Three-Dimensional MRI Assessment of Median Nerve Variability in the Carpal Tunnel

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Introduction: Carpal tunnel syndrome (CTS) describes a complex of symptoms arising from chronic compression of the median nerve where it passes through the narrow tunnel between the flexor retinaculum and the carpal bones. Associated symptoms include numbness, and tingling in the nerve's distribution within the hand, progressing to pain and loss of hand strength and dexterity. Compression of the median nerve causing chronic insult or ischemia is widely recognized as the proximate cause of CTS symptoms. The source of this insult is generally thought to arise from fluid pressure and from impingement/compaction by neighboring anatomic structures -especially the digital flexor tendons- but the underlying mechanisms remain unclear.

MRI can generate exquisite soft tissue contrast and is often used in the assessment of CTS, but its primary application within that context has been to rule out other potential causes of symptoms. Some previous MRI work has evaluated tendon and nerve morphology and geometry, primarily in cadaveric specimens [1-3]. However, an important consideration in the evaluation of the biomechanics of the tendons and nerve is the normal range of variation in their conformation and relative arrangement within the tunnel under otherwise equivalent external conditions. Knowledge of these variations is necessary for evaluation of biomechanical models of nerve and tendon interactions, as well as for assessment of abnormal changes in CTS-afflicted subjects. The purpose of this study was to investigate the range of median nerve deformation and position within the tunnel over a series of imaging evaluations and following a set of specific pre-scan activities.

Methods: Three subjects (two female, one male, ages 29, 23, and 23) were scanned over multiple sessions (three days, one or two sessions on each day) on a Siemens TIM Trio 3T scanner. Subjects were positioned head-first prone in the scanner. Plastic splints formed at angles of 0° (neutral position) and 35° of flexion held the wrist in the desired position, and a transmit-receive extremity coil was used to accommodate variations in wrist pose. Volumetric data were acquired with a 3D Dual Echo Steady State (DESS) sequence over the length of the wrist (centered on the tunnel) within the coil (TR/TE = 13/4.3ms, 25° flip angle). Resolution was 0.4mm × 0.4mm × 1.0mm (192 × 144 × 72 matrix), with a scan duration of 90 seconds per volume.

Each imaging session generated four volume data sets. An initial volume scan was acquired with the wrist in a neutral position, followed immediately by the acquisition of a second volume with the wrist flexed to 35°. Subjects then performed ten minutes of normal activities (typing, texting, lifting) prior to a series of scripted hand motions to "precondition" the tendon/nerve arrangement into a potentially more controlled state. Volume scans were then acquired for the wrist again in neutral and in 35° flexion. On Day 2, the order of scans was reversed so the flexed position was imaged before the neutral position. On days with multiple imaging sessions, the splinting order was reversed from that of the initial session, with 30 minutes of recovery time between sessions. A total of 60 volume scans were obtained over the course of the study.

The resulting 3D volumes were processed using a semi-automated algorithm developed in MATLAB to segment anatomic structure boundaries and to follow the individual tendon and median nerve geometries and trajectories throughout the volume. For each volume, the median nerve was characterized by its aspect ratio (major axis/minor axis), orientation (angle of its major axis relative to that of the tunnel), and location (distance and angle from centroid and major axis of the tunnel). The variation in anatomic location of the nerve for a set of imaging and preconditioning conditions was described by a *radius of variability*, defined as the radius of the minimum enclosing circle of the centroid of the nerve locations observed in each volume. All measures were taken from axial slices at the level of the hook of the hamate.

Results: Significant differences were found in comparisons of median nerve aspect ratio ($p < 0.01$) and orientation ($p < 0.05$) between neutral and flexed positions for all three subjects. Figure 1 summarizes the radius of variability for the nerve position with versus without the application of preconditioning exercises, demonstrating that preconditioning afforded no improvement in nerve position consistency. Figure 2 shows slices and 3D reconstructions of tendon and median nerve positions within the tunnel at two sessions for the neutral position, demonstrating the migration and deformation of tendons and nerve under otherwise identical conditions. Of particular note are changes in the adjacency of the tendons, with different tendons impinging on the nerve in each situation. Figure 3 shows images and 3D reconstructions of the pathways for a wrist in 35° flexion at two sessions. Again, the change in nerve position and deformation and the relative arrangement of the tendons is readily appreciated. As a point of comparison, the average diameter of the tendons is nominally 3.25 mm, and the average nominal separation of adjacent tendons is 0.77 mm, implying that typical nerve excursions involve substantial biomechanical encounters among (abutments and extrusions between) "large" nearby tendons.

Discussion: The results of this study demonstrate that the median nerve, along with its relationship to surrounding tendons of the carpal tunnel, experiences complex motion and deformation in both neutral and flexed wrist positions. The use of preconditioning exercises to standardize the structure arrangement within the tunnel does not yield a reduction in the variability of the nerve pathways. An understanding of the normal range of variability of carpal tunnel contents configuration over a range of natural wrist positions is essential to developing informative biomechanical models to evaluate the median nerve stresses and strains present in healthy and CTS-afflicted wrists.

References: [1] Bower JA et al., *Clin Biomech* 21:816, 2006.
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[3] Pacek CK et al., *Hand*, doi:10.1007/s11552-009-9220-9, 2009.

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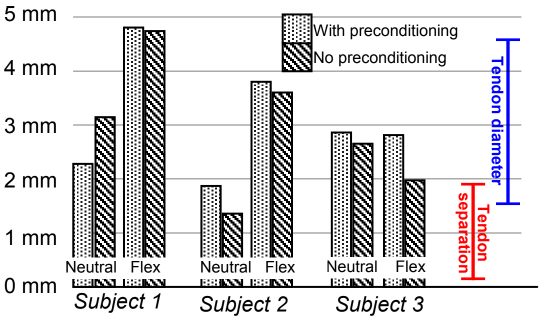

Figure 1: Radius of variability of nerve location with and without preconditioning for neutral and flex positions in all three subjects. Preconditioning did not reduce overall variability in nerve position. For reference, colored bars indicate tendon diameter (blue – average 3.25 mm) and separation (red – average 0.77 mm).

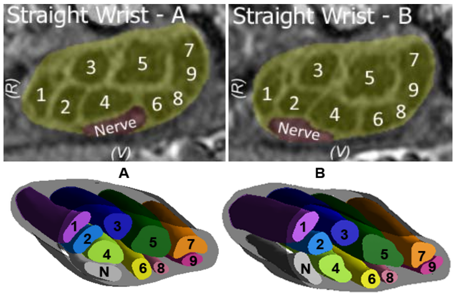

Figure 2: Identification of tunnel, nerve, and tendons on source images (top) and in 3D reconstructions (bottom) of a neutrally positioned right wrist imaged during two separate sessions (R = radial, V = volar).

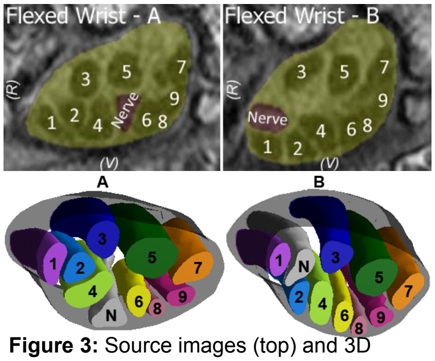

Figure 3: Source images (top) and 3D reconstruction (bottom) from two separate sessions depicting the tunnel, nerve, and tendons while the wrist is in 35° flexion.