Carpal Arch Width Narrowing and Creep In Vivo
Scott A. Galey, Tamara L. Marquardt, Joseph N. Gabra, Zong-Ming Li.
Cleveland Clinic, Cleveland, OH, USA.

Disclosures:
S.A. Galey: None. T.L. Marquardt: None. J.N. Gabra: None. Z. Li: None.

Introduction: The wrist is comprised of eight carpal bones, held together by a complex network of interosseous ligaments. Previous studies have demonstrated relative carpal bone movement during wrist motion and external force application (1-5). Narrowing of the carpal arch width (CAW), the distance between the hook of the hamate and the ridge of trapezium, has been shown to increase the cross sectional area of the carpal tunnel (5-7). In a cadaveric study, CAW narrowing as a result of transverse force application was correlated with an increase in carpal arch area (6). However, the use of a non-invasive, transverse force to narrow the CAW has not been studied in vivo. Additionally, the time-dependent effects of a constant, transverse force on CAW narrowing have not been examined, even though ligaments are known be viscoelastic in nature (8-10) and creep behavior has been demonstrated for other bone-ligament structures (11). Therefore, the purposes of this study were to investigate the change in the CAW as a non-invasive, transverse force was applied across the wrist and to determine the creep-behavior of the wrist under prolonged transverse compression. It was hypothesized that the prolonged application of force across the carpus would narrow the carpal tunnel structure in a viscoelastic manner.

Methods: Six female subjects (age 22 ± 2 years), with no history of musculoskeletal injury or disease to the right hand or wrist, were recruited to participate in this study. Each subject placed their right hand in a supinated position within a splint that immobilized their digits in full extension. An ultrasound probe was positioned over the volar surface of the wrist to image the carpal tunnel at the hamate-trapezium level. A custom apparatus was designed to apply a transverse, compressive force across the carpal tunnel at the hamate-trapezium level (Fig. 1). The force application was achieved by an air compressor coupled with cylindrical end effectors (Ø = 25 mm). During the experiment, a force of 15 N was applied for 5 minutes while an ultrasound video was recorded to capture carpal tunnel deformation. After collection, a custom MATLAB program was used to extract one frame from every 3 seconds of video. These images were analyzed by a custom LabVIEW program to track the coordinates of hook of the hamate and the medial ridge of the trapezium. These coordinates were used to calculate the CAW (Fig 2). The creep function of the CAW over time was fit with the Standard Linear Solid (SLS) viscoelastic model. The model consists of a spring (E1) in parallel with a Maxwell element (a spring (E2) in series with a dashpot (η)). According to the SLS model, the percent change of CAW (λ) over time is expressed as: λ(t) = λ0(1-Ae-t/τ), where λ0 is the initial percent change of CAW, A=E2/(E1+E2), and B = E2E1/(η(E1 + E2)).

Results: Over the five minutes of force application, the mean CAW progressively narrowed as time increased (Fig. 3). Significant narrowing from the baseline CAW was observed after 1, 2, 3, 4, and 5 minutes of force application (p < 0.05). The amounts of CAW narrowing were 2.23% (SD 1.05%), 2.86% (SD 1.46%), 3.20% (SD 1.7%), 3.35% (SD 1.48%), and 4.06% (SD 1.97%) from baseline, at times of 1, 2, 3, 4, and 5 minutes, respectively. The best-fit of the viscoelastic model to the average CAW data produced a curve with an R2 value of 0.898 (Fig 3). The values for the springs and dashpot in the SLS model fit were E1=0.645 x 10^6 N/m, E2=1.10 x 10^6 N/m, η =113 x 10^6 Ns/m.

Discussion: In this study ultrasound was used to monitor the real time structural changes of the carpal tunnel in response to a force applied in the transverse direction at the hamate-trapezium level. The carpal tunnel demonstrated a trend of continued CAW narrowing over the five minutes of force application. This suggests that the wrist is a deformable and viscoelastic structure, and that the time of force application should be taken into account when observing carpal deformations at the level of the CAW. To extrapolate the viscoelastic properties of the wrist under prolonged compression, a model of viscoelasticity was fit to the CAW data. The model captured the creep behavior of the wrist. The equation fit to the data can be used to extrapolate the long term behavior of the carpal bones under a compressive, transverse force. The model predicts that the CAW can be ultimately narrowed by 4.7% under the current loading condition. At time 300 s, the CAW achieved 78% of its predicted maximal narrowing. The model also predicts that it takes 510 s of force application for the CAW to achieve 90% of its maximal narrowing. Future studies can further investigate the application of different force magnitudes and durations to optimize comfort and amount of CAW narrowing. Due to the time it took for the air compressor to reach the target force, data at and beyond the 12 s time point was used for fitting of the viscoelastic model assuming an instantaneous force application of 15 N. Therefore, the modeling has the limitation of not accounting for creep during the force ramping period within the initial 12 s.

Significance: CAW narrowing may increase the cross sectional area of the carpal tunnel (6, 7). This strategy could prove useful in decreasing intra-tunnel pressure and providing pressure relief on the median nerve in carpal tunnel syndrome patients. Knowledge of the viscoelastic properties of the carpus can help optimize strategies for carpal tunnel manipulation in achieving the best therapeautic effect.

Acknowledgments: NIH R21AR062753
References:
11. Toosizadeh N, Nussbaum MA, Bazrgari B, Madigan ML. PloS ONE.

Fig 1. In vivo ultrasound imaging while the wrist was compressed to narrow the carpal arch width.
Fig 2. An ultrasound image representative of the tracking and analysis performed. The hook of the hamate and ridge of the trapezium were tracked over the time of force application (red boxes). The CAW (yellow line) was measured as the distance between these two bony landmarks.

Fig 3. Mean (n=6) CAW narrowing over the five minutes of compression and the SLS model fit curve (R²=.898).