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A PARAMETRIZED MODEL OF THE LONG FINGER EXTENSOR MECHANISM

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INTRODUCTION

The extensor mechanism (EM) of the finger is a complex anatomical structure which transmits the forces of the extrinsic and intrinsic hand muscles to the finger joints. The EM has been incorporated into biomechanical models of the finger and is usually represented as a 3D-network of extensible or non-extensible strings placed on finger bones at given joint angles.

However, such 3D-models contain many unknown parameters that should be determined. It seems that most studies in this field have only focused on EM modelling but not on its parametrization and validation.

The purpose of this study was to create a numeric model of the long finger EM that includes main tendons and ligaments as well as to perform a parametric identification of the model to match the force distribution in the simulated EM with the experimental data.

METHODS

The EM was modeled as a network of elastic bands. Each EM component, or band, was discretized by the chain of the points, connected by elastic elements. Hence, the EM position was represented by the array of the point coordinates. Each two sequential points, discretizing an EM band, were connected by a spring with a linear elasticity model. The forces of four muscles (dorsal ulnar interosseous, extensor digitorum, dorsal radial interosseous and lumbrical) were applied to the model. The principle of Minimum Potential Energy was used to find the equilibrium state, in which the EM internal forces balance the muscle forces.

The distribution of the internal forces among the simulated tendons in the model were characterized by a vector \mathbf{C}^{**} . A model parametrization was performed to make \mathbf{C}^{**} fit the experimental values \mathbf{C} , observed by Chao [1] for the extended posture. The lengths of two intercrossing bands, extensor lateral and interosseous medial band (1 and 2 in Figure 1) were chosen as the identified parameters. Nelder-Mead algorithm (`fminsearch` function in Matlab R2012b, MathWorks, Natick, MA) was used to minimize the root-mean-square error between \mathbf{C}^{**} and \mathbf{C} .

As the EM is deformable, the internal force distribution among the simulated bands can vary when the muscle forces change. To quantify this variation, the model sensitivity was calculated as the partial derivative of \mathbf{C}^{**} with respect to the muscle forces.

RESULTS AND DISCUSSION

The lengths of extensor lateral band and interosseous medial band, that minimizes the RMSE between \mathbf{C}^{**} and \mathbf{C} were

found. Their values were 38.0 mm and 32.7 mm, the RMSE was 0.11.

The parametrized model was used to simulate three postures: full extension (Figure 1a), mid-flexion (Figure 1b), and full flexion (Figure 1c). The scaled-up retention apparatus during full extension (Figure 1d) and full flexion (Figure 1e) is also shown.

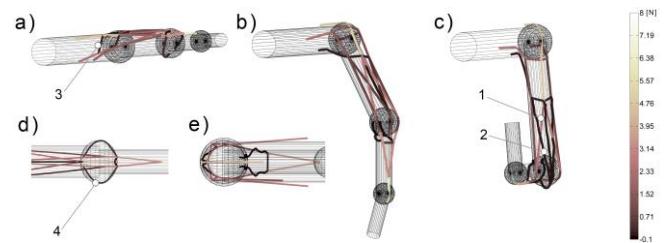


Figure 1: The extensor mechanism simulation for three finger postures.

The changes of the EM configuration are seen from the figure, e.g. the distal shift of the extensor hood and the relaxation of the retinacular ligament could be observed (3 and 4 in Figure 1). The changes of the simulated EM configuration are consistent with the experimental data, reported in [2].

The sensitivity analysis has shown that the force distribution among the simulated tendons are most sensitive to lumbrical muscle force variation. This finding confirms the importance of balance of muscle forces applied to the EM.

CONCLUSIONS

In this study, a biomechanical model of the EM was proposed to simulate the changes in the EM configuration with posture in order to better understand force transmission in the bands. The parametrization of the model was firstly performed to fit the distribution of the forces among the tendons to experimental data. Finally, we calculated the sensitivity of the parametrized model to the variation of the muscle force values.

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