected 2D ultrasound image.

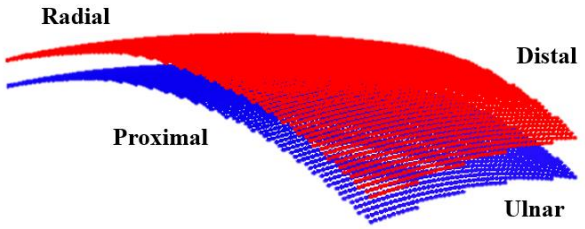

Figure 2: Reconstructed volar and dorsal surfaces of TCL

With the assistance of a robot arm affixed with an ultrasound probe, positioning information was used to convert the TCL region of interest from 2D images into a 3D point cloud and an anatomical construct. TCL thickness determined from the reconstructed volar and dorsal surfaces of the ligament agreed well with previous studies [2, 3]. Using the reconstructed anatomy, a point was defined for injection target, which was used to program the robot and needle system motion to accurately deliver injection. This study established a workflow to obtain patient-specific anatomy for accurate delivery of collagenase to the TCL.

Significance

Our established methodology can be used in the future to deliver collagenase to the TCL, potentially decreasing TCL stiffness to alleviate pressure in median compression neuropathy.

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References

[1] Fuss & Wagner. Clin Anat. (1996). 9(2):100-8. [2] Pacek et al., Hand (2010). 5(2): 135-40. [3] Shen & Li. Ultrasound Med. Biol. (2012). 38(6)