BIOMECHANICAL EVALUATION OF THE CHANGE IN THUMB EXTENSION FOLLOWING RELOCATION OF THE EXTENSOR POLLICIS LONGUS TENDON

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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.

METHODS

Mathematical Model

A biomechanical model of the system was created based on anatomic geometry (Fig. 1). 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.

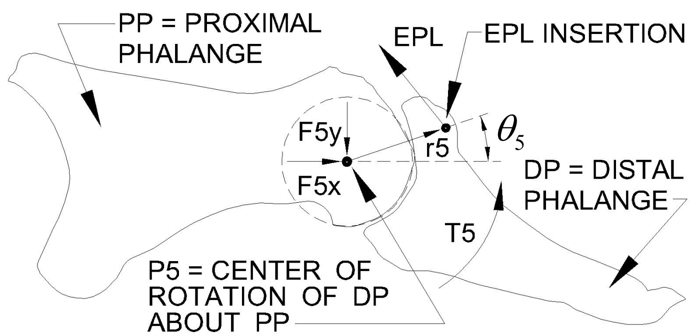

Figure 1: Model of distal thumb segments. Applying force to the EPL tendon results in thumb extension, as the distal phalange rotates about P5, the DIP joint.

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 and one through the distal interphalangeal (DIP) joint of the thumb (Fig. 2). 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 thumb extension angle 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.

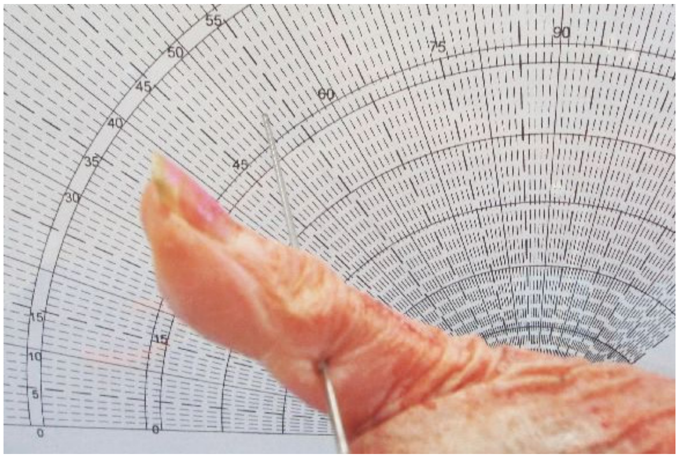

Figure 2: A K-wire through the DIP Joint (P5) was used in the experiment to measure thumb extension angle.

RESULTS AND DISCUSSION

For the natural cadaveric thumb, the mean range of motion in extension (min, max) was 47.7° (14.0°, 94.7°). This range of motion is consistent with other published findings [1]. Following EPL relocation, the mean range of motion 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. 3). Model accuracy may be improved through further model calibration and accounting for additional parameters that may affect the movement.

The nonlinearity of the thumb motion suggests that the thumb extension angle may be dependent on multiple parameters including the force applied to the tendon, the unique resistance of each joint, and the geometrical path through which the EPL travels. Although the configuration is naturally 3-dimensional (3D), thumb extension activity is primarily dominated by 2D motion. Therefore, a planar analysis was performed in order to reduce the complexity. The range of thumb motion observed in this experiment parallels other studies [2] that use a similar projected planar analysis of motion.

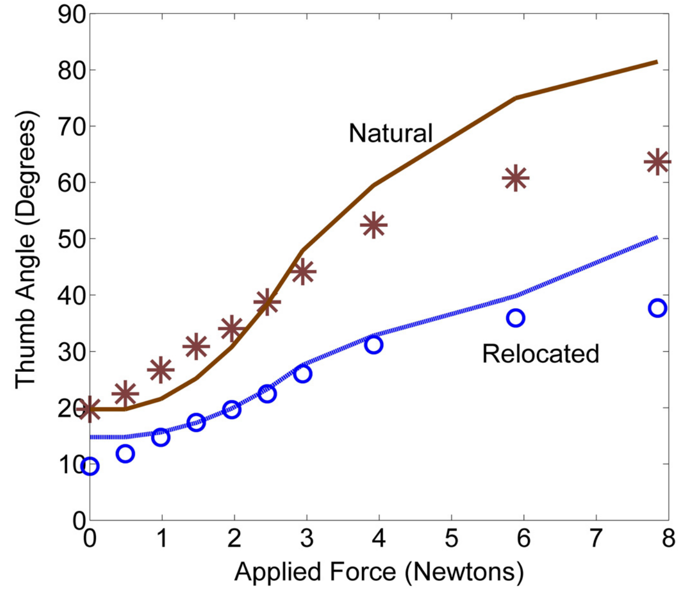

Figure 3: Mathematical model of the natural extension of the thumb (solid) correlates well with the experimental data (stars). Likewise, the modeled relocated results (dashed) correlate well with the measured data (circles).

This study suggests that it may be possible to preoperatively predict thumb extension for surgical procedures involving EPL relocation. Clinically this information may be applied to improve function of the post-surgery thumb. The model suggests that removing excess EPL tendon length may improve thumb extension performance.

CONCLUSIONS

The calibrated mathematical model correlated well with experimental data. Together they provide new information on the biomechanical relationship between EPL tendon motion and thumb extension, both before and after EPL relocation. They also lay a foundation to guide ongoing research targeted at improving EPL tendon surgery outcomes. In the future, these results may be used to assist in surgical planning for EPL relocation, with the goal of improved thumb function and patient quality of life.

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.