ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

HIP JOINT CONTACT FORCES CALCULATED USING DIFFERENT MUSCLE OPTIMIZATION TECHNIQUES

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SUMMARY

The goal of this study was to calculate muscle forces using different optimization techniques and investigate their effect on hip joint contact forces in gait and sit to stand. These contact forces were compared to measured hip contact forces [3]. The results showed that contact forces were overestimated, especially when muscle forces were calculated using computed muscle control. For static optimization, results were closest to measured contact forces. Also, differences between measured and calculated contact forces were dependent on the movement analyzed.

INTRODUCTION

Musculoskeletal models can be used to calculate joint contact forces. To do so, muscle forces need to be calculated for which several optimization techniques can be used. These techniques are often compared at the level of muscle forces itself [1], [4]. However, there is a direct relation with the contact forces. The extent of the influence of the different optimization techniques on the contact forces is unknown. Also, hip contact forces, in contrary to muscle forces, can be validated to available measured hip contact forces [3]. Therefore, the goal of this study is to calculate muscle forces using different optimization techniques and examine their effect on hip joint contact forces.

METHODS

Five subjects (56±3 yrs.), 2 male and 3 female, were included in the study and signed an informed consent. For each subject one gait and sit to stand trial at self-selected speed were selected for analysis. 3D marker trajectories were captured using Vicon (VICON, Oxford Metrics, Oxford, UK) and force data was measured using two AMTI force platforms (Advanced Mechanical Technology Inc., Watertown, MA).

The musculoskeletal model consisted of 12 segments, 19 degrees of freedom and 92 musculotendon actuators. All analyses were performed in OpenSim 2.4.0 [5]. To calculate hip joint contact forces, the model was first scaled using the marker trajectories of a static pose. This scaled model was used for an inverse kinematics procedure after which a residual reduction algorithm (RRA, [9]) was used. This procedure was used to minimize the effects of errors in modeling and marker kinematics by changing the kinematics and adjusting the mass of the segments and the center of mass of the torso.

To calculate muscle forces, different methods were used. Two procedures in OpenSim were used, static optimization ($SO_{OpenSim}$) and computed muscle control (CMC, [8]). $SO_{OpenSim}$ is an inverse dynamics approach which calculates individual muscle forces by minimizing muscle activation. CMC combines a static optimization with feedforward and feedback controls to calculate muscle excitations, and therefore muscle forces. Two methods outside of OpenSim were also used, a static optimization algorithm developed in the lab using Matlab (SO_{Matlab}, The MathWorks Inc.) and the physiological inverse approach (PIA, [4]). SO_{Matlab} is based on the optimization algorithm developed by Lenaerts et al. [6]. This optimization has constraints to the cost function which impose a physiological increase and decrease of muscle activation in time. An important difference between $SO_{OpenSim}$ and SO_{Matlab} is that SO_{Matlab} also accounts for the passive forces. PIA is an optimization technique that combines an inverse dynamics approach with muscle activation and contraction dynamics [4]. Finally, hip joint contact forces were calculated using the JointReaction analysis in OpenSim for all different methods [7].

The calculated contact forces were evaluated against contact forces measured with instrumented hip implants (HIP98, [3]). For every method the typical signals of the minimum, maximum, 25^{th} and 75^{th} percentile and median were calculated over the resultant forces of the five subjects [2]. Root mean squared error (RMSE) and Pearson correlation coefficient (R) were calculated with respect to the average curve of the HIP98 dataset.

RESULTS AND DISCUSSION

For gait, the results show an overestimation of the contact forces for all optimization techniques. For all techniques, the first peak tends to be higher than the measured forces (figure 1). The contact forces calculated using CMC are highest, while both static optimizations are closest to HIP98. For the second peak, the calculated contact forces are much higher than HIP98 (figure 2). Again the forces calculated using CMC are highest and can be unrealistically large. Since CMC uses feedforward and feedback controls, this could cause an increase in muscle force and therefore an increase in contact force. The large overestimation is also reflected in the RMSE values, where CMC has a large error compared to

both static optimizations and PIA (table 1). However, correlation varied between moderate and high for all techniques (table 1).
For sit to stand, the calculated contact forces are closer to HIP98 (figure 3). However, there still is an overestimation for all optimization techniques. Again, both SO techniques result in contact forces closest to the measured HIP98 data. The error is smaller than for gait and correlation is high for all optimization techniques.

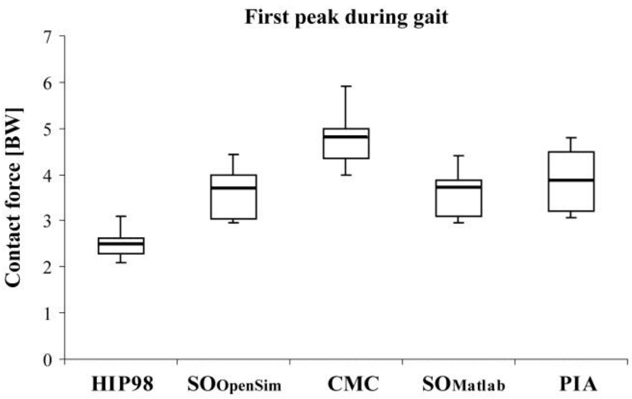

Figure 1: Variation in the first peak of hip contact force in gait (expressed in body weight (BW)) using different optimization techniques.

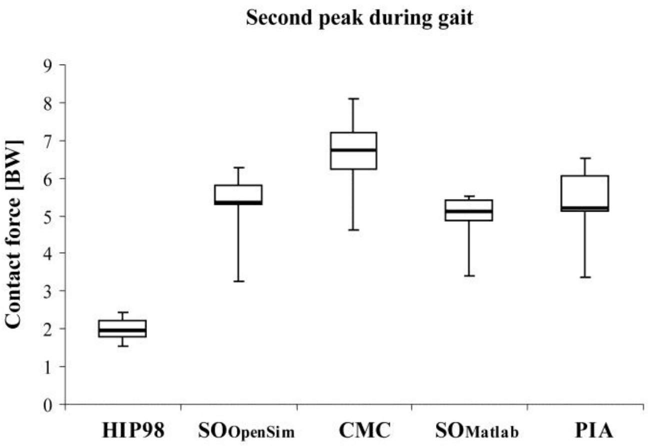

Figure 2: Variation in the second peak of hip contact force in gait (expressed in body weight (BW)) using different optimization techniques.

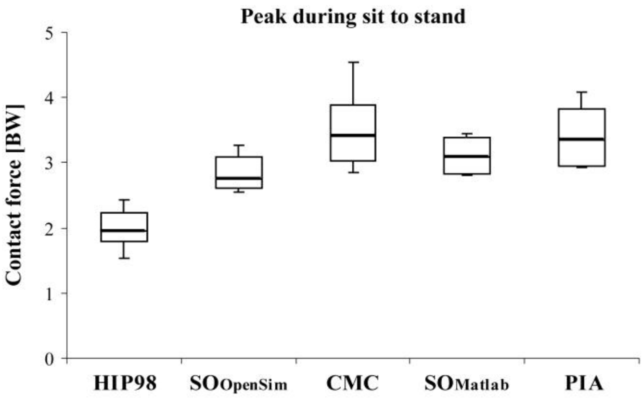

Figure 3: Variation in the peak of hip contact force in sit to stand (expressed in body weight (BW)) using different optimization techniques.

CONCLUSIONS

In conclusion, all optimization techniques used to calculate muscle forces show an overestimation of contact forces compared to data measured using instrumented hip implants. The magnitude of overestimation differs depending on the simulated motion. Both static optimization techniques produce results closest to measured contact forces, with the smallest error and a high correlation compared to measured hip contact force.

ACKNOWLEDGEMENTS

The support of the Agency for Innovation by Science and Technology (IWT-TBM no 100786) is gratefully acknowledged.

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Table 1: The range of RMSE (expressed in body weight (BW)) and R for the hip contact forces calculated using different optimization techniques.

		$SO_{OpenSim}$	**CMC**	**SO_{Matlab}**	**PIA**
Gait	RMSE range [BW]	0.694-1.720	1.494-3.446	0.736-1.678	0.798-1.886
	R range	0.758-0.929	0.636-0.949	0.754-0.949	0.715-0.927
Sit to stand	RMSE range [BW]	0.355-0.815	0.568-1.975	0.495-0.920	0.375-1.339
	R range	0.974-0.996	0.886-0.994	0.975-0.995	0.971-0.995