Novel predictive simulations produce common gait alteration from gait retraining: towards *in silico* informed rehabilitation for knee osteoarthritis

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Summary

Gait retraining is emerging as a popular therapeutic intervention of knee joint osteoarthritis (OA) aiming to reduce compressive loading on the affected joint. Instructions are typically generic and uniform for all patients, however, novel predictive *in silico* models can be used to inform, personalize, and optimize treatment effects. Here we present a framework with practical proof-of-concept for personalized *in silico* informed gait retraining. Initial results indicate changes to lumbar and hip kinematics can effectively reduce compressive loads with minimal changes to other joint kinematics.

Introduction

Osteoarthritis (OA), in particular knee OA, is a highly prevalent and debilitating disease. No cure or proven strategy to prevent or slow the disease is widely accepted. OA is a highly multifactorial disease with abnormal mechanical loading seen as a key driver [1]. As such many treatments are aimed at reducing this loading such as gait retraining – targeting kinematic alterations to achieve this goal.

Gait retraining typically uses generic instructions such as trunk lean or altered foot progression angle with only limited effects. Instead, a highly personalized approach may optimize long term effects. To do so – *in silico* based predictive simulations present an exciting opportunity. Previous research [2] has attempted to do just this, however without direct estimates of contact forces, and by highly constraining the solution to a specific form of gait adaptation. As such, new, and potentially more optimal solutions could be ignored.

Methods

A novel predictive simulation framework [3] was customized. Specifically, adding terms to (1) minimize knee joint contact forces (JCF), and (2) loosely track patient specific initial kinematics. The used musculoskeletal model was updated to reflect the state-of-the-art used for inverse simulations [4] and to allow separate estimation of medial and lateral JCF. We used a single patient's gait pattern to loosely track and run multiple predictive simulations. Specifically (1) standard optimal control problem (OCP) as a reference, (2,3) JCF minimization and loose tracking with uniform weights on sagittal plane hip, knee, and ankle kinematics, and (4,5) same as 2,3 but with non-uniform weights. Following predictive simulations, resulting kinematics, and ground reaction forces were reprocessed using COMAK to estimate more precise JCF and kinematics. Joint kinematics, and JCFs were then compared to determine the effect of changing the OCP and evaluate utility for personalized *in silico* gait retraining.

Results and Discussion

By changing the OCP and including tracking terms for JCF minimization and kinematics– unique gait patterns were generated. Each gait pattern resulted in altered JCF (Figure 1A), as well as kinematic variation (Figure 1B).

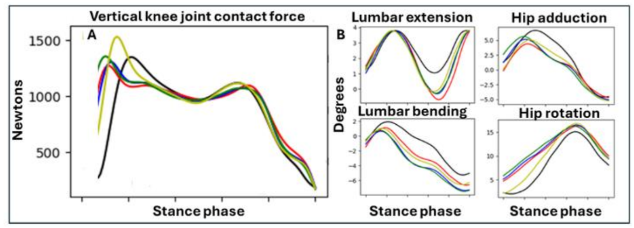

Figure 1: (A) Total vertical knee JCF and (B) selected kinematics for reference (black), uniform kinematic tracking of weights 2 and 3 (red & blue respectively), non-uniform tracking of knee and ankle (yellow & green respectively)

When changing from the reference, kinematic changes can primarily be seen in the lumbar and non-sagittal hip degrees of freedom (DOFs). Although JCF from the later simulations are of similar magnitude to the reference– it should be noted that this condition is not tracking the initial gait pattern. By altering the weights on specific DOFs, reductions, particularly at first peak are achieved. Interestingly the DOFs variations emerging when reducing JCF, are those often implemented in gait retraining i.e., trunk lean and foot progression angle.

Conclusions

The developed workflow provides an exciting opportunity for *in silico* informed gait retraining whereby patient specific geometry, and initial gait patterns can be accounted for when determining the optimal gait retraining strategy. This builds on existing predictive simulations [3], by allowing kinematic tracking and JCF minimization. It also builds on earlier [2] approaches by explicitly estimating JCFs and allowing more complex OCP. The developed framework pairs seamlessly with the COMAK workflow allowing for the inclusion of patient specific alignment and geometry as well framework validation. On-going research is focused on investigating altered OCP formulations, including patient specific geometry and alignment, adding more patients, and an *in vivo* validation with real patients.

References

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