

IMPACT OF ANATOMICAL ADHESIONS ON STRESS DISTRIBUTION WITHIN THE EXTENSOR HOOD OF THE INDEX FINGER

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INTRODUCTION

The extensor hood is a complex structure which transmits forces from finger muscles to the phalanges. In the index finger alone, four and possibly five tendons are incorporated into this aponeurosis which runs the length of the finger. These tendons arise from the first palmar interosseous (FPI), lumbrical (LUM), extensor digitorum communis (EDC), extensor indicis (EI), and, in some instances, the first dorsal interosseous. While the extensor hood consists of a continuous sheet of collagenous tissue, it is often represented as a network of discrete tendons [1-2], typically with a rhomboid structure [3]. The tendons representing the central slip (CS) and terminal slip (TS) are the two that actually attach to the bones, namely to the middle and distal phalanges, respectively.

Whether modeled as a network of tendons or as a continuous sheet, the question arises as to the need to include further connections, beyond those of CS and TS, between the bones and the extensor mechanism. A number of fibrous adhesions along the extensor mechanism help to reduce translation of the hood with respect to the phalanges. Otherwise, contraction of FPI, for example, which connects to the ulnar edge of the extensor mechanism, might produce medial displacement of the hood. It is not known, however, the role these adhesions play in force transmission.

Thus, the goal of this study was to quantify the impact of these adhesions on the distribution of stresses within the hood. A finite element model (FEM) of the hood was created and simulations with and without certain adhesions were run. We hypothesized that these connections would

substantially impact the stress distribution and need to be included in extensor hood models.

METHODS

A FEM of the extensor hood and bones (the metacarpal and proximal, middle, and distal phalanges) of the index finger was created (Fig. 1). Anatomical magnetic resonance images of a cadaver hand were obtained; these images were segmented in Amira (Visage Imaging, Inc., San Diego, CA) to generate 3D surfaces of the extensor hood and bones. A deformable shell mesh was created for the extensor hood using the finite element preprocessor, TrueGrid (XYZ Scientific, Livermore, CA), while the surface meshes for the bones were used to generate rigid shell meshes. A mesh convergence study was conducted for the extensor hood to assure proper discretization.

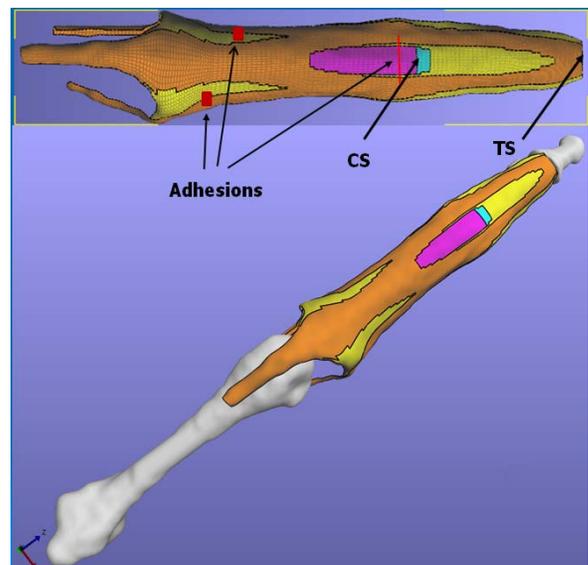


Figure 1: Finite element model of the extensor hood. Regions with different colors have different material properties. CS: central slip; TS: terminal slip.

The extensor hood was represented as a homogeneous, isotropic, compressible, St. Venant-Kirchhoff elastic material with a constant thickness of 1.0 mm. The elastic modulus and Poisson's ratio ($E = 1825.5$ MPa, $\nu = 0.4$) for the banded portions of the extensor hood were obtained from previously published research [4]. As the extensor hood is a heterogeneous structure, different moduli were used for different parts of the hood, in accordance with measured values [4] (see Fig. 1). Rigid attachments between the extensor hood and the bones were created through rigid node sets located at the attachments of the CS and TS with the middle and distal phalanges, respectively. All FE pre-processing (after mesh generation), post-processing, and analysis were conducted with the FEBio Suite of software (<http://mrl.sci.utah.edu/software>).

Locations of major adhesions were determined through dissection of cadaveric fingers. These adhesions were included in the models through the introduction of springs connecting the bone and the hood. The springs exert force only when stretched, not when compressed. Two sets of these adhesions were modeled sequentially for this study.

Thus, three conditions were simulated: no adhesion (NO), two adhesions distal to the MCP joint, one on the radial side and one on the ulnar side (RU), and one adhesion just proximal to the PIP joint, representing a connection between the central slip and the joint capsule (CS). These three conditions were run at two different finger postures (MCP flexion, PIP flexion, DIP flexion): $(0^\circ, 0^\circ, 0^\circ)$, $(0^\circ, 45^\circ, 30^\circ)$. The following loading pattern was used: EDC/EI – 12 N, LUM – 0.25 N, FPI – 0.25 N.

RESULTS AND DISCUSSION

Both finger posture and the presence of the adhesions had a profound impact on stress distribution within the hood. The flexed posture led to localized stresses an order of magnitude greater than those observed in the extended posture for all three conditions (NO, RU, and CS) for loading of EDC/EI.

Inclusion of the adhesions affected magnitude and distribution of the stresses (Fig. 2). The RU adhesions generated larger stresses in the more proximal portion of the hood, while the CS

adhesion produced very high stresses around the PIP joint.

Interestingly, the ratio of the CS:TS insertion forces also changed with the inclusion of certain adhesions. In the flexed posture, the NO and CS models yielded ratios of 3.6:1. In contrast, the RU model produced a ratio of 1.1:1, which is much closer to the 0.6:1 ratio reported from cadaver experiments [5]. Thus, these adhesions may play an important role in force distribution through the hood and warrant further investigation.

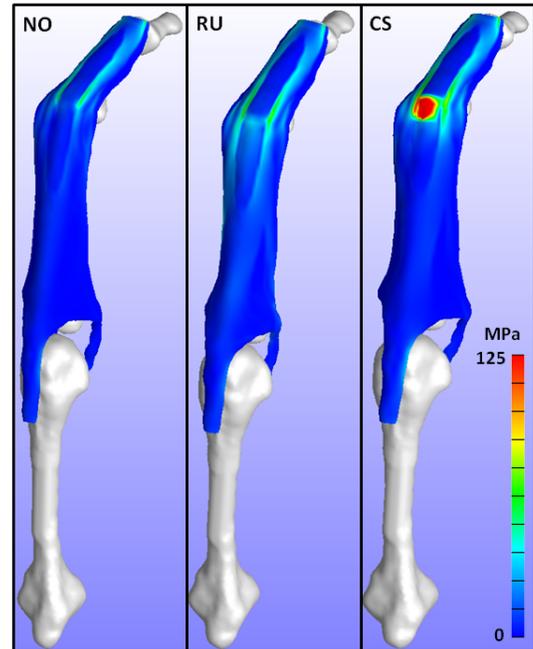


Figure 2: Simulation results at the flexed finger posture of (MCP, PIP, DIP) = $(0^\circ, 45^\circ, 30^\circ)$ for a loading pattern of (EDC, LUMB, FPI) = (12 N, 0.25 N, 0.25 N). NO: no adhesions; RU: adhesions on radial and ulnar sides of MCP. CS: adhesions to joint capsule just proximal to PIP joint.

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