INTRODUCTION:
The Extensor Pollicis Longus (EPL) muscle is located within the forearm and is used primarily for thumb extension. Current surgical procedures used to treat rheumatoid arthritis, wrist tenosynovitis, and other distal radioulnar conditions often require relocation of the EPL tendon to allow access to structures deep within the wrist. In this procedure the ligamentous sheath that guides the EPL tendon is cut, freeing the tendon. Reconstruction of this sheath is not feasible due to the development of scar tissue that would inhibit proper tendon motion.

The purpose of this study was to evaluate the effect of EPL tendon relocation on thumb extension. A rigid body mathematical model was developed to simulate thumb extension for both the natural and relocated positions. A cadaveric experiment was conducted to obtain calibration parameters and to validate the mathematical model. The goal of this research was to use the mathematical model to improve biomechanical understanding of thumb extension following EPL relocation with a long term goal of developing better surgical procedures which improve functional outcome.

METHODS:

Mathematical Model

A mathematical model was developed to simulate thumb extension movement resulting from force applied to the EPL tendon. It consisted of the EPL tendon and four rigid body segments; distal phalange, proximal phalange, first metacarpal, carpal (wrist) segment (distal segments shown in Figure 1).

Torsional springs were utilized at each joint to represent joint stiffness due to elasticity of the joint capsule, ligaments, and other passive tissues spanning the joint. Joint torque, \( T_j = -k_j \theta_j \), was modeled as a function of the spring stiffness,

\[
 k_j = a + bL_j(\theta_j)
\]

where \( k_j \) is the torsional spring stiffness for each joint, \( j \) is the joint number, \( a \) and \( b \) are calibration constants, \( L_j \) is the arc length of the joint contact surface, \( \theta_j \) is the angular deflection of each joint from its neutral position (i.e. zero force equilibrium position).

Using MATLAB software (MathWorks, Natick, MA), the applied EPL force was incrementally increased and static equilibrium was evaluated to determine the unique joint configuration at each step. Angular rotations for each joint were tracked so the overall motion of thumb could be computed. Calibration parameters, \( a \) and \( b \), were found empirically by correlating the motion of the model with the experimental results described below. The calculations were repeated for the relocated tendon condition.

Cadaveric Experiment

Eight fresh, or fresh frozen and thawed, cadaveric limbs were positioned on a fixture that maintained the natural positions of the radius and ulna. A Kirschner wire (K-wire) was inserted through the distal interphalangeal joint (J4) of the thumb. A suture was secured to the proximal end of the tendon and various forces (up to 5.4 N) were applied using weights. The thumb angle at each applied force was measured visually using a calibrated scale (Figure 2). Following this testing, the EPL was surgically released from its ligamentous sheath (relocated) and the test was repeated.

RESULTS:

For the natural cadaveric thumb, the mean extension angle was 27.7°, similar to previous findings [1, 2]. Model calibration yielded \( a = 0.58 \) and \( b = 0.001128 \) for joints 2-4. For the multiple bone carpal joint, different calibration parameters were needed; \( a = 2.78 \) and \( b = 0.001334 \). Once calibrated, the mathematical model matched well with experimental data (Figure 3). Following EPL relocation, the mean extension angle was reduced to 21.1°. The model accounted for tendon relocation while retaining the original calibration parameters. This change resulted in a shift in the model prediction which correlated with the experimental data after tendon slack was removed from the system, thus validating the model.

DISCUSSION:

Tendon slack length was found to be an important factor in achieving proper thumb extension. This slack was observed in both the mathematical model and the experimental data. Relocating the EPL tendon affected thumb biomechanics by shortening the effective path length causing slack in the relocated tendon. When large, this slack may cause the EPL muscle to function in a contracted state, limiting thumb extension function. The model showed that when this slack was removed, function was improved. Future work will investigate the force length relationship of the EPL muscle and quantify how removal of EPL tendon slack may increase performance during thumb extension.

REFERENCES: