In Vivo Forces Generated by Finger Flexor Muscles Increase with Finger and Wrist Flexion

*Kursa, K E; **Tran, S T; *Lattanza, L; *Diao, E; +*Rempel, D M.
+*University of California, San Francisco, CA

Introduction

Risk factors for tendon disorders of the hand may include the force level, number of repetitions, and hand posture. To better understand injury mechanisms and to develop effective preventive measures, it is important to understand how these external factors affect internal tendon forces. *In vivo* forces in one or both flexor tendons have been measured and reported during active and passive motion of the fingers and wrist (1, 2). However, the influence of finger and wrist joint positions on the amount of force generated during active finger flexion was not assessed. The goal of this investigation was to determine whether the positions of the wrist and the index finger metacarpophalangeal (MP) joint affected the *in vivo* forces in the flexor digitorum profundus (FDP) tendon and the flexor digitorum superficialis (FDS) tendon when the subject actively flexed his or her fingers.

Methods

Eight subjects (5 females and 3 males, average age 45 years) participated in the study after reading and signing a consent form. The procedures were approved by the University of California, San Francisco, Committee on Human Research. The experiment was conducted during open carpal tunnel release surgery with local anesthesia at the incision site. After the flexor retinaculum ligament was released, two tendon force transducers were placed on the FDP and FDS tendons of the index finger (3). The centers of joint rotation of the index finger and wrist were marked with a surgical pen and the radial side view of the hand was recorded with a video camera mounted directly above the sterile field at 30 Hz. Simultaneously, force data was collected from the tendons at 100 Hz during active finger flexion. The subjects were instructed to move their fingers from a fully extended position to a flexed one. The wrist was stabilized by the surgeon in either a neutral position or in 30° flexion and the motion was repeated twice at each wrist angle. After the experiment was completed, the transducers were removed and the surgery was finished.

For each motion, FDP and FDS tendon forces were determined at five different MP joint positions (maximum extension, maximum flexion, 15° flexion, 45° flexion and 60° flexion) and two wrist positions. A three factor repeated-measures analysis of variance was used to test the null hypothesis that there is no difference in the forces generated by the two tendons at different finger positions and at different wrist positions ($p = 0.05$). It was followed up by Tukey-Kramer test for multiple comparisons.

Results

Forces measured in the FDP and FDS tendons of the index finger are presented in Table 1. During an active flexion of the fingers, the *in vivo* forces significantly differ with position of the MP joint and position of the wrist, as well as between the two tendons. Statistical analysis showed no interaction between these three factors. The forces in the FDP tendon are significantly greater than those in the FDS tendon. The forces in the tendons are also significantly greater when the wrist is maintained in 30 degree flexion compared to the neutral position. Pair-wise comparisons showed that the tendon forces are smaller when the MP angle is at 15 degrees flexion compared to 60 degrees or maximum flexion. The forces at maximum extension are also smaller than those experienced in the two positions when the finger is most flexed.

MP Joint Position	FDP Force (N) [e]		FDS Force (N) [e]	
	Wrist in Neutral [f]	Wrist in Flexion [f]	Wrist in Neutral	Wrist in Flexion
MP ext [c,d]	1.78 ± 1.56	1.50 ± 1.43	1.41 ± 0.66	1.24 ± 0.56
MP 15 [a,b]	2.05 ± 1.39	2.21 ± 2.07	1.61 ± 0.86	1.31 ± 0.59
MP 45	2.31 ± 1.71	4.34 ± 3.29	1.13 ± 0.68	2.33 ± 2.22
MP 60 [a,c]	2.22 ± 1.67	4.69 ± 5.61	1.24 ± 0.65	4.81 ± 6.11
MP flex [b,d]	4.17 ± 3.38	4.64 ± 4.63	1.71 ± 1.26	3.97 ± 4.87

Table 1. Forces in the FDP and FDS tendons at different wrist and finger positions. Data reported as average ± standard deviation.
a, b, c, d, e, f indicate statistically significant differences ($p < 0.05$)

Table 2 displays the measured MP joint angles that correspond to the forces presented in Table 1. Some subjects were not able to attain 60 degrees of flexion and some others did not extend their MP joint more than 15 degrees. Thus the variability of the angles at the end of the range of motion is larger.

MP Joint Position	MP Angle (degrees)			
	Wrist in Neutral		Wrist in Flexion	
MP ext	15 ± 11	n = 8	13 ± 9	n = 7
MP 15	17 ± 3	n = 7	16 ± 2	n = 6
MP 45	45 ± 3	n = 8	45 ± 1	n = 8
MP 60	59 ± 1	n = 7	58 ± 2	n = 5
MP flex	64 ± 11	n = 8	51 ± 7	n = 7

Table 2. Measured MP joint angles at different wrist and finger positions. Data reported as average ± standard deviation.

Discussion

This study shows that the amount of force generated by the FDP and FDS muscles in order to flex the index finger depends on the position of the finger and wrist joints. The larger force contribution of the FDP muscle to finger motion is in agreement with models and *in vivo* measurements found in the literature (1, 4). However, a model developed to estimate finger joint positions that minimize and maximize tendon forces during piano play predicted that tendon forces would decrease as the MP joint flexion increased (4). An increase in MP joint flexion should increase both flexor tendons' moment arms about the joint leading to a decrease in their internal forces. The difference between the effect of MP joint flexion in the model and the one found in our results may be due to the differences in the positions of the other joints and the fingertip. Since the flexor tendons span multiple joints, the positions of the other finger joints will also affect the internal tendon forces. In addition, a larger flexor force may be necessary to overcome some passive forces that increase with flexion.

Another study reported *in vivo* flexor tendon force values during active DIP flexion and active PIP flexion. The average FDP forces were 18.6N and 1.0N for the two motions while the FDS forces were 0.2N and 8.8N (1). The differences in the biomechanics and control mechanisms of movements limited to one joint and those involving the entire finger may account in part for the differences between the values reported in the literature and those from the current study. The lack of position data in the other study also limits the comparison between the values. An increase in passive *in vivo* FDS force when a finger was moved from flexion to extension (0.5N to 6N) has also been reported (2). This increase in force may be absent from our data since most subjects did not extend their fingers fully.

The position and sedation of the subjects during the experiment, as well as the surgical procedure, may influence the results. These conditions may also have reduced the range of motion that the subjects achieved during the task.

The results of this study imply that limiting the amount of finger and wrist flexion with appropriate tool design and work station setup can decrease the amount of force in the finger flexor tendons and thus may reduce the incidence of associated injuries. In addition, information about the amount of force in tendons during different maneuvers and positions may be useful for devising a safe and effective post-operative rehabilitation protocol to promote healing while preventing adhesions, gap formation and tendon rupture. The results of this study demonstrate the importance of *in vivo* measurements in helping us understand the different external factors that influence internal forces in tendons and the associated biomechanics.

References

1) Schuind et al. (1992) *J Hand Surg.* 17A(2): 291-298. 2) Dennerlein et al. (1999) *J Orthop Res.* 17: 178-184. 3) Dennerlein et al. (1997) *J Biomech.* 30: 395-397. 4) Harding et al. (1993) *J Biomech.* 26: 1403-1412.

** University of California, Berkeley, CA