Identifying and characterizing biomechanical gait subpopulations in hip osteoarthritis with explainable machine learning

Bernd J. Stetter[1], Jonas Dully[1], Stefan van Drongelen[2], Felix Stief[3], Jana Holder[4], Hannah Steingrebe[1,2], Frank Zaucke[2], Stefan Sell[1,5], Thorsten Stein[1]

[1]Institute of Sports and Sports Science, Karlsruhe Institute of Technology, Karlsruhe, Germany

[2]Dr. Rolf M. Schwiete Research Unit for Osteoarthritis, Goethe University Frankfurt, Frankfurt am Main, Germany

[3]Berufsgenossenschaftliche Unfallklinik Frankfurt, Function and Motion Lab, Frankfurt am Main, Germany

[4]Department of Sport and Exercise Science, University of Salzburg, Salzburg, Austria

[5]Joint Center Black Forest, Hospital Neuenbuerg, Neuenbuerg, Germany

Email: bernd.stetter@kit.edu

Summary

Understanding specific biomechanical gait adaptations to hip osteoarthritis (HOA) and joint replacement is highly relevant in providing tailored rehabilitation. In this study, we identified three characteristic subpopulations among 108 patients with unilateral HOA. We then assessed their gait kinematics and joint moment differences compared to healthy controls (n = 56). Additionally, the subpopulation-specific effects of total hip replacement (THR) were analyzed based on data from 64 patients.

Introduction

Machine learning offers powerful methods to advance HOA research and treatment options by analyzing high-dimensional biomechanical datasets, supporting targeted treatment [1,2]. The aims of this study were (1) to identify groups of patients (i.e., subpopulations) who respond differently to HOA by exhibiting different adaptations in gait kinematics and joint moments, and (2) to assess the subpopulation-specific effects of surgical treatment in a second examination after THR.

Methods

Three datasets were analyzed: a dataset of 108 unilateral HOA patients before THR (PRE), a subset of PRE consisting of 64 patients who participated in a second examination (7-25 month) after THR (POST), and a dataset of 56 healthy controls (HC). All datasets included 3D laboratory-based gait analysis data. Principal component analysis was used to reduce the gait cycle waveforms (angles and moments) of 3D pelvis, ipsilateral 3D hip, ipsilateral 3D knee, and ipsilateral sagittal ankle joint as well as the ipsilateral foot progression angle to 14 features. These features were used for k-means clustering to identify PRE subpopulations. Linear Support Vector Machines were applied to classify the subpopulations and the HC, and the POST was re-evaluated using these models. Classification rates were determined as the percentage of correctly classified individuals. SHapley Additive explanations were used to identify the most important biomechanical waveforms. In addition, a low-dimensional classifier-oriented gait score was evaluated as a measure of gait quality [3].

Results and Discussion

Three PRE subpopulations were identified that exhibited different adaptations in gait kinematics and joint moments. Individual classification rates for the subpopulations ranged from 51.4% to 85.2%. Across all subpopulations, hip flexion and rotation waveforms (angles and moments) were identified as most important for classification. Two subpopulations showed reduced hip moments, while one subpopulation showed altered hip and pelvic kinematics. The classifier-oriented gait score improved uniformly in all subpopulations, suggesting an overall beneficial effect of THR (Figure 1). However, subpopulation two showed minor improvements in gait biomechanics compared to HC, supporting different functional outcomes after THR [2].

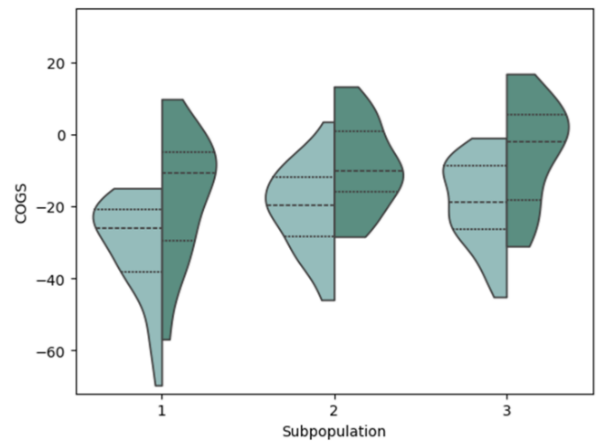

Figure 1: Violin plots for the classifier-oriented gait score (COGS). Negative values indicate classification as HOA, with a higher value indicating greater biomechanical differences compared to HC. Light green = PRE; dark green = POST.

Conclusions

This study provides a differentiated view of gait adaptations in patients with HOA before and after THR. Identifying a patient's affiliation with a specific subpopulation allows clinicians to gain deeper insights into gait adaptations in HOA, enabling the development of rehabilitation programs tailored to their individual needs.

Acknowledgments

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References

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