Utilizing the ground reaction force vector and lateral knee marker for estimating knee moments in gait

Jere Lavikainen[1,2], Mika E. Mononen[1], Lauri Stenroth[1]
[1]University of Eastern Finland, Department of Technical Physics, Kuopio, Finland
[2]Diagnostic Imaging Center, Kuopio University Hospital, Wellbeing Services County of North Savo, Kuopio, Finland
Email: jere.lavikainen@uef.fi

Summary

We developed surrogates for inverse dynamics knee adduction and flexion moments to enable their estimation during walking without an extensive marker set and model calibration. Our surrogates have excellent intra-trial correlation with inverse dynamics moments (R>0.8), but their error varies throughout the stance phase. Nonetheless, they correctly detect the intra-subject direction of change in knee moment peaks with more than 80% accuracy when walking speed is modified. Therefore, they may present a simpler alternative to biomechanical modeling and linked segment inverse dynamics calculations for gait retraining purposes where knee loads are to be altered.

Introduction

Knee adduction moment (KAM) and knee flexion moment (KFM) can be targeted in retraining programs to reduce physical knee loads [1]. However, their evaluation requires creating a participant-specific biomechanical model, solving its kinematics using motion capture data, and utilizing inverse dynamics (ID) to calculate the net joint moments. The process is cumbersome, requiring the placement of multiple motion capture markers [2]. We examined the feasibility of estimating KAM and KFM from force plate data and a single motion capture marker on the lateral epicondyle of the knee to develop more accessible surrogates for KAM and KFM.

Methods

We analyzed the motion capture data of 36 participants where each participant had ten overground walking trials per three walking speeds (self-chosen comfortable, slow, and fast) [3]. A set of markers placed on key anatomical landmarks was used to create participant-specific skeletal model by scaling followed by calculation of KAM and KFM using inverse kinematics followed by inverse dynamics.

Additionally, we estimated the knee joint center by offsetting the position of the lateral knee epicondyle marker by the marker's dimensions and half of the manually measured width of the knee perpendicular to the direction of motion, i.e., along one of the axes of the laboratory coordinate system. We then calculated the cross product between the GRF vector and the vector from the center of pressure of the foot to the estimated knee joint center. We extracted surrogates for KAM and KFM from the components of the cross product in the laboratory coordinate system.

We compared the full time series and first and second peaks of surrogate moments against ID moments to evaluate their accuracy and sensitivity to changes. To evaluate how the surrogate moments can predict the direction of change of intra-participant KAM and KFM peak variation, we compared the sign of change from the mean value of the comfortable speed walking trials between the surrogate moments and corresponding ID moments in each trial.

Results and Discussion

Overall, in 1080 walking trials, the mean intra-trial root mean square error of the surrogates was 9.11 Nm for KAM and 12.9 Nm for KFM, and the mean intra-trial linear correlation was R=0.87 for KAM and R=0.97 for KFM. The inter-subject differences in the errors are likely explained by the surrogates' sensitivity to knee marker placement and knee width measurement.

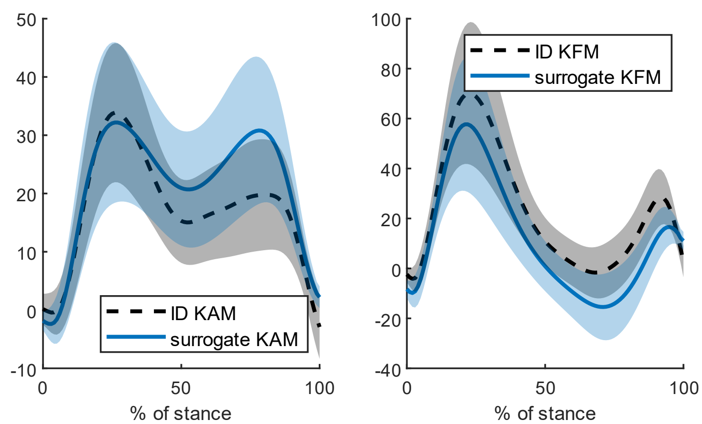

Figure 1: The mean and standard deviation (shaded area) of the surrogate and inverse dynamics (ID) KAM and KFM over all 1080 walking trials.

Conclusions

The reported surrogates of KAM and KFM present a way to estimate loads in the knee joint. They are particularly useful when evaluating the direction of change of external knee moments with a very limited marker set.

References

[1] Richards RE et al. (2018). *Osteoarthr. Cartil.*, **26**: 1203-1214.
[2] Karatsidis A et al. (2016). *Sensors*, **17**: 75.
[3] Lavikainen J et al. (2024). *Data in Brief*, **56**: 110841.

Table 1: Fraction of walking trials where the surrogate moment correctly predicted the direction of change from the mean moment of comfortable walking speed trials.

Surrogate peak	KAM (1st peak)	KAM (2nd peak)	KFM (1st peak)	KFM (2nd peak)
Accuracy of change (%)	80.6	86.7	95.6	80.4