Simulating Finger-Tip Force Using Two Common Contact Models: Hunt-Crossley and Elastic Foundation

Kevin A. Hao[1] and Jennifer A. Nichols[1]
[1]Department of Biomedical Engineering, University of Florida, Gainesville, FL, United States
Email: khao2016@ufl.edu

Summary

Musculoskeletal models of the hand rarely include contact mechanics, thereby limiting our ability to model hand-object interactions. Here, two common contact models are used to examine finger-tip contact forces. The contact force is sensitive to finger pad size, when using the elastic foundation model.

Introduction

Every day we use our hands to grasp and manipulate objects. A key component of grasp is the finger pad. As we interact with objects by modulating our finger-tip forces and/or joint posture, the contact area of the finger pad changes, thereby altering the frictional properties between our skin and the object [1]. Accurately modelling the finger pad could improve our ability to use musculoskeletal simulations to study how the hand dexterously manipulates objects.

Contact mechanics have been widely incorporated into musculoskeletal models of the lower limb to simulate foot-floor contact and internal joint loads. However, to our knowledge, there are limited studies incorporating contact mechanics into musculoskeletal models of the hand [2]. In this study, we examine how two common contact models (Hunt-Crossley and elastic foundation) can be used to represent the finger pad. We specifically evaluate how changes in simulated contact area influences estimation of finger-tip force.

Methods

A musculoskeletal model of the index finger [3, 4] was adapted to develop dynamic simulations of finger-tip contact. The simulations specifically examined contact between the finger pad, represented as a sphere, and a flat, planar surface (Fig. 1). Two contact models (Hunt-Crossley and elastic foundation) and three finger pad sizes (sphere radii of 1.0, 1.5, and 2.0 cm) were examined. Sphere sizes represent the full range of experimentally reported index finger pad sizes [1].

For each combination of contact model and finger pad size, forward dynamic simulations were run in OpenSim v. 3.3 [5]. The input muscle activations were equivalent across all simulations and correspond to the muscle activity required to maintain a static finger joint posture while generating a linearly-increasing force (0-20 N). This force magnitude is within the typical operating range of the index finger, as it corresponds to that required to pull a plug from an outlet [6]. Forces estimated by each simulation were compared. For brevity, only forces normal to the plane are reported.

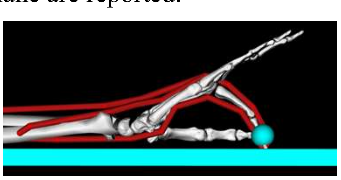

Figure 1: Index finger posture and simulated contact geometries.

Results and Discussion

When using the Hunt-Crossley model, the estimated contact force did not vary with finger pad size (Fig. 2A, peak force is 16.8 N for all simulations). This reflects the fact that this model assumes the surfaces are non-conforming, meaning that the force between a sphere and a plane occurs at a single point regardless of sphere size. In contrast, when using the elastic foundation models, the estimated contact force varied substantially with finger pad size (Fig. 2B, peak force increases from 11.4 to 17.8 to 23.8 N with increasing finger pad size). This reflects the fact that this model incorporates variable contact area, meaning the force is distributed over a larger area as the size of the sphere increases.

Interestingly, when using the elastic foundation model, as the finger pad size increased the simulation time required to reach the peak contact force also increased (Fig. 2B). Additionally, these simulations did not maintain the peak force for the duration of the simulation due to inconsistent interactions between the sphere and plane geometries as the simulations progressed. These findings highlight the computational costs and computational sensitivity of the elastic foundation model.

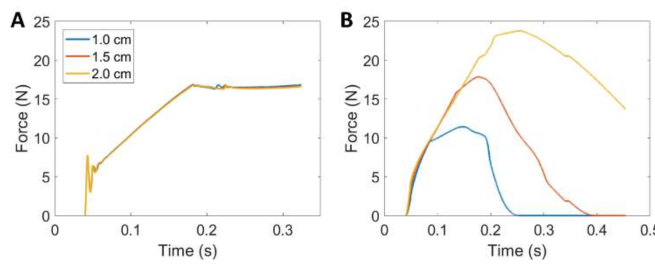

Figure 2: Contact force versus time for the (A) Hunt-Crossley and (B) elastic foundation models across three finger pad sizes.

Conclusions

This study illustrates that simulation results are sensitive to the selected contact model. Thus, contact models should be carefully selected based on the research question. In the near future, we will extend this work to incorporate changes in friction parameters with increasing finger pad size, thereby enabling more accurate simulations of hand function.

Acknowledgments

This work was supported by the University Scholars Program at the University of Florida.

References

[1] Liu, X., et al. (2018). *Skin Res Technol.*, **24(1)**:31-44.
[2] Sancho-Bru, J, et al. (2014). *Comp Methods Biomech Biomed Eng.*, **17**(4):297-310.
[3] Barry, AJ, et al. (2018). *J. Biomech*, **77**:206-210
[4] Binder-Markey BI, et al. (2017). *J Biomech*, **61**:250-257
[5] Delp, SL, et al. (2007). *IEEE Trans Biomed Eng,* **54(11)**
[6] Smaby, N., et al. (2004). *JRRD*, **41(2)**