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Thumb Extension Changes Due to Surgical Relocation of the Extensor Pollicis Longus Tendon: A Mathematical Model with Experimental Calibration

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INTRODUCTION

Surgical procedures to treat rheumatoid arthritis, wrist tenosynovitis, and other distal radioulnar conditions resulting in wrist reconstruction require an incision in the back of the wrist to access the bones and structures within. As part of this surgical procedure, the Extensor Pollicis Longus (EPL) tendon is relocated from the ligamentous sheath that guides it around Lister's tubercle. Since the EPL no longer follows its natural path, the mechanical pulley effect provided by engagement with Lister's tubercle is lost. Consequently, the effective length of the tendon is increased. Clinical evidence shows that EPL relocation often reduces thumb function and range of motion: patients with compromised thumb motion may be unable to use scissors or perform other tasks requiring thumb extension.

The purpose of this study was to evaluate the effect of EPL relocation on thumb extension. Based on wrist and hand anatomy, a rigid body mathematical model was developed to simulate thumb extension. A cadaveric experiment was also conducted and the results were used to calibrate and verify the model (Fig. 1).

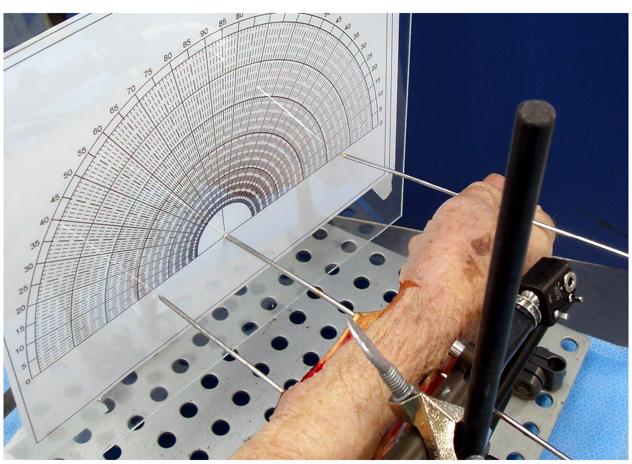

Figure 1: Experimental assembly: frame-mounted cadaveric limb, using K-wires for reference and measure.

METHODOLOGY

Mathematical Model

A biomechanical model of the system was created based on anatomic geometry (Fig. 2). The model consisted of five rigid body segments representing the distal phalange, proximal phalange, first metacarpal, and two carpal (wrist) segments. Torsional springs were placed at each joint to represent joint stiffness due to elasticity of the joint capsule, ligaments, and other passive tissues spanning the joint. The spring constant (k) at each joint (i) was selected to be proportional to the joint size, allowing for the calculation of torque at each involved joint, $T_i = -k_i \theta_i$.

Equilibrium equations were calculated for each segment. This resulted in 15 equilibrium equations similar to the three shown below for the distal phalange segment:

$$\sum M_{P5} = T_5 + EPL_x r_5 (\sin \theta_5) + EPL_y r_5 (\cos \theta_5) = 0 \quad (1)$$

$$\sum F_x = F_{5x} - EPL_x = 0 \quad (2)$$

$$\sum F_y = -F_{5y} + EPL_y = 0 \quad (3)$$

The system was modeled using MATLAB software (MathWorks; Natick, MA). Forces were applied to the EPL and the corresponding thumb extension angles were calculated. The model was calibrated by adjusting the torsional spring constants based on measured experimental and anatomical data.

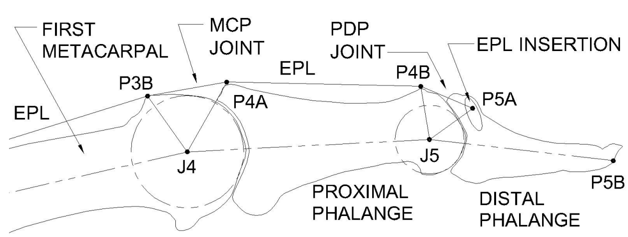

Figure 2: Model of distal thumb segments, showing EPL traversing the bone segments toward its insertion point.

Experiment

Twelve cadaveric forearms were dissected and an external fixator was installed to immobilize the wrist in a neutral position. The limb was secured to a test frame and two Kirschner wire (K-wire) pins were installed: one through Lister's tubercle (Fig. 3) and one through the distal interphalangeal (DIP) joint of the thumb. The EPL tendon was exposed in its natural position. A suture was secured to the tendon and force was applied using known weights. The applied force, EPL displacement, and angle of thumb extension were recorded. After each measurement the force was removed to minimize mechanical creep. Upon completion of the experiment in the natural position, the EPL was surgically relocated (radial to Lister's tubercle) and the experimental procedure was repeated.

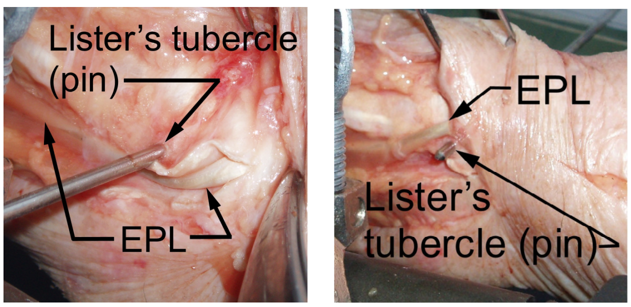

Figure 3: Photos of the Extensor Pollicis Longus tendon (EPL) in its natural position (left) and in the relocated position (right). A K-wire was located directly through Lister's tubercle as a visual and structural reference.

RESULTS

For the natural cadaveric thumb, the mean range of motion (ROM) in extension (min, max) was 47.7° (14.0°, 94.7°). This ROM is consistent with other published findings [1]. Following EPL relocation, the mean ROM decreased to 31.1° (10.7°, 80.7°). This result supports clinical evidence that thumb motion is reduced after relocation. The mathematical model coordinates well with the experimental data for the naturally positioned EPL. Following relocation, the model also follows the general trend of the experimental results, but not as accurately (Fig. 4). Model accuracy may be improved through further model calibration and by accounting for additional parameters that may affect the movement.

DISCUSSION

The nonlinearity of the thumb motion suggests that the thumb extension angle may be dependent on multiple parameters such as the force applied to the tendon, each joint's unique resistance, and the anatomical and geometrical path through which the EPL travels.

Although the configuration is naturally 3-dimensional (3D), thumb extension activity is primarily dominated by 2D motion. Planar analysis was performed in order to reduce this complexity. The range of thumb motion observed in this experiment parallels other studies that use a similar projected planar analysis of motion [2]. This study suggests that it may be possible to preoperatively predict thumb extension for surgical procedures involving EPL relocation. Clinically this may improve post-surgery thumb function. The model suggests that reducing EPL length may improve thumb extension performance.

CONCLUSIONS

The calibrated mathematical model correlated well with experimental data. New information is provided on the biomechanical relationship between EPL tendon motion and thumb extension, both before and after EPL relocation. This study lays a foundation to guide ongoing research targeted at improving EPL tendon surgery outcomes. The results may potentially be used to assist future surgical planning for EPL relocation, with the goal of improved thumb function and patient quality of life.

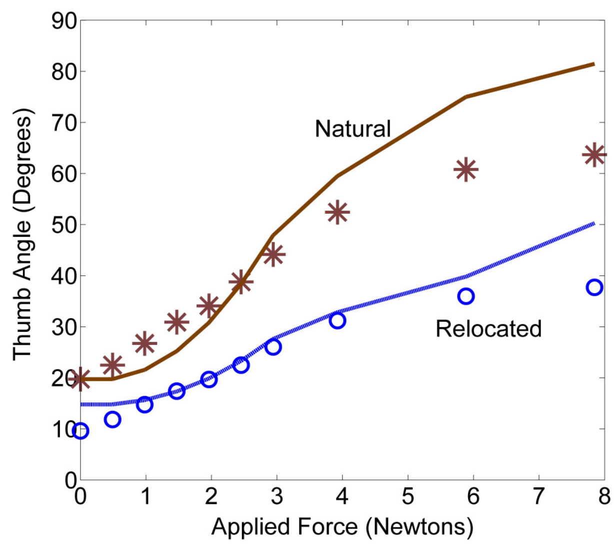

Figure 4: Mathematical model of the natural extension of the thumb correlates well with the experimental data (stars). Likewise, the modeled relocated results correlate well with the measured data (circles).

REFERENCES

1. Imaeda T, An KN, and Cooney WP. *Hand Clinics*, **8**, 9–15, 1992.
2. Tang J, Zhang X, and Li Z. *Ergonomics*, **51:**7, 1109 – 1118, 2008.