Musculoskeletal Modeling Approach through Multisegment Foot Dynamics can efficiently support Diabetic Foot Prevention

M. Dalle Vacche[1], E. Sarcina[1], F. Spolaor[1], Z. Sawacha[1]
[1]Department of Information Engineering, University of Padua, Padua, Italy
Email: maria.dallevacche@unipd.it

Summary

In this study, an enhanced musculoskeletal 8 degrees-of-freedom (DOF) foot model implemented in OpenSim was adopted [1]. The model includes extrinsic and intrinsic foot muscles, foot ligaments, multisegmental foot kinematics and kinetics, as well as the dynamics of other joints throughout the body. This comprehensive approach ensured precise characterization of foot biomechanics that can be useful in characterizing the impact of neuropathy and diabetes on foot biomechanics. Results showed significant differences in muscle forces: reduced Peroneus Brevis and Flexor Digitorum forces across the stance phase in all pathological subjects, along with increased Flexor Hallucis forces during midstance and pushoff. These findings suggest an imbalance between flexor and extensor foot muscle forces in diabetic and neuropathic individuals, supporting the need for targeted physical activity protocols involving selective muscle strengthening to improve gait mechanics and prevent foot complications.

Introduction

Peripheral neuropathy and vasculopathy, common complications of diabetes mellitus, can lead to callus formation, ulcers, and amputations. The literature has identified biomechanical analysis as an effective tool for prevention [2]. Specifically, gait analysis and musculoskeletal modeling can provide insights into variables such as joint kinematics, kinetics, and plantar pressure analysis. When integrated, these variables enable a more precise understanding of gait differences between healthy, diabetic and neuropathic individuals, facilitating the development of personalized treatments [2,3].

Methods

20 subjects (mean age and BMI: 55.4 ± 11.4 years, 25 ± 4.1 kg/m²) were enrolled for this study. In particular, 9 control, 6 diabetic, and 5 neuropathic subjects' gait were acquired through 6 BTS cameras (60 Hz), synchronized with two Bertec force platforms (960 Hz), a 12-channel sEMG system (1000 Hz) and 2 plantar pressure systems (Imago Ortesi). 13 reflective markers were placed according to Padova Foot Model protocol [3]. Data files (.c3d) were first processed using Matlab's MOtoNMS toolbox [4] and then used to feed an 8-DOF Foot musculoskeletal Model [1]. The inverse kinematics and inverse dynamic simulations were conducted in OpenSim, where ground reaction forces were segmented into rearfoot, midfoot, and forefoot contributions to better analyze foot mechanics [1]. Moreover, muscle activations and muscle forces were estimated via Static Optimization and compared with sEMG envelopes for validity assessment [2]. Statistical Parametric Mapping (SPM) analysis [5] was conducted to compare the three groups.

Results and Discussion

In Figure 1 the estimated muscle forces obtained through Static Optimization can be observed. Statistically relevant differences with respect to the control subjects can be observed especially for Flexor Digitorum and Peroneus Brevis. A reduced Peroneus Brevis force was measured over the whole stance phase of gait accompanied by a reduced Flexor Digitorum force, while excessive forces were registered at Flexor Hallucis at midstance and pushoff.

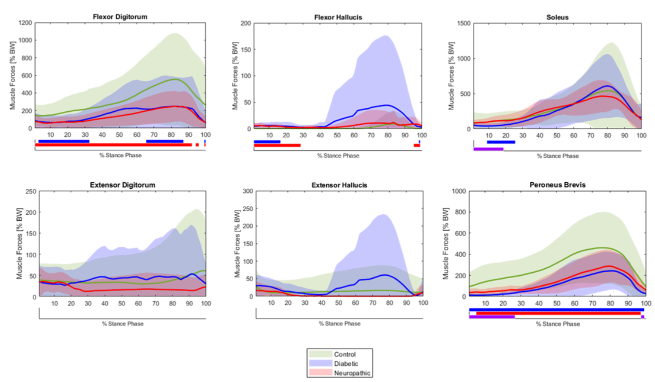

Figure 1: Muscle forces comparison between control (green), diabetic (blue) and neuropathic (red) group: mean ± std. *statistical significance (p<0.05)

Conclusions

Results of the present study seem to indicate an imbalance of the flexor and extensor foot muscle forces during gait in pathological subjects. This methodology could be used for planning specific selective foot muscles strengthening protocols, and assessing the effect of the interventions.

References

[1] Malaquias TM et al. (2017). *Comput. Methods Biomech. Biomed. Eng.*, **20**: 153-159
[2] Scarton A et al. (2018). *Gait & Posture*, **60**: 279-285.
[3] Sawacha Z et al. (2012). *Gait Posture*, **36**: 20-26.
[4] Mantoan et al. (2015). *SourceCode for Biology and Medicine*, **10**: 12.
[5] Pataky TC (2012). *Comput. Methods Biomech. Biomed. Engin*, **15**: 295-3