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PREDICTED RATHER THAN MEASURED GROUND REACTION FORCES IN MUSCULOSKELETAL MODELS SEEM TO REDUCE HIP JOINT CONTACT FORCE ESTIMATIONS

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SUMMARY

We computed the hip (HCF) and knee (KCF) compressive forces based on two full-body musculoskeletal models for three functional tasks; gait, counter movement jumps and a simple task, where the subject alternated between standing on his left and right leg (LRL). The kinematics was identical in the two models and recovered from skin marker trajectories obtained from motion capture experiments. In the first model, measured ground reaction forces (GRF) were applied under the feet. In the second model, contact conditions, including Coulomb friction, between the feet and ground were introduced and the model set up to compute the GRF together with all other forces in the model, simultaneously. A substantial drop in the computed HCF for jump and LRL and a slight increase during gait around toe-off were observed, although the computed GRF showed similar magnitudes as the measured GRF.

INTRODUCTION

The potential of musculoskeletal models can only be realized if they can be shown to provide reproducible and valid predictions of muscle and joint reaction forces. To date, musculoskeletal models tend to over-predict joint forces compared to forces measured *in vivo* [1,2]. The cause of this over-prediction is not fully understood but it has been hypothesized that the cause is due to inaccurately modeled muscle moment arms, muscle unit parameters, kinematics or the kinetic boundary conditions. As musculoskeletal models usually are scaled versions of a cadaver dataset, discrepancies between the kinematics and kinetics of the test subject and the model must be expected, but it is puzzling why over-predictions seem to occur almost exclusively. A possible explanation may be that the correct joint reaction forces represent a minimum in the set of possible computational results.

In musculoskeletal modeling based on inverse dynamics, muscle recruitment is expressed mathematically as an optimality condition [3], usually as a function of muscle forces. The forces, exchanged between the body and the environment, are functions of the muscle recruitment. When these forces are specified by means of force plate input, they mathematically function as constraints on the optimization problem and by way of the lower bound theorem increase or, in the best case, maintain the optimum value of the objective.

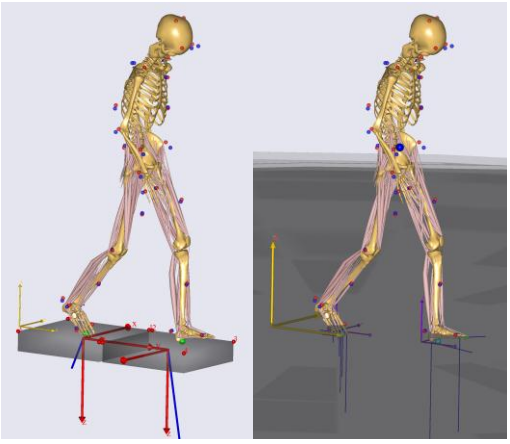

Figure 1: Musculoskeletal models during double support of gait. Left: Shows the model with the measured GRF applied under the feet. Right: Shows the model that predicts the GRF.

Thus, imposed GRF may increase the external forces in the system beyond what is necessary to maintain the overall balance of the model.

To investigate this theory, we evaluated the effect of introducing the computation of the GRF as part of the muscle recruitment problem on the hip and knee joint compressive force estimations. Also, the computed GRF were compared to the measured forces.

METHODS

One male subject (age: 32 years, mass: 65 kg, height: 1.75 m) participated in this gait lab study. The subject performed three functional trials: gait at a self-selected pace, counter movement jumps and a simple task, denoted Left-Right-Left (LRL), where the subject alternated between standing on his left and right leg. A full-body skin marker set, consisting of 37 markers was employed and their trajectories measured at 100 Hz using QTM v. 2.7 (Qualisys, Sweden). GRF were synchronously measured at 1000 Hz using two AMTI force plates (AMTI, MA, USA). Three gait cycles (from heel strike to heel strike) with clean hits on the force plates of the subject's right leg were recorded. Four counter movement jumps were repeated in sequence and three stance phases of these were identified from the first foot hit the force plate to the last foot left the force plate. Finally, three LRL cycles

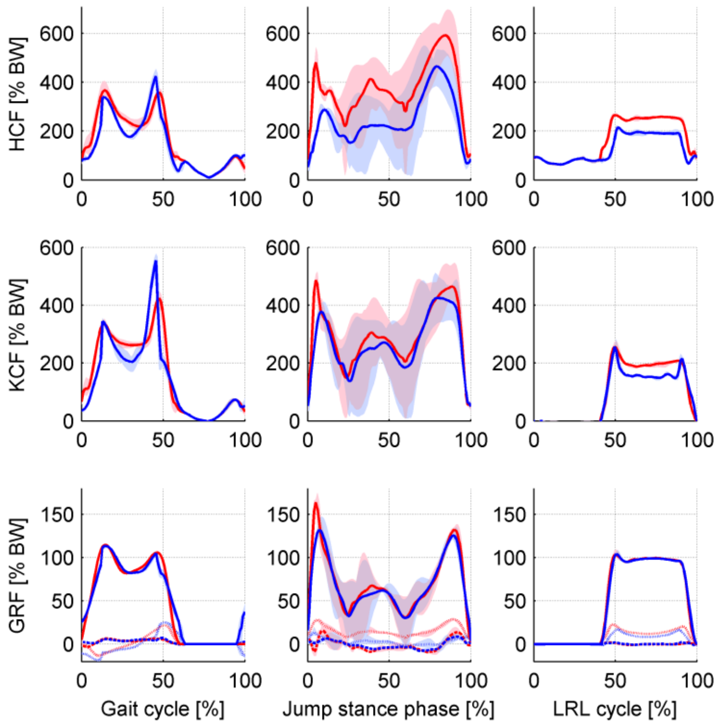

Figure 2: HCF and KCF forces computed with measured (red) and computed (blue) GRF. The shaded areas show the range over the three repetitions of each trial. In the GRF plots, the solid line shows the normal force, the dashed the medial/lateral force and the dotted line the anterior/posterior force.

were recorded. The LRL cycle was defined from the moment when the right foot left the ground until the consecutive right foot left the ground again.

Musculoskeletal models were constructed in the AnyBody Modeling System v. 5.3 (AnyBody Technology A/S, Denmark) based on the *GaitFullBody* model in the AnyBody Managed Model Repository (AMMR) v.1.5. For each functional trial, two musculoskeletal models were constructed. In the first, the typical inverse dynamics-based modeling approach was employed were the kinematics was driven by the measured marker trajectories and the measured GRF applied under the feet in the kinetic analysis. In the second model, the kinematics was identical to the first model, but the GRF was computed by the model (Figure 1). 12 contact points were defined under each foot and conditional contacts, including Coulomb friction, were established. Contact between a node and ground was defined as established when the node was within 50 mm of the ground plane and the velocity of the node relative to the ground was below 1.1 m/s

RESULTS AND DISCUSSION

The computed HCF, KCF and the measured and computed GRF are depicted in Figure 2. For the jump and LRL trials, a substantial drop of 50 % to almost 200 %BW in the HCF was observed. For gait, a slight drop in the HCF was observed during the majority of the stance phase. However, an increase in the HCF and KCF was observed around toe-off of gait.

The computed GRF show a large degree of similarity with the measured GRF in all three directions. It therefore appears that small deviations of the GRF can significantly affect the predicted joint contact forces.

Modeling errors and measurement uncertainties create a mismatch between measurements and the model. Due to the distance from the ground to the hip, a small error in the direction of the GRF, point of force application or hip joint center location can substantially affect the external hip moment. Including GRF in the muscle recruitment rather than imposing the forces seems to allow the algorithm to not only compute forces very close to the correct values but also make the small corrections necessary to make the model consistent. The simple contact model and the rigid foot segment model is likely the cause of the increase in the HCF and KCF observed around toe-off.

CONCLUSIONS

We observed a drop in the computed HCF between a model that predicts the GRF compared to a model with the external load applied. Future work should establish whether the reduction in HCF force holds across a larger population and compare the computed joint reaction forces against forces measured *in vivo* [3]. More advanced foot and contact models should also be applied.

ACKNOWLEDGEMENTS

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REFERENCES

1. Fregly BJ, et al., *J. Ortho. Res.* **30** (4): 503-513, 2012.
2. Bergmann G, et al., *J. Biomech.* **26**(8) : 969-990, 1993.
3. Rasmussen J, et al. *J. Biomech.* **34** (3): 409-415, 2001.