

# A TECHNIQUE FOR DETERMINATION OF TRANSVERSE MATERIAL PROPERTIES OF HUMAN FLEXOR DIGITORUM TENDONS

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## INTRODUCTION

Carpal tunnel syndrome (CTS) is among the most important of the family of musculo-skeletal disorders. Mechanical insult to the median nerve, due to contact with the flexor digitorum tendons, is considered a proximate cause. However, there is little biomechanical information available for transverse compressive properties of the flexor tendons to explain the objective characterization of this local biomechanical insult. To obtain apparent tendon transverse compressive properties, biaxial tests were undertaken using human cadaver tendons. The apparent tendon anisotropic material behavior was characterized using finite element (FE) analysis.

## METHODS

Tendon behavior in compression is presumably influenced by longitudinal tension, owing to the composite-like tissue architecture of collagen fibers embedded in extra-fibrillar matrix. To measure transverse compressive stiffness of the flexor tendons as a function of independently prescribed levels of longitudinal tension, an MTS-mounted biaxial testing device was developed (Figure 1). The tendon specimen is oriented horizontally, with a pneumatic actuator used to apply longitudinal loads. After tensioning to a physiologically representative level (16.9 N, 33.8 N, and 50.7 N), the MTS actuator-mounted upper platen applied transverse displacement at a rate of 0.25mm/sec, while the transverse

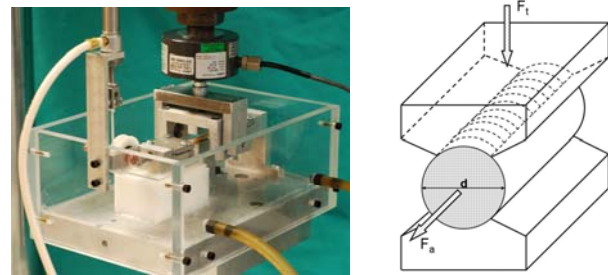


Figure 1: Test Apparatus and Parameter Definitions

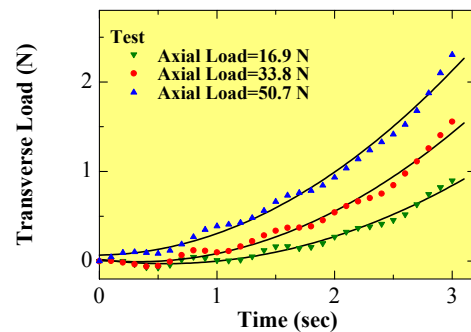
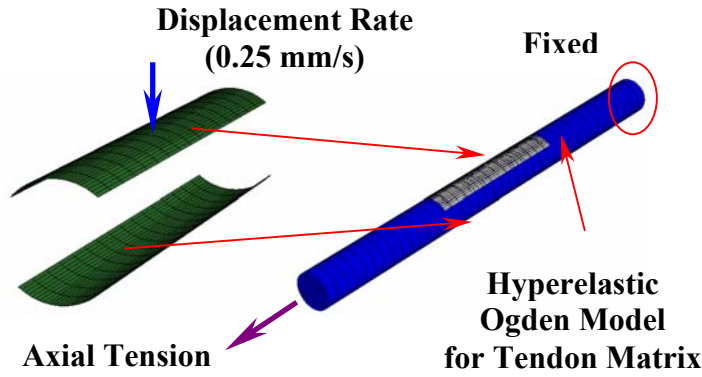


Figure 2: Transverse Load History (normal digital flexor tendon, from a 55-year old fresh-frozen cadaver specimen)

load was continuously measured by an in-line load cell during 3.0 sec (Figure 2).

A three-dimensional finite element (FE) model of the experimental set-up was created (Figure 3). The tendon FE model was positioned between the two rigid platen surfaces, with the lower surface model being completely fixed. ABAQUS Standard (v6.5) was used as a solver. To quantitatively identify flexor tendon material properties, two types of tendon material characteriza-



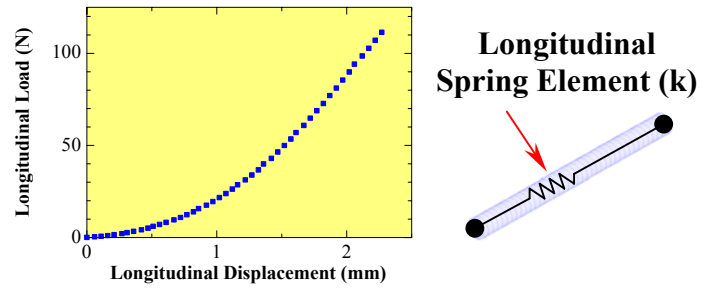
**Figure 3: 3-D FE Modeling and Boundary Conditions of Test Set-up**

tions were introduced. Isotropic Ogden hyperelasticity was applied for the tendon matrix. With an incompressible Ogden model condition, only two material parameters  $\alpha$ ,  $\mu$  are considered, with strain energy  $U$  being expressed as a function of stretch ratios  $\lambda_1, \lambda_2, \lambda_3$  (Equation 1). Also, to describe tendon anisotropy, a spring element was superimposed between the end nodes of the tendon FE model, within the tendon isotropic matrix (Figure 4). The spring stiffness data ( $k$ ) were estimated from tendon longitudinal displacement-load data.

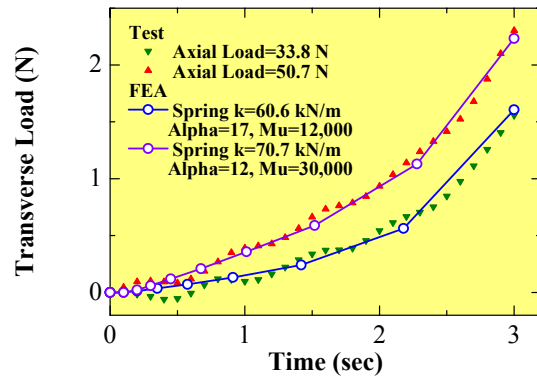
$$U = \frac{2\mu}{\alpha} (\lambda_1^\alpha + \lambda_2^\alpha + \lambda_3^\alpha - 3) \quad (1)$$

## RESULTS AND DISCUSSION

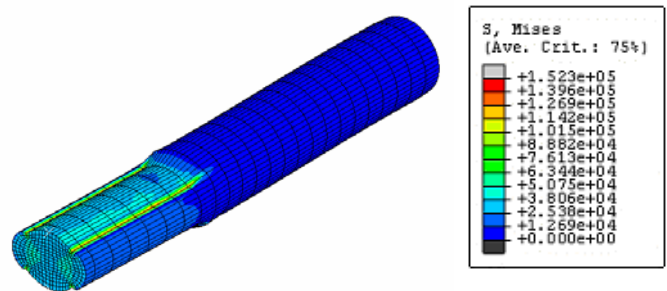
Iterative parameter searching with  $\alpha$ ,  $\mu$  was used to obtain transverse load history matching with experimental data (Figure 5). The determined Ogden model parameters were  $\alpha=17$ ,  $\mu=12,000$  in case of axial tension 33.8 N, and  $\alpha=12$ ,  $\mu=30,000$  in case of axial tension 50.7 N, respectively. An example of mid-cross section deformation and stress contours is illustrated in Figure 6. It was found that the present FE analysis method is effective to determine the apparent transverse compressive material properties of the flexor digitorum tendons,



**Figure 4: Tendon Longitudinal Test and Spring Element Application**



**Figure 5: Comparison of FEA and Test Results**



**Figure 6: Example of 3-D FE Simulation**

which then can be used for patho-physiological study of the role of median nerve entrapment and compression by tendons, in CTS.

## ACKNOWLEDGEMENT

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