IN VIVO PASSIVE FORCES OF THE INDEX FINGER MUSCLES: VALIDATING CURRENT MODELS

Jin Qin, David Lee, Jack Dennerlein

Harvard University, Boston, MASS, USA
E-mail: jax@hsph.harvard.edu Web: www.hsph.harvard.edu/ergonomics

INTRODUCTION

The passive properties of the muscle have been found to be an important element in the biomechanical modeling of hand movements (Dennerlein et al., 1998; Keir et al., 1996; Sancho-Bru et al., 2001). However, due to the unique physiological characteristics of the intrinsic hand muscles and the complicated structure of the extensor hood mechanism, it is difficult to model the passive forces of the hand. Although few studies have measured the extrinsic muscle passive length-force property from cadaver fingers (Keir et al., 1996; Lee et al., 1990), the biomechanical parameters that predict the passive forces from these cadaver studies have limited in vivo validation. Therefore, we utilized a standard biomechanical model that incorporates typical exponential force-length relationship and *in vivo* fingertip forces. Through comparing the two, we implemented a particle swarm optimization (PSO) to determine the parameters of the exponential relationship. PSO is a population based stochastic computer algorithm developed by Eberhart and Kennedy in 1995 and it has been successfully applied in many research and application areas. It has been demonstrated that PSO gets better results in a faster, cheaper way compared with other methods (Schutte et al., 2005).

METHODS

We conducted a laboratory experiment measuring the passive fingertip forces of index finger in 18 postures in ten subjects. EMG confirmed no activity in the forearm muscles. Fingertip forces were averaged across the ten subjects for each of the 18 postures. For each posture we computed change of muscle length of six muscles -- flexor digitorum profundus (FDP), flexor digitorum superficialis (FDS), radial interosseous (RI), ulnar interosseous (UI), lumbrical (LU) and extensor digitorum communis (EDC) -- based on the excursions of the tendons of the finger adopted from the method used by Lee et al. (1990). Based on these length changes, we calculated muscle passive forces via the exponential relationship with its length excursion (e.g. Lee et al., 1990).

$$F_p = \beta_1 \cdot e^{(\beta_2 \cdot \Delta l)} \qquad (1)$$

where, F_p is the passive muscle force, β_1 and β_2 are biomechanical coefficients, and Δl is the muscle length excursion from reference position. From these passive forces we calculated the fingertip force via

$$F_{tip} = (J^T)^{-1} R F_p \qquad (2)$$

where, F_{tip} is the fingertip force, J is the Jacobian matrix for the one of the 18 postures, and R is the moment arm matrix for the posture.

Particle swarm optimization searched the parameter space for the biomechanical coefficients β_1 and β_2 which yield the passive fingertip forces that are closest to the measured experimental data.

RESULTS AND DISCUSSION

The average values from ten sets of the global best solutions of β_1 and β_2 after 10000 iterations were different than values presented by Lee and Rim (Table 1), which are based on fitting the length-force curves from three cadaver fingers.

The simulated betas of FDP, FDS and LU from the model were higher than their reported values, and betas of RI, UI and EDC were lower. This may due to the reason that the 18 postures measured in the experiment did not cover the whole range of muscle excursions. The excursions of FDP, FDS and LU calculated from the postures are on the lower side of the exponential curve and the excursions of RI, UI and EDC are on the higher side. We also only explored flexion forces and no extension due to the experimental protocol. This may explain the railing of the EDC passive force parameters.

Another reason that may cause the difference is subject variability. The subjects in this study were young and healthy (average age = 29.9±6.4 years), while the average age was 72 years for the cadavers.

The average best global fitness value of the ten runs was 0.0966 N / posture, and the average passive fingertip force across all postures was 0.4957 N. The optimization time for 10000 iterations is about 30 minutes on an IBM computer (Duo processor 6600 at 2.40 GHz).

In addition, we have assumed a specific configurations for the tendons of the finger; however, the extensor mechanism of the finger is quite complex and hence the model may not be completely representative.

CONCLUSIONS

A biomechanical model of passive muscle forces of the index finger using PSO algorithm was proposed. This model produced promising results to estimate and predict the passive forces and moments for different postures. Future work needs to be done on collecting data on a wider range of excursion distribution to improve the robustness of the model.

REFERENCES

Dennerlein J.T., Diao E., Mote C. D., Rempel D. M. (1998). *J. Biomechanics*, **31(4),** 295-301
Keir P.J., Wells R.P., Ranney D.A. (1996). *Clinical Biomechanics*, **11(7),** 401-409
Lee J.W., Rim K. (1990). *Proc Inst Mech Eng* [H], **204**, 169-178
Sancho-Bru L., Pérez-González A., Vergara-Monedero M., Giurintano D. (2001). *J. Biomechanics*, **34(11),** *1491-1500*
Schutte J.F., Koh B.I., Reinbolt J.A., Haftka R.T., George A.D., Fregly B.J. (2005). *J Biomech Eng-T ASME,* **127(3),** 465-474

Table 1: Average values of β_1 and β_2 of ten runs with 10000 iterations for index finger.

	Original Coefficients*		Coefficients after PSO	
	β_1	β_2	β_1	β_2
FDP	1.072	0.122	2.418	0.568
FDS	1.575	0.112	2.360	0.382
LU	0.198	0.255	2.407	0.431
RI	2.474	0.360	0.906	0.095
UI	1.966	0.408	0.549	0.098
EDC	4.164	0.118	1.939	0.001**

* from Lee. and Rim (1990)
** Minimum allowable value during PSO

XVIIth Congress of the International Society of Electrophysiology and Kinesiology

MUSCLES IN MOTION: Moving Research into Clinical Practice

18–21 June 2008 Niagara Falls, Ontario, Canada
***MUSCLES IN MOTION:* Moving Research into Clinical Practice**

NOTE TO READER: The full proceedings of the XVII Congress of the International Society of Electrophysiology and Kinesiology (ISEK), hosted in Niagara Falls, Ontario, Canada from 18 June 2008 to 21 June 2008, were constructed as a set of web pages delivered on a CD. As such, each abstract was contained in a separate PDF file, each file being hyperlinked from a Table of Contents and also from an Author Index. We have combined those files into this one PDF file. First, we provide the Table of Contents (without hyperlinks). Second, we provide the Author Index (without hyperlinks). Third, we provide all of the presented abstract papers, concatenated. Readers are encouraged to peruse the Table of Contents and Author Index in order to identify abstracts of interest to them. To find the full abstract within the abstract file, readers can search within the PDF file by the identified title or author. Note that some author last names are not unique and many authors contributed multiple papers.

Edited by Linda McLean and Paolo Bonato, Scientific Program Chairs