Carpal Tunnel Release: Do We Understand the Biomechanical Consequences?

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J Wrist Surg 2014;3:235–238.

Abstract

Keywords

- carpal tunnel release
- transverse carpal ligament
- carpal canal
- biomechanics
- pillar pain

Carpal tunnel release is a very common procedure performed in the United States. While the procedure is often curative, some patients experience postoperative scar sensitivity, pillar pain, grip weakness, or recurrent median nerve symptoms. Release of the carpal tunnel has an effect on carpal anatomy and biomechanics, including increases in carpal arch width and carpal tunnel volume and changes in muscle and tendon mechanics. Our understanding of how these biomechanical changes contribute to postoperative symptoms is still evolving. We review the relevant morphometric and biomechanical changes that occur following release of the transverse carpal ligament.

Carpal tunnel syndrome (CTS) is a common condition, with a reported incidence of 1–4% in the United States.^{1,2} Consequently, carpal tunnel release (CTR) is performed millions of times per year. While the majority of patients have relief of symptoms postoperatively, there remain a significant number of patients who experience disabling postoperative symptoms such as scar sensitivity, pillar pain, or grip weakness. These effects may be due to biomechanical alterations caused by CTR, a phenomenon that we are still seeking to understand fully.^{3–5} An appreciation of the biomechanical changes caused by the release of the transverse carpal ligament (TCL) may improve the overall management of our patients.

Anatomy and Function

One cannot hope to understand fully the biomechanics of the TCL and its release without a detailed knowledge of anatomy, though that is not the intended scope of this article. To review briefly however, the TCL forms the “roof” of the carpal tunnel. Nine tendons (the flexor digitorum superficialis and flexor digitorum profundus to each of the four fingers, and the flexor pollicis longus to the thumb) and the median nerve classically travel deep to it. Proximally, the TCL attaches to the scaphoid tuberosity and pisiform; distally it attaches to the hook of the hamate and the ridge of the trapezium. It is continuous

proximally with the antebrachial fascia and distally with an aponeurosis between the thenar and hypothenar muscles. The TCL is roughly 10 times thicker than the antebrachial fascia⁶ and has broader insertions distally than proximally.⁷ In the coronal plane, the carpal tunnel has an hourglass shape, with the narrowest part at the level of the hook of the hamate. The average width of the carpal tunnel is 25 ± 1.2 mm proximally, 20 ± 1.2 mm at the hook, and 25 ± 1.5 mm at its distal extent.⁶ The TCL serves at least three primary functions: to provide transverse stability to the carpus; to anchor the thenar and hypothenar muscles; and to act as a pulley for the extrinsic flexor tendons.^{8,9} Understanding the anatomy and function will guide our understanding of the biomechanical effects of TCL release.

Carpal Arch Morphometrics

Carpal Arch Width

The first carpal tunnel release is believed to have been performed by Herbert Galloway in 1924.¹⁰ Since that time there have been several described techniques for TCL release, from open to mini-open and endoscopic, as well as single- and multiple-incision techniques.¹¹ Whether performed using open or endoscopic techniques, however, the goal of the operation is the same: complete decompression of the carpal tunnel by transection of the TCL. Division of the TCL typically

leads to an increase in carpal arch width and carpal tunnel volume, thus lowering the pressure within the carpal tunnel and potentially decreasing carpal tunnel symptoms. Carpal arch width is typically measured at its narrowest location, namely the distance from the hook to the trapezium. Tanabe and Okutsu reported that in a cadaveric study, endoscopic release of only the TCL caused a TCL diastasis of only 1.3 ± 0.2 mm but, when combined with release of the distal aponeurosis between the thenar and hypothenar muscles, caused a TCL diastasis of more than 6.6 ± 0.2 mm.¹² In a related clinical study, Garcia-Elias et al found that the distance between the hook and trapezium increased an average of 11% when the TCL was released by open means, and this increase was not significantly different whether the wrist was flexed or extended.¹³ A considerable difference between these two studies, however, is the role of the superficial subcutaneous tissue and skin itself. In the Tanabe and Okutsu study, the superficial tissues were removed¹²; in the Garcia-Elias et al study, the diastasis was measured with Kirschner wires (K-wires) that pierced the skin (and were potentially tethered).¹³ As such, the role of the superficial tissue in stabilizing the carpus is unclear.

Several other clinical studies have examined the morphologic changes associated with CTR. Gartsman et al did a retrospective review of patients who had undergone open CTR an average of 19.7 months prior and found that 94% of patients still had an average of 13.6% (2.9 mm) carpal arch widening on carpal tunnel radiographs.³ The carpal tunnel radiographs taken in their study required that the wrist to be held in 50° extension to obtain the radiographs; therefore, it is unclear what the widening would be in a more neutral biomechanical position, as the magnitude of carpal arch widening may differ depending on the position of the wrist.⁵ Using the same assessment technique, Viegas et al found a 7% (1.7 mm) increase in carpal arch width following endoscopic CTR, with very few patients having a change of more than 10%.¹⁴ Gartsman et al found that with an increase in carpal arch width more than 20% there was a statistically significant decrease in grip strength of 26%; there was no statistically significant change in grip strength with a carpal arch width change of less than 10%.³ As such, some may feel that since endoscopic release may result in less carpal arch widening, this is evidence that supports endoscopic CTR techniques versus open techniques. Gartsman et al found that increased widening did not necessarily correlate with the incidence of postoperative wrist pain, however.³

Carpal Tunnel Volume

There have been several studies that have examined carpal tunnel volume as a metric of carpal tunnel decompression. Roger et al used computed tomography (CT) to perform a morphometric analysis of the carpus following transection of the TCL.¹⁵ They found an increased carpal canal caliber throughout the length of the carpal canal after transection of the TCL, regardless of the position of the wrist. Schmitt et al similarly noted that carpal tunnel volume increased following CTR and attributed this to a volar soft tissue prolapse in 90% of cases and to an increase in carpal arch cross-sectional area in

10%.¹⁶ In both studies, the authors felt that these morphometric changes could explain the decreased pressure within the carpal tunnel and the resultant improvement of symptoms following CTR.

In 1987, Richman et al showed that magnetic resonance imaging (MRI) could reliably measure carpal tunnel volumes.¹⁷ They later showed that there was a statistically significant increase in carpal tunnel volumes following open carpal tunnel release (from 6.3 ± 1.0 mL to 7.8 ± 1.5 mL after surgery) and that these volume differences persisted 8 months postoperatively. This increase in volume appeared to result more from a change to a more circular or convex volar aspect of the carpal tunnel than from increased carpal arch width; that is, the volar-dorsal change in the carpal tunnel dimensions was more significant than the radial-ulnar.¹⁸ They found that following release of the TCL, the median nerve displaced an average of 3.5 ± 1.9 mm volarly due to the change in carpal tunnel shape. The carpal arch width increased by $6.3 \pm 4.6\%$; however, this difference did not persist when reassessed 8 months postoperatively.¹⁸ This suggests that there may be some recoil in the carpal arch, though it is not clear whether measuring was appropriately controlled by using exactly the same locations used for the previous measurements.

AblOVE et al and Kato et al utilized MRI to study the morphologic changes in the carpal tunnel following endoscopic CTR.^{19,20} Like Richman et al, AblOVE et al found that the volume of the carpal tunnel changed from 6.1 ± 2.2 mL to 7.5 ± 2.5 mL following endoscopic CTR.^{18,19} Also like Richman et al, Kato et al observed a significant increase in the volar size of the carpal tunnel.^{18,20} Specifically, they observed that the volar cross-sectional area increased 3.6 times (from 32 ± 8 mm² before release to 114 ± 13 mm² postoperatively) while the dorsal cross-sectional area increased by only ~3% (from 200 ± 20 mm² to 206 ± 30 mm²). They concluded from these data that the change in the carpal tunnel volar-dorsal dimension due to diastasis of the TCL was most responsible for the change in carpal tunnel volume and that widening of the carpal arch itself did not play a major role in increasing the volume of the carpal tunnel after endoscopic carpal tunnel release.²⁰ Also like Richman et al, they found that there was no statistically significant difference in carpal arch width 7 months postoperatively.^{18,20}

While carpal tunnel release is often curative for carpal tunnel syndrome, some patients experience postoperative scar sensitivity, pillar pain, and/or grip weakness. While the incidence of pillar pain (i.e., pain at the bases of the thenar or hypothenar eminences) is between 6% and 36% regardless of the surgical technique, the etiology of pillar pain remains unknown.^{4,5} Due to the morphologic changes that occur as a result of TCL release, it is possible that the etiologies of these postoperative complications are interconnected. Ludlow et al outlined four potential etiologies of pillar pain: structural alteration of the carpal arch; ligamentous or muscular; neurogenic; and edematous.⁴ We review the theories that apply to biomechanical and kinematic changes.

Biomechanical Consequences

Structural Alterations

As discussed above, when the TCL is cut, the transverse arch of the hand flattens slightly, allowing the radial side of the hand to fall away from the ulnar side. While some studies have shown that there may be some recoil in the carpus,^{18,20} they were not able to comment on any dynamic changes that may be observed or felt with physiologic loading. Guo et al used a finite element model to study the effects of CTR on carpal behavior under a simulated grasp. They found that following release of the TCL, the carpal bones deviated radially. They also observed changes in the maximum contact stresses in the midcarpal joints, most notably the scaphotrapezotrapezoid and triquetrohamate joints.²¹ Seradge and Seradge felt that the alterations resulting from TCL release would particularly put stress on the pisotriquetral joint in addition to other intercarpal joints.⁸

Garcias-Elias et al analyzed the biomechanical characteristics of cadaveric wrists and found that release of the TCL decreased the stiffness of the transverse carpal arch 7.5%.²² The study group corroborated this data with an analytical model with simulated dorsal-volar compression, in which they again showed a decrease of transverse carpal arch stiffness of 7.8% with release of the TCL.⁹ They found that it was actually the intercarpal ligaments that played the critical role in carpal arch stability and commented that if the TCL was released in the setting of a single intercarpal ligament insufficiency, then gross instability of the carpal arch could occur. As Gartsman et al noted that there was a group of patients who experienced increased (viz. more than 20%) carpal arch widening following CTR, perhaps there is a subset of patients at greater risk for symptomatic biomechanical changes.³ Although the exact biomechanical implications are poorly understood, it is reasonable to conclude that these changes are not inconsequential and could contribute to pillar pain and decreased grip strength.

Muscle and Tendon Effects

The TCL plays important roles for the thenar and hypothenar muscles as well as the extrinsic digital flexors. The normal hypothenar and thenar muscular origins may be relaxed following CTR, causing altered mechanics of opposition and pinch.²³ In a cadaveric study, Fuss and Wagner noted significant muscle shortening and loss of pull after bisection of the TCL.²⁴ Compared with normal resting length, the length of the superficial head of the flexor pollicis brevis decreased 25%, the ulnar part of the abductor pollicis brevis decreased 20%, the opponens pollicis decreased 20%, and the opponens digiti minimi decreased 10%. They concluded that this muscular shortening would significantly alter hand biomechanics, leading to decreased strength.²⁴

Another muscular biomechanical change that occurs after CTR is the volar displacement of the flexor tendons traversing the carpal tunnel.⁵ The TCL is believed by some to be an important “pulley” in the flexor tendon system.⁵ As such, division of the TCL may significantly increase flexor tendon excursion during wrist flexion. Increased excursion has been

noted after 20–30° of wrist flexion.²⁵ Thus, bowstringing of the flexor tendons with wrist flexion could be another cause of postoperative wrist flexion weakness.⁵ As most gripping occurs with wrist extension, however, this bowstringing is unlikely to be responsible for the decreased grip strength that is sometimes observed following CTR.

Neurogenic and Edematous Effects

Sensory nerve branches in the palmar and subcutaneous tissue may be injured when incising in Wilson’s “critical pillar rectangle,” the area bordered proximally by the distal wrist flexion crease, radially by the scaphoid tubercle, ulnarly by the hook of the hamate, and distally by a line 1 cm distal to the hook.²⁶ Postoperative edema superficial to the severed TCL may also be a source of pain in this area. The opposing pull of the thenar and hypothenar muscles, as well as the overall slight relaxation of the transverse carpal arch, may contribute to tension on the surgical scar and lead to scar sensitivity. Resolution of postoperative edema is often coincident with a decrease in pain.⁴

Future Directions

Although CTR has been performed for at least 90 years, the biomechanical consequences of the procedure are still not fully understood. Do the morphologic changes described warrant repair of the transverse carpal ligament, or should other procedure modifications be incorporated? To this point, there has been no convincing evidence that any one technique is superior to another in terms of postoperative results and complications.¹¹ Is there a way to prevent some of the adverse biomechanical consequences while still achieving symptom relief from median nerve compression? Clearly these questions remain unanswered, and further study is warranted.

To study the biomechanical and anatomical changes of CTR, human hands are ideal, though an animal model could still play an important role, especially in the development of alternative techniques. Tung et al compared carpal tunnel compliance among humans, dogs, rabbits, and rats and found that the human carpal tunnel was the longest, thickest, and least compliant followed by dog, rabbit, and finally rat. Even though the anatomy of the dog forepaw is considerably different than that of the human wrist (flexor digitorum superficialis is not contained within the carpal tunnel), the dog forepaw may serve as a reasonable experimental model, as it is closest in compliance.²⁷

Conclusion

Surgery for carpal tunnel syndrome has been performed for at least 90 years,¹⁰ yet the effects of the postoperative biomechanical changes are still being clarified. Although the majority of patients experience symptomatic relief, some patients experience disabling postoperative symptoms such as scar sensitivity, pillar pain, and/or grip weakness. These effects may be due to biomechanical alterations caused by CTR. Studies have shown that the transverse carpal width increases slightly following CTR, though it is debatable

whether this change persists and, if so, what effect it has on hand biomechanics. There is more consensus as to the fact that carpal tunnel volume increases due to TCL diastasis and transformations in the carpal tunnel volar geometry. The change in carpal arch shape may stress intercarpal articulations. TCL division has an effect on the mechanics of the thenar and hypothenar muscles as well as the extrinsic flexors of the fingers and thumb. Because of the morphologic changes that occur as a result of TCL release, it is reasonable to assume that the etiologies of postoperative complications such as pillar pain and decreased grip strength are related to the biomechanical consequences of CTR.

Conflict of Interest

None

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