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Biomechanical Changls of Finger Flexion After Carpal Tunnel Release with Respect to Wrist Positions

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— **Abstract** —

This study was designed to investigate whether sectioning of the transverse carpal ligament (TCL) modifies the biomechanical behavior of the finger flexion in respect to dynamic changes of the wrist. Changes of work, load, and excursion of the flexor tendons were measured using fresh frozen cadaver hands with the wrist in 30° flexion, neutral, and 30° extension before and after division of the TCL. Change in work efficiency between intact and cut TCL groups was noted most with the wrist in flexed position (12.5%) compared to 3% in neutral wrist position and no change in wrist extension. The extended wrist group as a whole had greatest increase in the efficiency of work and load with greater than 16.2% and 14.8% changes, respectively. The significant decrease in the excursion efficiency of the flexor tendons was demonstrated when the wrist was in the flexed position. This effect was accentuated when the TCL was divided causing the bow-stringing phenomenon. The increase in the excursion of the flexor tendons could clinically result in decreased grip strength when the wrist is flexed. Furthermore, the effects of TCL division were least significant when wrist position was in extension. One could conclude from this that post-operative management after carpal tunnel release procedures should include placing the wrist in moderate extension.

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most common of the nerve entrapment syndromes. Since Phalen[1] brought CTS to our attention in 1951, division of the transverse carpal ligament (TCL) to restore median nerve function by decompressing the carpal canal has become the standard of care[2]. Decreased grip strength and bow-stringing of the flexor tendons are some of the long-term complications of surgical decompressions of the carpal tunnel that previously reported. The post-operative weakness has been hypothesized to stem from either local palmar pain, deep pain secondary to

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carpal stretching, and/or loss of mechanical efficiency secondary to bowstringing of the flexor tendons at the level of the carpal canal[3].

The TCL has been proposed as an important retinacular pulley for the digital flexors, but this theory has not yet been confirmed to be as essential as the pulleys in the more distal digital flexor tendon sheaths. Studies have demonstrated that the release of the TCL brings about a substantial increase in carpal canal volume and anteriorly displaces the carpal tunnel contents[4,5]. If the digital retinacular pulleys are important to maintain full finger flexion, the presence of the TCL in conjunction with the position of the wrist may also significantly affect the efficiency of the digital flexion. To date no studies have been performed evaluating the biomechanical changes for finger flexion after carpal tunnel release. This study was designed to investigate whether sectioning of the TCL modifies the biomechanical behavior of the finger flexion in respect to dynamic changes of the wrist.

MATERIALS AND METHOD

Six fresh frozen cadaver hands were used in this study. The frozen hands had been severed from the upper limb at a level one inch proximal to the proximal wrist crease. Prior to testing, each hand was defrosted for four hours in an air-tight bag and placed in a warm water bath. After defrosting and isolation of the tendon ends, each hand was mounted on a previously described motorized testing platform that comprised the base of our tensiometer (Fig.1)[6]. This was accomplished by two 1.2 mm Kirschner wires passed transversely through the distal metacarpal shafts, with care taken not to transfix any flexor or extensor tendons. The Kirschner wires then were mounted to outriggers on the platform, consisting of a slide tray powered by a high-torque motor, which provided a constant 4 cm/min. excursion. A special block was built and placed on the slide tray allowing for the controlled placement of the wrist in angles of fixed flexion or extension. The proximal end of each tendon was individually anchored to a force transducer (Lucas Schaevitz, Pennsauken, NJ; accuracy +/-0.02%) via an 0-Ethibond suture (Ethicon Co.) placed in modified Kessler stitch fashion. A linear variable differential transformer (LVDT; Lucas Schaevitz, Pennsauken, NJ; accuracy +/- 0.01%) was connected to the moving platform and was used to monitor tendon excursion. Each finger tip was flexed into contact with a Greenleaf pinch meter placed on the distal palmar crease and pulled to the maximal force of one kilogram to provide a uniform termination. Work and load changes of the tendon were obtained at the pinch strength of 1,000 grams.

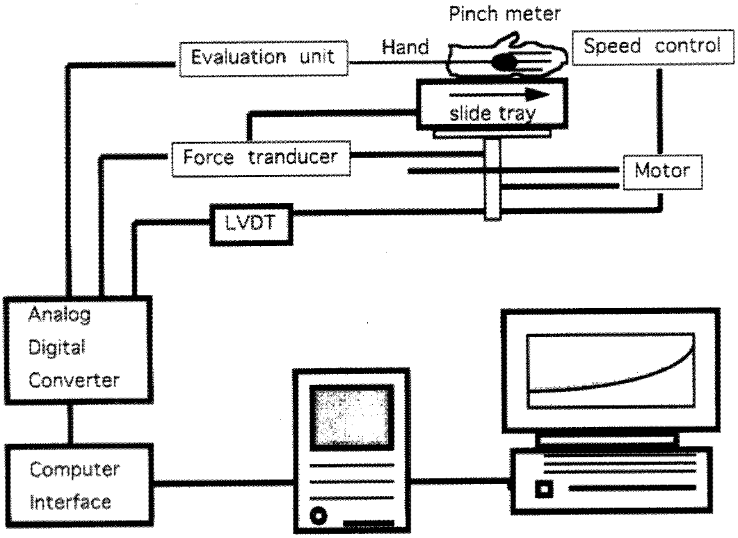

Fig. 1. Experimental setup of tensiometer. A hand is mounted on a platform powered by a high-torque, constant-speed motor. Analog signals from LVDT, force transducer, evaluation unit are digitally sampled and sent through computer interface for acquisition and analysis.

Signal conditioning (Omega Engineering Inc. Stamford, CT) was used in order to amplify output signals. Analog data, gathered continuously at 10 Hertz, were converted to digital format (10 Tech Inc. Cleveland, Ohio) and then sent through a computer interface unit (Mac SCSI 488), where custom software was used for formatting and analysis of the data.

The profundus tendon of the index, long, and ring fingers were pulled individually three times with the wrist in neutral, 30 degrees of extension and than 30 degrees of flexion. These pulls were redone after the TCL was cut in the standard manner. The changes of work, load, and excursion were determined by using the wrist with TCL intact neutral position pulls as the norm for each hand[7,8,9]. The post release results were reported as a percentage of the pre-release value in all hands. Work and load changes were calculated as a ratio of the experimental data to the control data as follows:

$$\text{Work (\%change in efficiency)} \; \frac{[\text{Cut TCL work data} - \text{Intact TCL work data}]}{\text{Intact TCL work data}} = \text{X } 100$$

The changes of load and excursion were calculated in the same manner. Data were compared by means of an Analysis of Variance for Repeated Measures and paired t-test, where a P value of less than 0.05 was considered significant.

Table 1. Mechanical data of finger flexion in different wrist positions

Position	Condition	Work(joules)	Load(Newons)	Excursion(cm)
30° flexion (n=6)	Intact	1.35	25.0	3.91
	Cut	1.20	22.6	4.27
	%change in Efficiency	12.5%	10.6%	8.4%
Neutral	Intact	1.36	27.7	3.68
	Cut	1.32	26.2	3.98
	%change in Efficiency	3.0%	5.7%	5.4%
30° extension (n=6)	Intact	1.14	23.6	3.43
	Cut	1.14	23.6	3.44
	%change in Efficiency	0%	0%	0.3%
Significant effect from ANOVA test		Condition p=0.0005 Position p=0.124	Condition p=0.0001 Position p=0.0008	Condition p=0.012 Position p=0.05

Table 2. Mechanical data of finger flexion comparing to neutral wrist with TCL

Position	TCL condition	Work(%)	Load(%)	Excursion(%)
30° flexion (n=6)	Intact	99.3	90.3*	106.3*
	Cut	88.2*	81.6*	116*
Neutral (n=6)	Intact	100	100	100
	Cut	97.1	94.6*	105.7
30° extension (n=6)	Intact	83.8*	85.2*	93.2*
	Cut	83.8*	85.2*	93.5*

Reference value ; statistical significance determined by paired t-test
*P<0.01

RESULTS

Part I: Effect of TCL release

Work, load, and excursion efficiencies of the finger flexion were calculated comparing the differences between the intact and cut TCL with the wrist in neutral, 30 degrees flexion and 30 degrees extension. Change in work efficiency between intact and cut TCL groups was noted most with the wrist in flexed position (12.5%) compared to 3% in neutral wrist position and no change in extended wrist position(Table 1). In a similar pattern, the excursion and load efficiency changes was greatest in the flexed wrist position followed by the difference in neutral wrist position. The extended position produced no notable changes in percent efficiencies for all three categories. Figure 2 is a bar graphs depicting the difference of

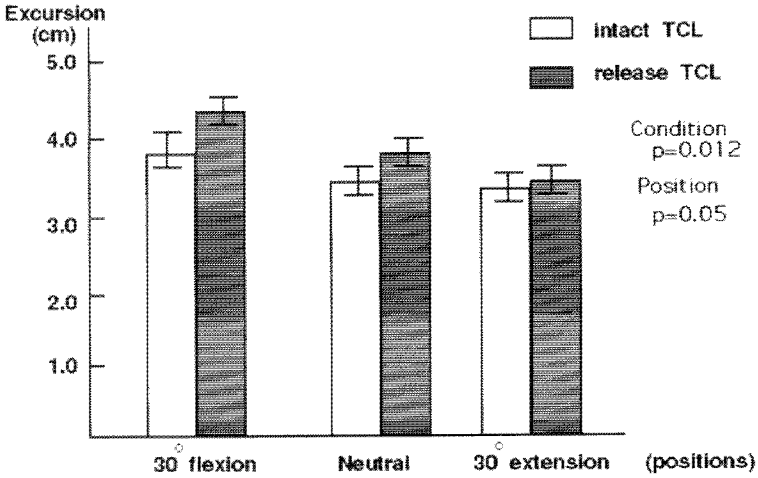

Fig. 2. Bar graph showing changes in excursion data of the flexor digitorum profundus tendons in different wrist positions. Data were analyzed before and after the release of transverse carpal ligament.

excursion between the intact and cut TCL as well as the contrast between the different wrist positions.

Intergroup analysis showed significant difference ($p < 0.01$) between the intact and released group within the wrist flexed, extended, and neutral positions.

Part II: Effect of the wrist positions (Table II)

Work Efficiency: Although the TCL sectioning within the wrist in extended position did not significantly influence the work efficiency of the system as mentioned above, the extended wrist group as a whole had greatest change with increase in the efficiency of work by greater than 16%. In comparison, the flexed wrist group produced a 0.7% improvement in the work efficiency from the intact TCL group. By cutting the TCL work efficiency improved to 11.8% compared to the neutral wrist with intact TCL.

Load Efficiency: When the wrists were placed in the 30 degrees of extension the load efficiency for both intact and resected TCL showed nearly 15% of improvement in efficiency. There was some difference between the intact and cut data for the flexed wrist position. Intact TCL with wrist flexed produced approximately 10% change of the load efficiency whereas the releasing of TCL nearly doubled the efficiency change to 18.4%. The values were all compared to the neutral wrist with intact TCL.

Excursion Efficiency: When the wrist was placed in flexion, significant decrease in excursion efficiency (increase in the excursion of the flexor tendons) was noted. Releasing TCL produced greater increase in excursion requiring 16% more than the control to produce the same amount of movement of the digits. As expected, there was significant ($p < 0.01$) increase in excursion efficiency for the extended wrist position regardless of the TCL condition with improvement of nearly 7% in comparison to the neutral wrist with intact TCL.

DISCUSSION

The static anatomy of the carpal tunnel has been well described; however, the dynamic and biomechanical function following release of the TCL is not well characterized. In the carpal tunnel, the TCL forms a roof over the concavity made by the carpal bones. The TCL is a stabilizer of the carpal arch providing an anchor points for the scaphoid and hammate; the nine flexor tendons and median nerve pass dorsal to the TCL in the canal. The ratio between the size of the carpal tunnel and its contents is thought to be more important than the size of the tunnel itself[10,11]. MRI studies have demonstrated that the flexor tendons change their location in different wrist positions leading to changes in the free space available within the carpal tunnel. It has been hypothesized that the positional free space changes occurring within the carpal tunnel--in wrist extension, neutral, and flexion--may in turn affect biomechanics of the flexor tendons.

In wrist extension, the cross-sectional area of the carpal tunnel is greatest. This is due to flexor tendons flattening and shifting dorsally during finger flexion. In contrast, a position of wrist flexion results in the smallest mean cross-sectional area of the carpal tunnel--due to volar shift of flexor tendons and concomitant extrinsic pressure to the tendon from the TCL. This change results in a 2-3 ㎟ reduction in free space. Finger flexion with the wrist flexed enhances the palmar shift of flexor tendons, and further changes of moment arm of flexor tendons[10,12]. During wrist flexion, excursion requirements are increased resulting in relative increase in work for adequate flexion. Passive extensor tenodesis effects also contribute to the increased work requirement.

Another factor that changes the biomechanics of the flexor tendons is the release of the TCL. There is significant linear and volumetric changes after TCL release. Release of the TCL disrupts the resistance against applied tensile stress and allows an anterior-posterior volumetric increase[4,12,13,14].

Gliding function of deep flexor tendons were studied both pre- and post-TCL release. Variables of terminal force during flexion and tendon excursion during flexion were investigated. Release of the TCL decreased frictional forces on the tendons in the canal and decreased work requirements in all wrist positions studied. Excursion after TCL release was increased secondary to the bowstring effect. As with any bowstring effect the moment arm was increased causing a decrease in work requirement while increasing tendon excursion as seen in this current study. In the flexed wrist, release of the TCL accentuated this bowstring effect, thus in turn weakened finger flexion and increased tendon excursion by 16%. These changes were not as dramatic in wrist neutral and hardly existed with wrist extension.

This work demonstrated the biomechanical importance of the TCL as a true A_0 pulley. The acute weakness post-TCL release can be somewhat modified by holding the wrist in mild extension post-TCL release to minimize the anterior displacement of flexor tendons as well as to increase the efficiency of the tendon excursion.

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