

# IMPACT OF JOINT CONSTRAINTS IN A MUSCULOSKELETAL MODEL WITH EXPLICIT REPRESENTATION OF CONTACTS AND LIGAMENTS

Manuel Romeo (1), Michele Conconi (1), Nicola Sancisi (1), Raphael Dumas (2)

1. Department of Industrial Engineering, University of Bologna, Italy;
2. Univ Eiffel, Univ Lyon 1, LBMC UMR\_T 9406, France.

## Introduction

The growing research for comprehensive musculoskeletal models aims to improve joint definition. Parallel mechanisms [1] have been introduced in musculoskeletal models [2] to best mimic natural knee and ankle kinematics, and to introduce an explicit representation of contact and ligament constraints. The impact of specific knee ligaments and the number of degrees of freedom defined for the ankle are to be examined. Using the TLEM 2.0 dataset [3], four models with similar kinematics but different joint constraints are developed and evaluated, pointing out the impact of each characteristic.

## Methods

Parallel mechanisms were synthesized from the natural kinematics, obtained as the envelopes of bone positions and orientations that maximize the joint congruences [4]. The geometric parameters were optimized to best fit the kinematics while maintaining articular contact and isometric ligaments. Two mechanisms for the knee and two for the ankle have been synthesized, their combination giving the four models. The first knee mechanism includes two sphere-on-plane contacts and three ligaments (i.e. PCL, MCL, and LCL) for the tibiofemoral joint, a hinge joint and the patellar tendon for the patellofemoral joint. The missing ACL complies with total knee arthroplasty, as in the data used for validation [5]. The second knee mechanism embeds ACL, MCL and PCL, as in the standard definition of knee parallel mechanism [1]. The first ankle mechanism shows 1-DoF and includes a spherical joint and two ligaments (i.e. TiCaL and CaFiL), while the second one shows 2-DoF by adding a hinge on the subtalar joint. All constraints in the model are represented explicitly, so that the individual forces at the contacts and ligaments are computed and considered during the static optimization step. The lower limb model [3] comprises five segments (i.e. pelvis, thigh, patella, shank, foot), four joints (i.e. spherical for the hip, parallel mechanisms for the ankle and knee) and 163 muscle lines of action. The inverse kinematics step minimizes the sum of squared distances between modelled and measured skin markers. Then, the inverse dynamics step simultaneously minimizes the sum of squared musculotendon, joint contact and ligament forces [2]. They were restricted to a minimum value of 0 to prevent ligaments and muscles from pushing.

## Results

Gait trials ( $n = 4$ ) from the Grand Challenge competition [5] were analysed. Marker trajectories are well

replicated in all cases, but the two models with the 2-DoF ankle mechanism get closer to a realistic position and estimate contact forces better (Fig.1). In addition, the model gives information on joint contact forces at the ankle and hip, and on ligament forces.

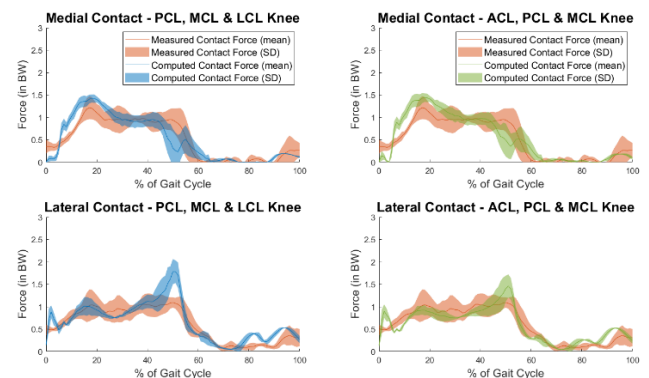


Figure 1: Measured and computed tibiofemoral contact forces using different knee mechanisms and the same 2-DoF ankle mechanism (Subject DM)

|         | JW        | PS        | SC        | DM        |
|---------|-----------|-----------|-----------|-----------|
| Medial  | 0.41-0.45 | 0.19-0.26 | 0.29-0.36 | 0.26-0.29 |
| Lateral | 0.25-0.38 | 0.26-0.33 | 0.20-0.31 | 0.24-0.29 |

Table 1: Ranges of rms errors between measured and computed tibiofemoral contact forces with the 4 models, over the 4 subjects (on each column)

## Discussion

The development of models with explicit representation of joint constraints makes it possible to directly calculate and interpret the forces comprehensively. All four proposed models predict contact forces (i.e. for scaled-generic models) and can be adapted to the outcomes that need to be investigated (e.g. healthy or prosthetic knee).

## References

1. Sancisi et al, *Meccanica*, 52: 695–71, 2017.
2. Moissenet et al, *J. Biomech*, 47: 50-58, 2014.
3. Carbone et al, *J. Biomech*, 48: 734-741, 2015.
4. Conconi et al, *IEEE Trans. Biomed. Eng.*, 68: 1084-1092, 2021
5. Fregly et al, *J. Orthop. Res.*, 30: 503-513, 2012.

## Acknowledgements

This work was supported by a grant from the Franco-Italian University (Partenariat Hubert Curien) project Galileo #48932SG.

