Stepwise Releases of the Flexor Retinaculum Affect Carpal Tunnel Structural Properties

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Introduction: The flexor retinaculum (FR) at the palmar roof of the carpal tunnel consists of three portions, specifically the distal aponeurosis, transverse carpal ligament (TCL), and antebrachial fascia [1]. Carpal tunnel release by transecting the FR is a standard surgical treatment for carpal tunnel syndrome. Incomplete release of the FR may pose residual mechanical constraints on the carpal tunnel and has been considered to be a cause of inadequate decompression of the median nerve. Therefore, the current study was motivated by the clinical implication of incomplete release of the FR, with the purpose of understanding the influence of incremental releases of the FR on the structural properties of the carpal tunnel. Specifically, the normalized carpal arch widths under loading were investigated to quantify the structural properties of the carpal tunnel. We hypothesized that the carpal arch width would become more compliant as the FR was progressively released.

Methods: Nine fresh frozen cadaver hands (five male and four female) with a mean age of 50 ± 11 years were used in this study. All specimens were screened through medical record and x-ray examination to exclude those with musculoskeletal or traumatic injuries, as well as arthritic changes in the hand and wrist. For each specimen, dissection was performed to expose the FR by removing the skin and palmar fascia. After the dissection, the three portions of the FR were identified. The TCL portion was defined by the dense transverse fibers inserting into the hook of hamate, trapezium, pisiform and scaphoid. The distal aponeurosis was identified as the tissue between the thenar and hypothenar muscles that overlaid the distal region of the TCL. The antebrachial fascia was designated by the membranous tissue contiguous to the TCL at the proximal part of the FR. A cortex screw (Synthes Inc, West Chester, PA), 2.0 mm in diameter, was drilled into each of the carpal bones at the position of TCL insertion until the screw head was flush with the bony surface. A thin wire was attached to each screw head for force application. A custom experimental apparatus was used to configure and stabilize each specimen at 20° of wrist extension. The apparatus included four pulleys that were adjustable in the horizontal and vertical directions for force alignment. Two pairs of 10 N forces were applied in the outward direction. One force pair was aligned along the line connecting the hamate and trapezium at the distal level, and the other was aligned along the line connecting the pisiform and scaphoid at the proximal level (Figure 1). During carpal bone loading, the coordinates at the center of each screw head surface were digitized using a 3D digitizer (MicroScribe, San Jose, CA). In addition to the intact FR condition, the digitization was performed at each of the following incremental releases: (1) 25% TCL, (2) 50% TCL, (3) 75% TCL, (4) complete TCL, (5) complete TCL and distal aponeurosis and (6) complete FR (Figure 2). Carpal arch widths were calculated at the distal level between the hamate and trapezium, and at the proximal level between the pisiform and scaphoid. The distal and proximal carpal arch widths were then normalized with respect to their respective baseline widths under the intact FR during the loading. Two-way repeated measures ANOVAs (6×2) were performed to investigate the effects of the FR release steps and carpal tunnel levels on the normalized carpal arch widths (α = 0.05).
**Results:** The carpal arch width was 29.2 ± 3.6 mm and 43.8 ± 4.7 mm at the distal and proximal levels, respectively, when the intact FR was subjected to the outward loading. After the complete release of the FR, the carpal arch width with loading increased 1.7 ± 0.4 mm at the distal and 3.8 ± 1.3 mm at the proximal level, in comparison to the intact FR condition with loading. Statistical analyses indicated that both the FR release steps (p < 0.05) and carpal tunnel levels had significant effects on the normalized carpal arch widths (p < 0.001). There was also significant interaction between these two factors (p < 0.001). The normalized carpal arch widths increased significantly as the FR was progressively released (p < 0.001). Post-hoc comparisons for each carpal tunnel level revealed that the complete TCL release, in comparison to the 75% TCL release, significantly increased the normalized carpal arch widths at both the distal and proximal levels (p < 0.001). Furthermore, release of the distal aponeurosis, in comparison to the complete TCL release, significantly increased the normalized carpal arch width at the distal level. The normalized carpal arch widths (p < 0.001) were significantly smaller at the distal tunnel in comparison to the proximal tunnel after each step of FR releases under carpal bone loading, which agree with previous studies showing that the carpal tunnel structure at the distal level was more rigid than at the proximal level [2]. It has been shown that the median nerve is prone to pathological compression at the distal tunnel that has local stenosis and rigidity. At the distal level, releases up to 75% of the TCL had a relatively small effect on the changes of carpal arch width, but release of the remaining 25% of the TCL provided a large increase in the stretchability. Further release of the distal aponeurosis continued to make the distal tunnel more stretchable. These results corroborate with the clinical importance of complete release of the TCL and the distal aponeurosis in improving the compliant nature of the carpal tunnel at the distal level that is critical in decompressing the median nerve.

**Discussion:** We confirmed our hypothesis that the carpal tunnel became increasingly more compliant with progressive releases of the FR. The more compliant carpal tunnel structural properties were evidenced by the increased stretchability of the carpal arch width at both the distal and proximal tunnel levels with incremental FR releases. Our results also indicated that the normalized carpal arch width were smaller at the distal tunnel in comparison to the proximal tunnel after each step of FR releases under carpal bone loading, which agree with previous studies showing that the carpal tunnel structure at the distal level was more rigid than at the proximal level [2]. It has been shown that the median nerve is prone to pathological compression at the distal tunnel that has local stenosis and rigidity. At the distal level, releases up to 75% of the TCL had a relatively small effect on the changes of carpal arch width, but release of the remaining 25% of the TCL provided a large increase in the stretchability. Further release of the distal aponeurosis continued to make the distal tunnel more stretchable. These results corroborate with the clinical importance of complete release of the TCL and the distal aponeurosis in improving the compliant nature of the carpal tunnel at the distal level that is critical in decompressing the median nerve.

**Significance:** Our results demonstrated the importance of complete releasing the FR to decompress the median nerve in patients with carpal tunnel syndrome. Our results has shown that incomplete release of the TCL and distal aponeurosis is particularly restraining for the relatively inflexible distal carpal tunnel and suggest the critical need of complete release of the FR in improving the flexibility of the tunnel for median nerve decompression.
Figure 1: Illustration of outward application to the carpal bones at the TCL insertion sites.

Figure 2: Schematic depiction of the stepwise release of the FR: (1) 25% TCL, (2) 50% TCL, (3) 75% TCL, (4) complete TCL, (5) complete TCL and distal aponeurosis, and (6) complete FR.
Figure 3: Normalized carpal arch widths under loading after stepwise FR releases

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