IN VIVO FINGER TENDON FORCE RATES DURING TAPPING

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Introduction: Risk factors for tendon disorders of the hand may include the force level, number of repetitions, hand posture, and hand velocity. To differentiate between these factors and better understand the injury mechanisms, it is important to understand how these external factors affect internal tendon loading. The relationship between the force at the fingertip and the *in vivo* force in a flexor tendon while tapping on a keyswitch has been reported previously (1). In addition to the force level, the force rate that a tendon experiences may influence the damage mechanism since loading rate influences tissue strain and fatigue properties. The goal of this investigation was to calculate the mean and maximum *in vivo* force rates in the flexor digitorum superficialis (FDS) tendon while tapping, compare the values during the loading (increasing force) and unloading (decreasing force) parts of the motion, and compute the corresponding force rates at the fingertip.

Methods: Five subjects 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 and the University of California, Berkeley, Committee for the Protection of Human Subjects. The experiment was conducted during open carpal tunnel release surgery with local anesthesia. After the incision was made, a tendon force transducer was placed on the FDS tendon of the long finger (2). The fingertip force was recorded by a load cell (GreenLeaf Medical Pinch Meter, Palo Alto, CA, USA) with a hard surface for the first subject and by a custom-designed load cell mounted inside a computer keycap and keyswitch assembly for the other four subjects. Data was collected from the tendon and fingertip at 2000 Hz. The subjects were instructed to tap once a second and minimize the time when the finger touched the keycap. They were given audio feedback upon contact. Data was recorded for 17–35 taps per subject. After the experiment was completed, the transducers were removed and the surgery was finished. (1)

The loading and unloading portions of each tap were identified by examining the fingertip and tendon force data. A force value at each time point was calculated by using a linear regression of 20 points (10 ms) around that time point. This smoothing technique resulted in a signal that retained 99% of the original signal's RMS^2 energy, as confirmed by power spectral analysis. The slope obtained from this moving window spline was used to estimate the instantaneous force rate. The mean and maximum values of the tendon force rate were identified separately for the loading and unloading portion of each tap. The same parameters were calculated for the fingertip. The values from the individual taps of each subject were averaged and used for statistical analysis. The loading and unloading parts of the motion were compared using paired t tests ($p = 0.05$). The tendon force rates were compared with the fingertip force rates using paired t tests, for both loading and unloading.

Results: Typical fingertip and tendon force amplitudes and rates are presented in Figure 1. The force rate in the tendon is positive during the loading part of the motion. It increases until the fingertip contacts the key, then decreases, and reaches a maximum after the end of key compression. The tip force rate reaches its maximum value when the key is fully depressed and becomes temporarily negative. Then both force rates decrease gradually until they reach zero when the force reaches its maximum. The force rate in the tendon remains negative longer than at the fingertip during unloading.

Table 1. Force rates in the tendon and at the fingertip during the loading and unloading portions of the tap. Data reported as average ± standard deviation.

Force Rates	Loading (N/s)	Unloading (N/s)
Mean tendon	84 ± 32	34 ± 10
Mean fingertip	25 ± 12	20 ± 10
Maximum tendon	278 ± 125	118 ± 33
Maximum fingertip	136 ± 27	47 ± 14

As shown in Table 1, the mean tendon force rate during the loading phase is significantly higher than during the unloading phase while the difference in the mean tip rates is not significant. However, the maximum loading force rates are significantly higher than the maximum unloading rates at both the fingertip and in the tendon. The mean loading rate in the tendon is significantly higher than the mean loading rate at the fingertip , but there is no significant difference in the mean unloading rates in the two locations. The maximum rates in the tendon are significantly higher than the maximum fingertip rates during both loading and unloading.

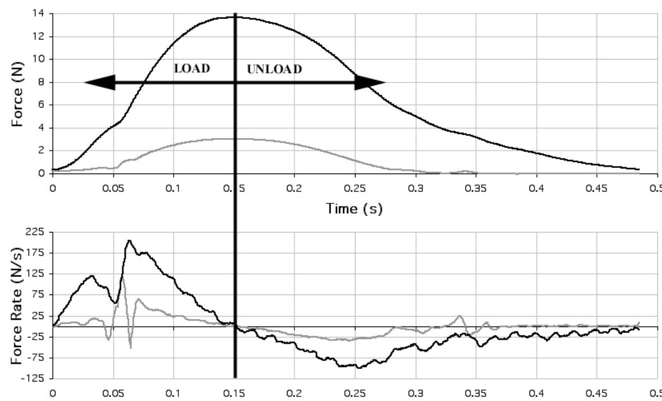

Figure 1. Typical Tap

Discussion: This study shows the flexor digitorum superficialis tendon of the long finger is subjected to maximum *in vivo* force rates of 146 N/s – 435 N/s during tapping on a computer keyswitch. The mean force rates in the tendon during the loading phase of the motion are higher than the rates at the fingertip since the tendon must generate a force four to seven times greater than that seen at the fingertip (1). The observed difference in the loading and unloading force rates can be explained by the muscle activities corresponding to these two parts of the movement. The loading phase occurs when the force in the tendon is increasing as the finger flexor muscles contract. The unloading phase corresponds to a decrease in force, most likely caused by antagonist contraction to retract the finger with reduced flexor muscle activity and by the flexor muscle-tendon unit's passive force. Thus, the extensors may be responsible for controlling the fingertip force rate during unloading while the flexor tendon force rate is dependent mostly on passive elements.

The force rates in the finger tendon are lower than those recorded *in vivo* during locomotion. The maximum force rates in the human Achilles tendon during running increased from 50 kN/s to 180 kN/s, as the subject's speed increased. (3) The rates in the cat soleus and gastrocnemius muscles during running at 2 m/s ranged from 250 N/s to 700 N/s. (4) The force rates in the tendons depend on the type and speed of motion, as well as on the particular tendon's properties. In addressing wrist problems, it is valuable to have data from the finger tendon during an activity that simulates motions commonly associated with wrist problems.

The position and sedation of the subjects during the experiment, as well as the presence of carpal tunnel syndrome, may affect subject performance and reduce their ability to produce a typical keystroke. Therefore, the tendon force rates observed in this study are probably lower than the rates that can be generated during touch typing in the workplace.

Knowledge of *in vivo* tendon force rates and their timing during repetitive, dynamic loading of the fingers will help us understand motor control mechanisms and muscle-tendon mechanics.

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