A Parabolic Modeling of Area Expansion of the Carpal Arch

David Jordan[1], Hui Zhang[1], John Elfar[2], C. Kent Kwoh[3], Zong-Ming Li[1,2,3]
[1]Hand Research Laboratory, Departments of Orthopaedic Surgery, Tucson, Arizona; [2]Departments of Orthopaedic Surgery, Tucson, Arizona; [3]Arthritis Center, University of Arizona, Tucson, Arizona
Email: lizongming@arizona.edu

Disclosures: Jordan (N), Zhang (N), Elfar (N), Kwoh (N), Li (N)

INTRODUCTION: Carpal tunnel syndrome is a common compression neuropathy of the median nerve [1]. Nonsurgical treatment has been shown to be achievable through augmentation of the carpal arch, leading to increases in tunnel space and decreases in median nerve compression [2]. The space increase can be accomplished by compressing the distance between the distal insertion sites of the transverse carpal ligament, at the hook of hamate and ridge of trapezium, using radial-ulnar wrist compression [3]; or through elongating the ligament [4]. Differences in patient morphology could diversify the magnitude of the space increase. Therefore, it is critical to identify how the gains in arch area are affected by the initial arch morphology to aid in the optimization and development of patient-specific treatment guidelines. The purpose of this study was to simulate the gains of carpal arch space in response to arch width narrowing, arch length elongation, and combined arch width narrowing and arch length elongation, for different variations in arch morphology, specified as differing magnitudes of carpal arch height. The hypothesis was that the gain in arch space would be less for greater initial arch heights.

METHODS: The carpal arch was modeled as a horizontal parabola (Figure 1). H represented the carpal arch height and W represented the carpal arch width. The carpal arch area was defined as the area underneath the arch. The arch length was defined as the length of the parabola. Three simulations were performed for the modeling of the arch space increase. The first simulation involved narrowing the arch width while keeping the arch length constant. The initial arch width was set to 20 mm. The initial arch height was set to 0 mm. The arch width was decreased by 2 mm in steps of 0.05 mm. The second simulation involved elongating the arch length, while keeping the arch width constant. The constant arch width was set to 20 mm. The arch length was increased by 2 mm in 0.05 mm increments. The third simulation involved simultaneously narrowing the arch width and elongating the arch length. The arch width was decreased by 2 mm in steps of 0.05 mm. The arch length was increased by 2 mm in increments of 0.05 mm at each increment of arch width decrease. Each simulation was conducted for initial arch heights of 0, 2, and 4 mm. Arch area and arch height were calculated for each incremental change in the respective simulations.

RESULTS: The formation of the carpal arch increased for each simulation (Figure 2). The formation of the arch was different for the initial arch heights of 0, 2 and 4 mm. There was a nonlinear increase in the carpal arch height and area with the arch width narrowing (Figure 3a) and the arch length elongation (Figure 3b). The gain in arch area and height decreased as the initial arch height was increased. For the arch width narrowing, the gain in arch height and area was 3.8 mm and 46.2 mm^2, for 0 mm of initial arch height; and was reduced to 1.6 mm and 14.3 mm^2 when the arch height was increased to 4 mm. For the arch length elongation, the gain was reduced from 4 mm of arch height and 53.8 mm^2 of arch area, when the arch height was 0 mm; to 1.9 mm of arch height and 25.3 mm^2 of arch area, when the arch height was increased to 4 mm. For the simultaneous arch width narrowing and elongation, the gain was reduced from 5.7 mm (Figure 3c) of arch height and 67.9 mm^2 of arch area (Figure 3d), when he arch height was 0 mm; to 3.2 mm of arch height and 32.7 mm^2 of arch area, when the arch height was increased to 4 mm.

DISCUSSION: This study simulated the morphological changes of the carpal arch with varying magnitudes of initial arch height, seeking to identify how initial arch morphology affects the efficacy of carpal arch space augmentation. It was shown that, for larger initial arch heights, the gains of arch area is lessened, showing that patient specific morphology is critically relevant for carpal arch space augmentation and can provide guidelines for determining the augmentation necessary for a specific degree of area increase. The in-vivo application of the augmentation is an important consideration. The decrease in arch width to increase arch area has been demonstrated in previous studies involving cadaveric and in-vivo implementation in individuals with carpal tunnel syndrome [5]. The elongation of the arch length requires further experimentation to identify feasible means of in vivo application, which could similarly involve the use of physical external forces to the wrist.

SIGNIFICANCE/CLINICAL RELEVANCE: This work provides a foundation for patient-specific modeling of the carpal tunnel, whereby the initial arch height of the patient can be used to predict the amount of augmentation necessary to increase the arch area by a sufficient amount for median nerve decompression.

REFERENCES: [1] Pauda et al., Lancet Neurol, 15, 2016. [2] Li et al., Clin Biomech, 28, 2013. [3] Marquardt et al., Clin Biomech, 30, 2015. [4] Li et al., J Biomech Eng, 131, 2009. [5] Marquardt et al., J Orthop Res, 37, 2016.

ACKNOWLEDGEMENTS: R01AR068278

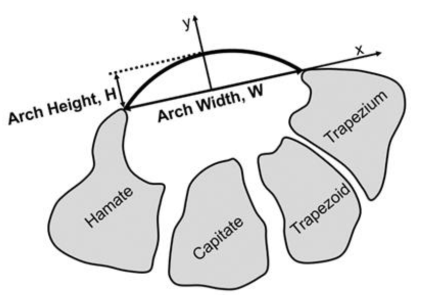

Figure 1: Geometric model of the carpal arch at the distal tunnel level.

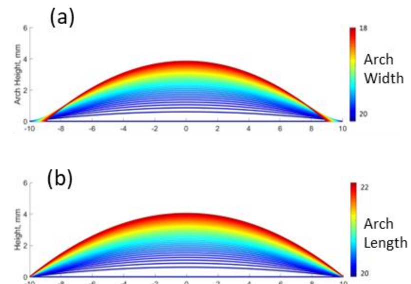

Figure 2: Carpal arch formation for an initial arch height of 0 mm for (a) decreasing arch width with constant arch length, (b) increasing arch length with constant arch width.

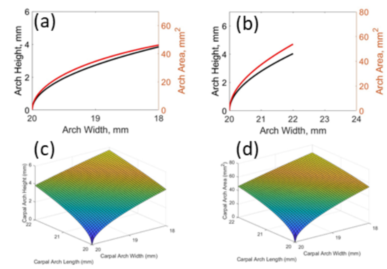

Figure 3: Increase in arch area with initial arch height of 0 mm for (a) arch width narrowing, (b) arch length elongation and (c) simultaneous arch width narrowing and arch length elongation. Increase in arch height for (a) arch width narrowing, (b) arch length elongation and (d) simultaneous arch width narrowing and arch length elongation.