FORCE GENERATED BY FINGER FLEXOR MUSCLES DEPENDS ON THE RATE OF FINGERTIP LOADING

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Introduction:

Risk factors for tendon disorders of the hand may include the force level, rate of force application, 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 loading. Static force models have been used to predict internal forces in tendons of the finger, but they include simplifying assumptions to solve the complex problem (1, 2). In an effort to validate these models, the relationship between the force at the fingertip and the *in vivo* force in one or both flexor tendons has been measured and reported during static loading (3, 4). The forces in the tendons exceeded model predictions and contained large variability between subjects in both studies. Finger position, force level and loading rate could affect the motor control strategy and distribution of forces among the muscles of the finger. The goal of this investigation was to determine whether the rate of force application affected the *in vivo* force in the flexor digitorum profundus (FDP) tendon and the flexor digitorum superficialis (FDS) tendon when the subjects pressed on a hard surface.

Methods:

Eight subjects (six females and two males, average age 44 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 (5). The hand was positioned with the wrist in 15° extension, the MP joint in 45° flexion and the other finger joints in a natural pinching position. The fingertip force was recorded by a six-axis load cell with a hard surface. (ATI Industrial Automation, Apex, North Carolina, USA). Data was collected from the tendons and fingertip simultaneously at 100 Hz during an isometric pinch. The subjects were instructed to apply an increasing force on the load cell at two different rates until the fingertip force reached 15N. They were asked to follow a linear ramp pattern displayed on a monitor in order to attain the maximum force in either one or ten seconds. After the experiment was completed, the transducers were removed and the surgery was finished.

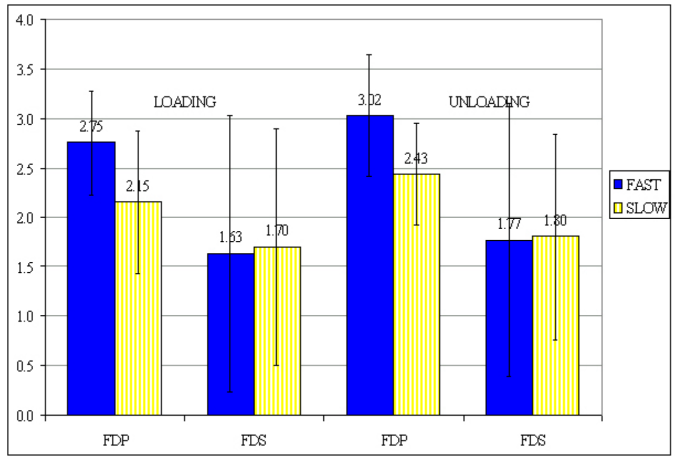
Data for each pinch was separated into the loading portion (period of increasing fingertip force) and the unloading portion (decreasing force). The ratio between the force in each tendon and the force at the fingertip was calculated using linear regression. The values for each subject were averaged over 2 to 6 trials. The relationship between the tendon and fingertip force was compared for the slow and fast loading rates using paired t-tests.

Results:

Figure 1 displays the ratios between the force in the tendons and the fingertip. The relationships between tendon and fingertip force are linear with mean R-squared values of 0.98 and 0.96. The figure shows how the ratios vary with direction of force application and fingertip loading rate. For the FDP, the force ratio was significantly higher when the force was applied at the faster rate ($p=0.049$). Similarly, the ratio was higher when the fingertip force was released more quickly ($p=0.028$). There was no significant difference in the ratio for the FDS tendon between the two rates of force application.

In most subjects, the FDP generated more force than the FDS for a given fingertip force when the person pressed on a hard surface. However, this difference was not significant for either the fast ($p=0.11$) or slow ($p=0.37$) loading rates.

Figure 1. Ratios of Flexor Tendon Force to Fingertip Force (n=8)



Discussion:

This study demonstrates that the force generated by the FDP muscle for a given fingertip force depends on the rate of force application. A rapid pinch requires greater FDP tendon force per unit of tip force than a slow pinch. The motor control mechanism governing this motion may be responsible for this difference. More extensor co-contraction may be necessary to control the increase in force at the faster rate, to stabilize the finger and to prevent overshooting the desired maximum force level. The need to compensate for this larger antagonistic force may explain the observed increase in FDP force. Static models used to predict force magnitude in finger tendons do not account for the effect of force rate or change in motor control mechanisms. In fact, the force in the extensor is often assumed to equal zero during flexion.

The ratio between *in vivo* FDP force and external fingertip force during a pinch has been reported in one other study as 7.92±6.33 (4) while values of 1.73±1.51 (4) and 3.3±1.4 (3) have been reported for the FDS ratio. Different finger positions and loading rates may account in part for the difference between the values found in literature and those from the current study. This study used a six-axis load cell to measure fingertip force in order to collect all components of tip force; the other studies used a single axis load cell.

The position of the wrist and MP joint was controlled in this study to eliminate some variability in the results. However, each subject was allowed to control the position of the other finger joints to mimic a natural pinching posture. The adoption of a hyper-extended rather than a flexed position by the DIP joint could lead to differences in the FDS to fingertip ratio (3).

The position and sedation of the subjects during the experiment, as well as the surgical procedure, may affect subject performance and influence the results. Changes in the loading rate during a pinch may also affect the results.

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 motor control mechanisms.

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