Letter to the Editor: In Response to “Consistency Among Musculoskeletal Models: Caveat Utilitor”

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To the Editor,

We read with great interest the paper “Consistency Among Musculoskeletal Models: Caveat Utilitor” by Wagner et al.12 The paper compares eight musculoskeletal models by scaling them to the same dimensions in order to evaluate differences in the quadriceps moment arms, muscle forces and tibio-femoral contact forces for a standardized knee flexion task. We would like to comment on the methods and interpretation of results presented in the paper, particularly with regard to the London Lower Limb Model (LLLM).10 As the authors of that paper, we note that the muscle force distribution between the quadriceps muscles reported in Figure 4 of Wagner et al.12 for the LLLM and described as the result of “a potential modelling error” arises from an unintended use of the model. We have not assessed the results reported by Wagner et al. for other models used in their study and so only comment on the use of our model.

The publicly available LLLM model was implemented in OpenSim,3 assessed and used for hip joint applications,10 with specific conditions and limitations associated with implementation and use of the model, reported in the documentation accompanying the model (uploaded as part of the model release pack on 3rd July 2011 available at https://simtk.org/home/low_limb_london).10 In particular, the publicly available model is meant to be used for estimating muscle forces by using the static optimization technique without including the force–length–velocity relationship. For this reason in our original publication we explicitly stated that “neither contraction dynamics nor force–length–velocity relationships were implemented for the muscle actuators”.10 The simplification we adopted is commonly accepted in studies dealing with research questions similar to ours,4,7 as the inclusion of muscle contraction dynamics does not significantly affect the simulation results in terms of muscle forces for level walking.1

Using the model as intended, the relative load share of the quadriceps muscles to equilibrate 90 Nm of torque applied at the knee (Fig. 4 of Ref. 11) calculated by minimizing the sum of muscle activation squared would have been the one reported in Fig. 1 of this letter. In order to validate results found through appropriate use of the model, we solved the static optimization problem in two independent ways for the LLLM scaled as described by Wagner et al.:12

(1) using OpenSim with a torsional spring of appropriate stiffness included in the model in order to apply a torque \( M = 90 \) Nm along the knee axis at the specified flexion angles;

(2) using an expression for the muscle forces obtained by directly solving the optimization problem. As the hip joint is fixed, the musculoskeletal model under consideration is effectively a single degree of freedom model with \( m \) muscles spanning a hinge joint (the knee), and analytical expressions can be easily calculated for each muscle force \( F_i \) as a function of the maximum isometric force \( F_{iso,i} \) and muscle moment arm \( r_i \). The expression for the \( i \)-th muscle force is given by Eq. (1):

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And the load sharing ratio between the $i$-th and $j$-th muscles is given by Eq. (2):

$$F_i = \frac{F_{iso,i}}{F_{iso,j}} \cdot \frac{r_i}{r_j}$$  \hspace{1cm} (2)

Our OpenSim simulations and the analytical solution implemented in Matlab gave identical force results (Fig. 1) within the numerical limits due to the use of different software (maximum difference in muscle forces between the two approaches was 0.12 N). The load sharing for 20° of knee flexion presents a contribution of the vastus lateralis similar to the “lower limb 2010” model as reported by Wagner et al., while the contribution of rectus femoris varies from 14.9 to 15.8% in the two postures and does not reach the high values (over 75%) reported by Wagner et al. In our results the force sharing between muscles (Eq. (2)) is almost constant in the two postures as although the moment arms of each muscle vary depending on the knee flexion angle, the ratios of the moment arms remain similar, due to the patella moving in a circle around an axis that is almost collinear with the knee axis.

We believe that Wagner et al. are right to advise users to beware of the influence adopting a specific musculoskeletal model can have on the muscle force distribution result. In addition we believe that users should be aware of the intended use and limitations of specific models, in order to avoid misinterpreting a “usage error” as a “modelling error”. Users are encouraged to develop existing models, noting that any revised model should be subject to verification, validation and falsification processes as appropriate for its intended use.

As authors and developers of the LLLM we will improve the documentation of our model in order to make clear its limitations for those OpenSim users that might not have carefully read the related publications. However, given the complexity of musculoskeletal models and the specific applications they are developed for, users are encouraged to familiarize themselves with the adopted model and take care to assess if their proposed use differs from that intended. From a user perspective, replicating analyses and attempting to contact the developers of a model to clarify uncertainties is in our opinion good practice, as is careful reading of the associated publications.

CONFLICT OF INTEREST

None of the authors have any financial or personal conflict of interest with regard to this study.

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