Using Optimal Control and Artificial Intelligence to Predict Transtibial Prosthetic Alignment Changes During Gait

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Summary

In this study, four methods were applied to analyze the effect of changes in prosthetic foot alignment on the gait of transtibial amputees (TTA). Inverse dynamics (ID) was performed in Vicon Nexus and in OpenSim respectively. Artificial intelligence (AI) informed by inertial measurement unit (IMU) data, and predictive simulation based on optimal control were used to predict gait kinetics respectively. The effect of altering prosthetic foot alignment was inconsistent between the ID methods, but we were able to predict the same effect using both AI and optimal control. This suggests that these methods may be useful for investigating prosthetic gait.

Introduction

Prosthetic gait differs considerably from the unimpaired gait. The alignment of the prosthetic foot and socket plays an important role in attaining optimal gait of individual TTA patients. Thus, inappropriate or suboptimal alignment can affect gait kinetics [1]. Therefore, the application of innovative methods to analyze the prosthetic gait may be of great value to better understand the effects of altered prosthetic alignment. The aim of this work is to compare four different methods of analyzing the gait of TTA under different prosthetic alignment conditions.

Methods

We captured the gait of 14 healthy subjects and 14 unilateral TTA patients. Motion capture, ground reaction force, and IMU data were collected. ID was performed in Vicon Nexus (VN-ID) and kinetic data was calculated using the predefined model. A long short-term memory neural network (NN) was generated to estimate gait kinetics using IMU data as input (IMU-AI). The NN was trained using VN-ID data. The result of one TTA (TTA1), which was not included in the training dataset, was analyzed. A musculoskeletal model of TTA1 was created using OpenSim and kinetic data was obtained using ID (OS-ID) [2]. Predictive simulation based on optimal control (Pred-OC) was performed and gait patterns independent of experimental data were predicted [3-4]. The gait of TTA1 was analyzed with optimal prosthetic alignment (REF), and with the prosthetic foot translated 10 mm posteriorly (POS).

Results and Discussion

Analyzing VN-ID results of the complete dataset, we observed a statistically significant ($p < 0.05$) decrease of the ipsilateral (IL) peak knee extension moment (PKEM) of the patients during the stance phase compared to the healthy subjects and to contralateral (CL) side. All methods showed a lower IL than CL PKEM during the gait of TTA1 (Figure 1). We also observed an increase in IL PKEM during the POS condition compared to REF in OS-ID, IMU-AI and Pred-OC. In VN-ID, the effect of POS on PKEM was the opposite as observed in the other methods on the IL side, but similar on the CL side (Figure 1).

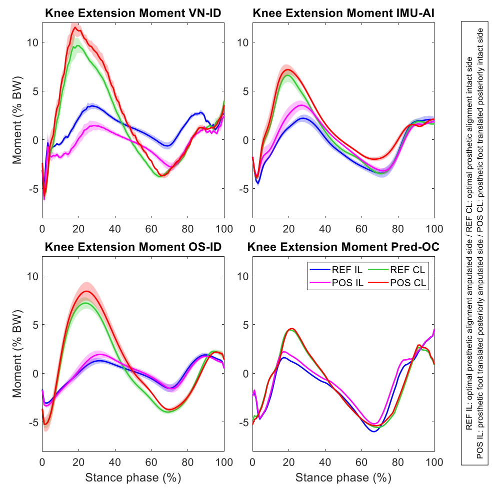

Figure 1: Internal knee extension moment of TTA1 walking with different prosthetic alignments.

VN-ID and OS-ID may be considered the gold standard in gait analysis. However, the effect of changing the prosthetic alignment on knee moment was inconsistent between these two methods (Figure 1). IMU-AI has the potential to allow measurements outside the gait laboratory. Pred-OC has been used to analyze the cause-effect relationship of alterations in musculoskeletal system. Even though IMU-AI was trained using data from VN-ID, the effect of the altered prosthetic alignment was consistent to OS-ID and Pred-OC.

Conclusions

We were able to predict the effect of changed prosthetic alignments using IMU-AI and Pred-OC in a representative patient, but the magnitude of the moments differed between the methods. Although the results may be promising, further analysis will be needed to investigate the utility of these different approaches.

References

[1] Zhang T et al. (2020). *Gait Posture*, **76**: 85-91.
[2] Delp SL et al. (2007). *IEEE Trans Biomed Eng*, **54**: 1940-1950.
[3] Falisse A et al. (2019). *J R Soc Interface*, **16**: 20190402.
[4] Santos GF et al. (2025). *PLoS One*, **20**: e0314758.