Performance assessment of a hinged knee prosthesis in daily dynamic activities through multibody modeling with integrated flexibility

PERFORMANCE ASSESSMENT OF A HINGED KNEE PROSTHESIS IN DAILY DYNAMIC ACTIVITIES THROUGH MULTIBODY MODELING WITH INTEGRATED FLEXIBILITY

Giovanni Putame (1,2), Federico Bologna (1,2), Alessandra Aldieri (1,2), Simone Borrelli (1,2), Alberto Audenino (1,2), Mara Terzini (1,2), Cristina Bignardi (1,2)

1. Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy
2. Polito^{BIO}Med Lab, Politecnico di Torino, Italy

Introduction

In silico approaches are garnering increased attention for their applicability and the resulting cost reduction in medical devices certification process. Nowadays, the market offers a variety of knee prostheses; in particular, hinged designs undergo significant reaction forces and incorporate more components than their unconstrained counterparts. The numerical modeling of these prostheses poses a challenge, especially when considering dynamic loading conditions from daily activities [1] within the Finite Element Method (FEM). This study aims to assess the mechanical performance of a hinged knee prosthesis under various Body Weights (BWs) and daily activities, exploring the applicability of a Multibody (MB) approach with integrated flexibility as an alternative to FEM.

Methods

Using the geometries of a left hinge knee prosthesis (Pantheon, Adler Ortho SpA), a MB model was developed in Adams (MSC Software Corp.), including contact pairs, kinematics constraints, and BW-dependent loading conditions defined according to the standard ASTM F3141-23. Additionally, a hinge component of the prosthesis, considered to be critical, was modelled as a flexible body based on the modal analysis. Then, twelve simulations were carried out by varying different BWs (50, 100, and 200 kg) and daily activities (walking - WN, stair ascent - SA, stair descent - SD, and sit-to-stand-to-sit - SS). Eventually, kinetics outcomes and von Mises stresses within the flexible hinge component were computed.

Results

Simulations revealed a linear dependence between the resulting reaction force magnitude at the hinge (RFM_H) and the BW. Overall, walking was the most demanding activity in terms of RFM_H showing the highest sensitivity to BW increase (9.5 N/kg). However, focusing on the antero-posterior direction, the highest corresponding reaction force component was observed during stair descent. Concerning the stresses experienced by the critical component of the hinge, walking produced the highest value (Table 1) with the peak stress located laterally at the posterior fillet (Figure 1). Conversely, the sit-to-stand-to-sit activity showed the lowest stress (Table 1) and sensitivity to BW variation (4.3 N/kg).

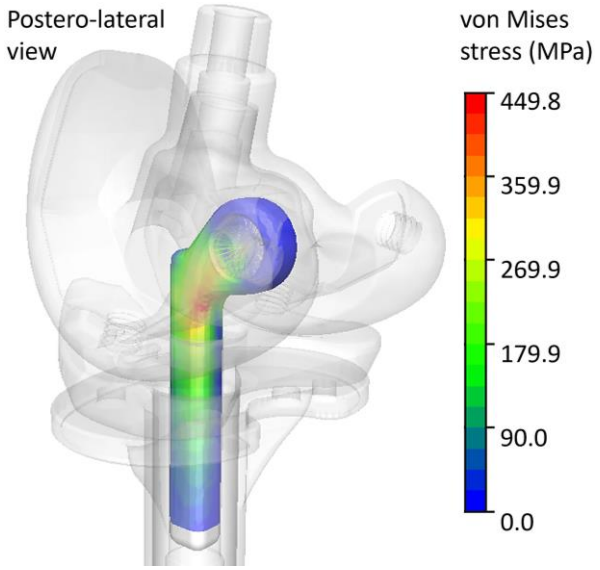

Figure 1: von Mises stress distribution on the hinge component during walking for a BW of 100 kg.

Activity	WN	SA	SD	SS
Stress (MPa)	449.8	205.9	304.9	181.8

Table 1: Maximum von Mises stress computed for different living activity considering a BW of 100 kg.

Discussion

The performed MB analysis, incorporating a flexible component, has demonstrated its efficacy not only in pinpointing the most crucial daily activity for a hinged knee prosthesis (*i.e.*, walking, given its higher dynamic loadings [1]) but also in providing the necessary stress distributions for the subsequent potential application of fatigue criteria. The adopted approach allowed for addressing dynamic loading conditions involving multiple contacts while maintaining a lower computational cost compared to the FEM. The implemented model can be easily generalized, serving as an *in silico* framework to expedite the performance evaluation of implant designs.

References

1. Bergmann et al., PloS ONE, 9:e86035, 2014.

Acknowledgements

Authors thank Adler Ortho SpA for providing the implant geometries used in the performed simulations.