Parameter estimations of the hill model in subject-specific musculoskeletal models

how many measurements do we need?

de Zee, Mark; Heinen, Frederik; Sørensen, Søren Nørgaard; King, Mark; Lewis, Martin; Rasmussen, John

Publication date:
2017

Document Version
Accepted author manuscript, peer reviewed version

XVI International Symposium on Computer Simulation in Biomechanics
July 20h – 22nd 2017, Brisbane, Australia

PARAMETER ESTIMATIONS OF THE HILL MODEL IN SUBJECT-SPECIFIC MUSCULOSKELETAL MODELS: HOW MANY MEASUREMENTS DO WE NEED?

Mark de Zee[1], Frederik Heinen[1], Søren N. Sørensen[2], Mark King[3], Martin Lewis[4] and John Rasmussen[2]

[1] Department of Health Science and Technology, Aalborg University, Denmark
[2] MAKE, Aalborg University, Denmark
[3] School of Sport, Exercise and Health Sciences, Loughborough University, United Kingdom
[4] School of Science and Technology, Nottingham Trent University, United Kingdom
Email: mdz@hst.aau.dk, Web: http://personprofil.aau.dk/102065

INTRODUCTION

Musculoskeletal models have been used for decades now to investigate fundamental questions regarding our complex musculoskeletal system. Ten years ago, Erdemir et al. [1] wrote in his review that estimation of individual muscle forces during human movement also might contribute to improved diagnosis and management of neurological and orthopaedic conditions. What we see now is a transition from the fundamental research towards applications within the clinical field and the industry. The requirements for a successful transition are studies reporting successful validation of musculoskeletal models and the ability to create subject-specific models.

The last couple of years a lot of focus has been on validation and the Grand Challenge Competition [2] to predict in vivo knee loads really has facilitated this. The second requirement regarding the ability to create subject-specific models has been less in focus, while a high level of subject-specific detail is required for applications within the clinical field.

Creating subject-specific models can be divided into two elements. The first element is making sure that the model represents the same geometry as the subject. With the present imaging technology, it is possible to create models with exact bone geometry as the real subject, see for a nice example Marra et al. [3]. The second element is making sure that the model represents the muscular capacity of the subject or, in other words, trying to obtain the subject-specific parameters of the Hill muscle-tendon model typically used in musculoskeletal models. This is not a straightforward process. Imaging cannot be used, because important parameters like tendon slack length cannot be measured. Moreover, there is no direct relationship between the visible muscle morphology in images and the parameters in the phenomenological Hill model. Methods using measurements obtained from dynamometers have been described in the literature for parameter estimation of the Hill model of an individual person [4]. Creating a full dataset of, for example, the lower extremity takes much time and is very hard for the subject/patient. It would therefore be a large improvement if a good estimation of the Hill parameters were obtained from a limited number of measurements.

The aim of this study is therefore to evaluate the predictability of a subject-specific musculoskeletal model based on only isometric joint torque measurements of the whole lower extremity based on a reduced data set and a full dataset.

METHODS

One male long distance runner (height: 1.85 m, weight: 66.5 kg) was included in this study. In accordance with the regional ethical review committee, a series of maximal isometric joint torque experiments were performed on a dynamometer for the ankle, knee and hip flexors and extensors of the dominant leg. Seven evenly distributed isometric measurements were taken around the ankle joint for three different knee joint angles. The same was done for the knee joint for three different hip joint angles.

A lower extremity model was used based upon the TLEMsafe 2.0 model [5] using the AnyBody Modeling System (AMS) (AnyBody Technology A/S, Denmark). The model was geometrically scaled based on anthropometric measurements. Each experimental condition was mimicked in the model to evaluate the joint strength of the model after which two optimization procedures were conducted using the SNOPT optimizer. The first optimization (Multi_opt) used the full dataset (around 70 isometric measurements) to minimize the difference between the

experimental and simulated isometric joint strengths by changing the Hill parameters.

The second optimization (Single_opt) used only the reduced dataset (around 24 isometric measurements), where for example the ankle joint data for only one knee angle was used. The two optimization results were compared to a reference model (Ref) which was identical to the optimised model but with muscle-tendon parameters from the standard scaling in AMS.

RESULTS AND DISCUSSION

The first observation (see also Fig 1) is that both the Single_opt and Multi_opt leads to a much better subject-specific model than the Ref scaling. The normalized RMS error for Ref was about a factor 4 larger than either optimized model.

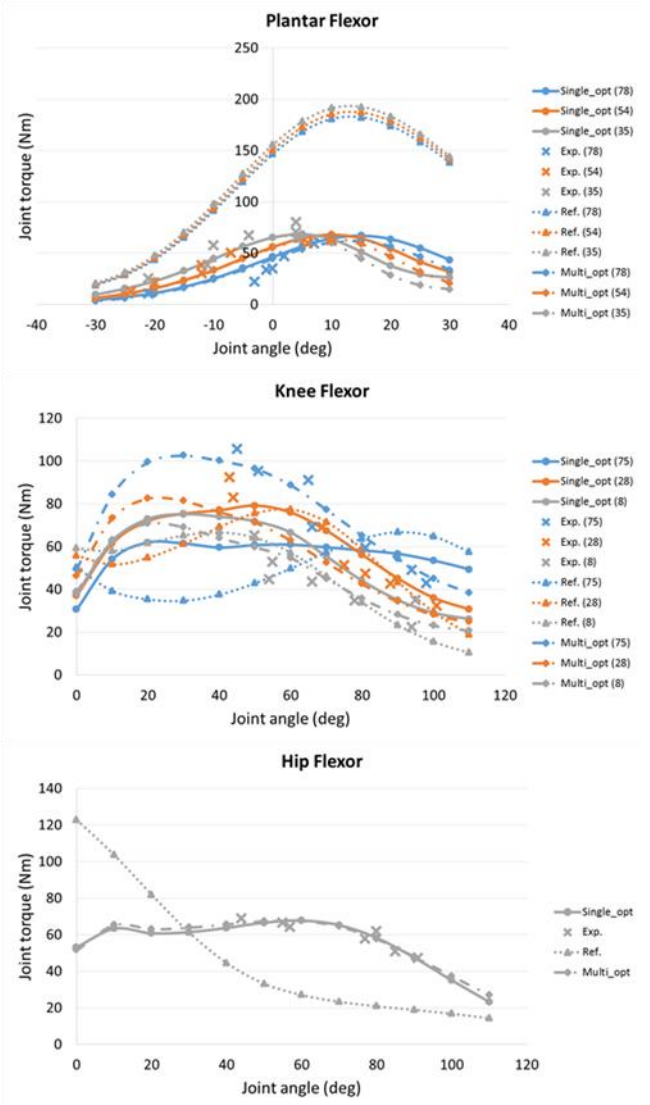

Fig 1: Isometric joint torque profiles for the plantar flexors, knee flexors and hip flexors of the: optimization based on a reduced data set (Single_opt), optimization based on a full dataset (Multi_opt), experimental data (Exp) and the reference AnyBody model (Ref).

Looking at the sum of the total normalized RMS error, the Multi_opt was somewhat smaller than the Single_opt with 27% difference. However, this difference was mostly coming from errors in the estimations for the knee flexors using Single_opt. For the other joints the difference between the Single_opt and Multi_opt were small. Figure 1 illustrates the differences for the plantar flexors, the knee flexors and hip flexors.

This could indicate that a reduced dataset is insufficient for predicting the muscle-tendon parameters of the knee flexors and hip extensors, but is sufficient for the knee extensors and the muscles around the other joints. The reason is probably that the knee flexor torque is primarily produced by bi-articular muscles and the optimizer needs therefore more data with different hip joint angles in order to obtain a good fit.

CONCLUSIONS

This study showed that estimating muscle-tendon parameters for the entire lower extremity based on a reduced dataset is sufficient for most joint torques. However, it might not be sufficient for the knee flexors/hip extensors, and the insufficiency may be due to the influence of bi-articular muscles for these joints.

The outcome of this study is important information for trying to minimize the experimental pressure on the subject and also time. However, the whole experimental procedure even with a reduced dataset plus the optimization time still takes a long time, which limits at present the applications in a true clinical environment.

REFERENCES

1. Erdemir A, et al. *Clin Biomech* **22**: 131-154, 2007.
2. Fregly BJ, et al. J. Orthop. Res., 30: 503–513, 2012.
3. Marra MA, et al. *J Biomech Eng* **137**: 020904-020904, 2015.
4. Heinen F, et al. *Proc Inst Mech Eng H.* **230**: 976–984, 2016.
5. Carbone V, et al. *J Biomech.* **48**: 734-741, 2015.