SB³C2015
Summer Biomechanics, Bioengineering and Biotransport Conference
June 17-20, 2015,Snowbird Resort, Utah, USA

USING OPENSIM TO PREDICT KNEE JOINT MOMENTS DURING CYCLING

Karim C. Dudum (2), Jake E. Deschamps (1), Juan D. Gutierrez-Franco (1), Luke I. Kraemer (1), Alejandro M. Gonzalez-Smith (1), Eshan M. Dandekar (3), Scott J. Hazelwood (1,2), Stephen M. Klisch (1,2)

(1) Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo, CA, USA

(2) Biomedical Engineering Department
California Polytechnic State University
San Luis Obispo, CA, USA

(3) Kinesiology Department
California Polytechnic State University
San Luis Obispo, CA, USA

INTRODUCTION

Cycling is a relatively low impact activity conventionally recommended as a rehabilitative or fitness sustaining exercise for patients at a high risk for knee osteoarthritis (OA) [1,2]. Expanding our understanding of knee joint loads is necessary to develop and improve evidence-based prescriptions for cycling as a rehabilitative and fitness therapy that limits the risk for knee OA.

OpenSim (www.simtk.org) is an open source biomechanical analysis software that can partition predictions of external joint loads (or net muscle moments) into muscle and joint contact loads [3]. Joint contact loads more accurately represent cartilage tissue loading and hence risk for cartilage damage and/or OA [4]. As a first step towards predicting knee joint contact loads during cycling, we hypothesized that OpenSim can predict external knee joint moments that are consistent with published data [5,6]. To address this hypothesis, we conducted cycling experiments and used OpenSim's scale tool, inverse kinematics (IK) solver, and inverse dynamics (ID) solver to model the recorded activity.

METHODS

Equipment. A LifeCycle GX stationary bike (Life Fitness, Schiller Park, IL) was used to record foot loads during the motion analysis studies. Each stock pedal was replaced with a custom pedal box containing a 6-axis load cell (AMTI, Watertown, MA) [7] to record kinetic data. An 8-camera Owl motion analysis system (Motion Analysis Corp., Santa Rosa, CA) recorded kinematic data. Cortex software (Motion Analysis Corp., Santa Rosa, CA) was used to post-process kinematic and kinetic data before usage in OpenSim.

Experimental Studies. Inclusion criteria included normal body mass index (BMI = 18.5-24.9) and no history of leg injuries. Retroreflective markers were placed on male subjects (n = 2) using a full body Helen Hayes marker set [8]; each subject first maintained a pose for 3 seconds, while a static trial was captured. Then, a dynamic capture was taken as subjects performed 2 minutes of continuously seated cycling at ~70 RPM while grasping the handlebars. Experimental protocols were approved by Cal Poly's Human Subjects Committee and were designed to minimize risk to human subjects.

Data Processing. Cortex exports kinematic data in a .trc file and kinetic data as a .kin file. The .trc file type contains 3D coordinate locations of markers relative to the origin of the capture volume, which is easily imported into OpenSim. The .kin files, which contain force vector locations, center of mass positions, and force vectors corresponding to the capture rate of the kinematics, have a file header unrecognizable by OpenSim. Thus, we used Excel to manually extract the appropriate force vectors from .kin files, 1 from each load cell, and saved the kinetic data with the appropriate .mot file header recognizable by OpenSim.

The static capture data were used to scale a full body OpenSim model [9]. Virtual markers were placed on the model in accordance with the Helen Hayes protocol [8]. The OpenSim scale tool used the .trc file from the static capture in order to correlate the experimental marker data with the virtual marker set created in the OpenSim environment, thus dimensioning model segment lengths and consequent mass distributions and further aligning model joint rotation axes with the experimental case. The IK tool, using the .trc file from the dynamic capture, solved for model specific kinematics in the form of joint angles and was formatted as a .mot. The ID tool utilized the IK output and the manually formatted .mot file representing the kinetic vectors, selectively applied as a body force to the talus of each foot, in order to quantify all model specific joint moments and residual pelvic loads. Since seat and handle bar forces were not directly measured, we used published values for these forces [6] to calculate a statically equivalent system of such loads at the pelvis. These handlebar/seat equivalents (HBSEs) were compared with OpenSim predicted pelvic loads from ID.

RESULTS

Both IK (Figs. 1, 2) and ID (Fig. 3) results were consistent between subjects. On average, knee joint angles ranged from 115.5° to 17.4° in flexion (Fig. 2). Further, knee flexion moments ranged from -14.7 N-m to 31.1 N-m (Fig. 3). Averaged over the entire crank angle, ID results for pelvic loads differed from HBSEs calculated from literature values [6] by up to 66.0 N in the superior-inferior direction and up to 33.4 N in the anterior-posterior direction (Fig. 4).

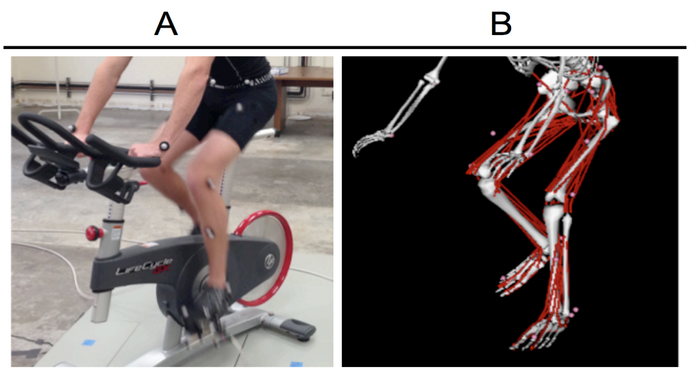

Figure 1. Sample frame of observed motion (A) and IK results (B).

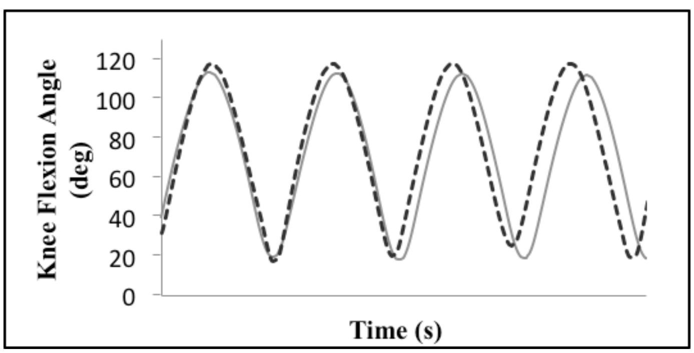

Figure 2. Knee flexion joint angles for both subjects from IK results for 2.5 revolutions of cycling.

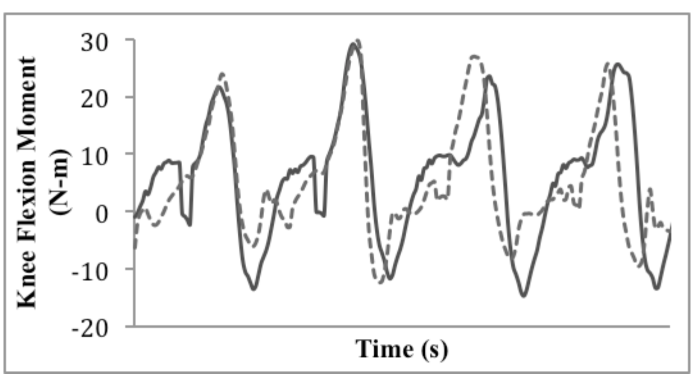

Figure 3. Knee flexion moments for both subjects from ID results for 2.5 revolutions of cycling.

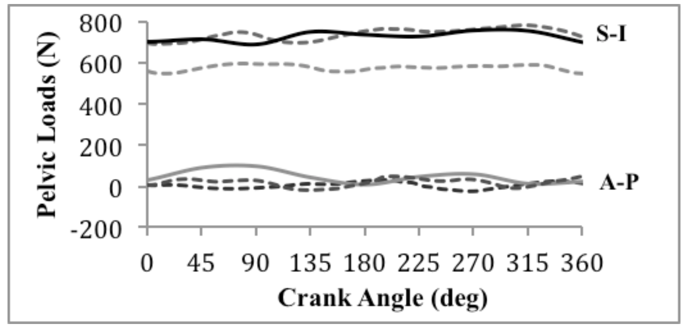

Figure 4. Pelvic loads for each subject (dotted) compared with HBSEs (solid). A-P = Anterior-Posterior, S-I = Superior-Inferior.

DISCUSSION

Our results support the hypothesis that OpenSim can effectively model cycling and predict external knee joint (i.e. net muscle) moments. Although peak values for knee flexion moments were lower than published values [6], other pilot experiment results revealed that higher peaks can be obtained by increasing machine resistance levels. The OpenSim predicted pelvic loads from ID reasonably matched the HBSEs. Interestingly, the ID results predicted the expected result that pelvic loads were dominated by the superior-inferior component; in that direction, ID results differed from HBSEs by 9.2%. Handlebar forces in the medial-lateral direction were not reported [6]; thus, appropriate HBSEs for that direction could not be computed.

In this study, kinetics were defined as body forces rather than more accurately defined as point forces, thus future work will include restructuring the method for kinetic data collection and subsequent import into OpenSim. Further, future work will include implementing a marker set more conducive to reducing soft tissue artifact. OpenSim's residual reduction algorithm (RRA) will be used in an effort to reduce modeling errors. Following RRA, further use of OpenSim tools [3] will be used to predict both muscle and joint contact loads, addressing our long-term goal of developing an improved understanding of knee joint contact loads during cycling for patients at high risk for knee OA.

ACKNOWLEDGEMENTS

Funding received from Quartus Engineering, Inc. and Cal Poly's Donald E. Bentley and STRIDE Centers.

REFERENCES

[1] McLeod, William D., and T. A. Blackburn. *The American journal of sports medicine* 8.3 (1980): 175-180.
[2] D D'Lima, Darryl, et al. *Clinical orthopaedics and related research* 440 (2005): 45-49.
[3] Dunne, James. "User's Guide." *SimTK.org*. Stanford University, 23 May 2014.
[4] Delp, Scott L., et al. *Biomedical Engineering, IEEE Transactions on* 54.11 (2007): 1940-1950.
[5] Ruby, Patricia, M. L. Hull, and David Hawkins. *Journal of biomechanics* 25.1 (1992): 41-53.
[6] Stone, Cal, and M. L. Hull. *Journal of biomechanics* 28.4 (1995): 365-375.
[7] Kraemer et al. SB^{3}C Conference Abstract (2015) (submitted)
[8] *KinTools RT For Cortex*. Santa Rosa: Motion Analysis Corporation, 2010. User's Manual.
[9] Hamner, SR, A Seth et al. Journal of Biomechanics, doi:10.1016/j.jbiomech.2010.06.025 (2010)