

# SIMULATION-BASED TREATMENT PLANNING FOR KNEE OSTEOARTHRITIS

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## INTRODUCTION

Few clinical interventions exist that can slow the progression of knee osteoarthritis (OA). A conservative surgical intervention is high tibial osteotomy (HTO), which shifts some of the contact load from the diseased medial to the healthy lateral compartment. A more conservative intervention to achieve this goal is gait modification (e.g., toeing out). For both interventions, the peak knee adduction torque during gait has been identified as a surrogate for medial compartment load and a predictor of long-term clinical outcome (Andriacchi, 1994).

This study presents a new simulation-based method for planning conservative treatment of knee OA. The method utilizes dynamic optimization of a patient-specific full-body gait model to predict how rehabilitation or surgical intervention will alter the patient's peak knee adduction torque. First, we use the method to design a novel gait motion that significantly reduces both adduction torque peaks. Next, we extend the method to predict the peak knee adduction torque for different measured gait motions. Finally, we apply the method to predict the effect HTO surgery on knee adduction torque changes.

## METHODS

We constructed a dynamic, patient-specific, full-body gait model for a single patient with knee OA. The three-dimensional model possesses 27 degrees of freedom (DOFs) composed of gimbal (3 DOFs – hips and back), universal (2 DOFs – ankles and shoulders), and pin (1 DOF – knees and

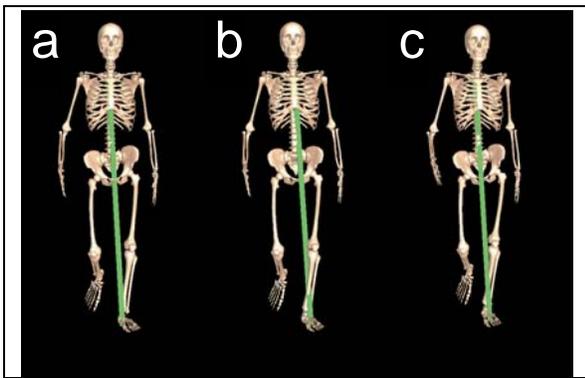
elbows) joints, with a free joint (6 DOFs) between the ground and pelvis. We calibrated the model's joint and inertial parameters to gait and isolated joint motion data collected from the patient (Reinbolt *et al.*, 2005). The patient gave informed consent for all experimental data collection.

Using this model, we performed inverse dynamics optimizations to predict patient-specific gait modifications to reduce both knee adduction torque peaks. The cost function minimized the knee adduction torque subject to reality constraints that tracked the patient's nominal gait kinematics and kinetics. After attempting to learn the predicted gait modifications, the patient was retested to assess their effectiveness at reducing both adduction torque peaks simultaneously.

We also formulated additional optimization problems to evaluate how patient-specific cost function weights affect the prediction process. We used surrogate modeling to identify cost function weights for the individual leg control torques such that minimization of the cost function yielded the patient's adduction torque curve and motion for toe out gait given his nominal gait data as the initial guess. Next, we evaluated the resulting cost function weights by predicting the patient's wide-stance gait adduction torque curve, again starting from his nominal gait data. Finally, we utilized the same cost function weights to predict how HTO wedge angle would alter the patient's peak knee adduction torque post-surgery. All predictions were evaluating using either the patient's own experimental gait data or published data from HTO studies.

## RESULTS AND DISCUSSION

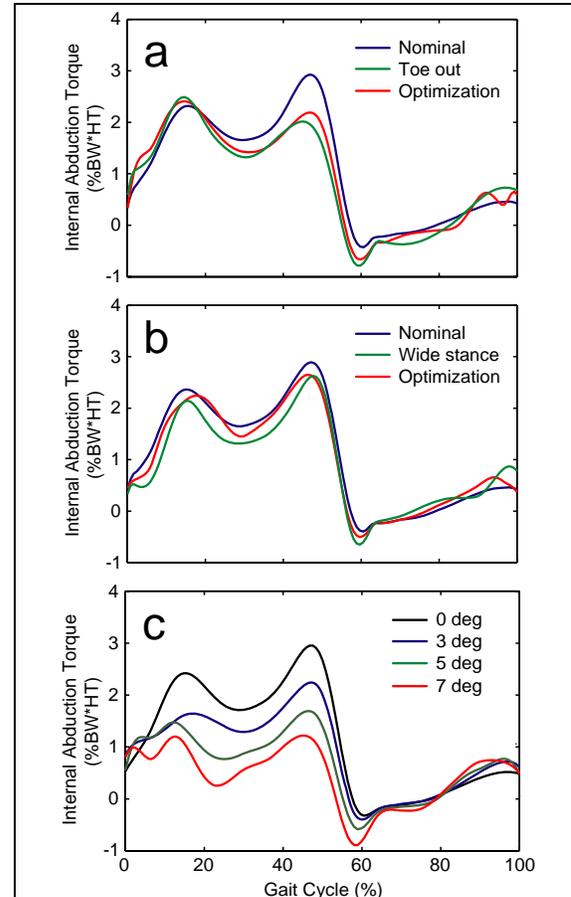
The first set of optimizations predicted “normal looking” gait motions that significantly reduced both adduction torque peaks (Fig. 1). The predicted reductions were 32 to 56% in both peaks, depending on the cost function weights. These reductions were produced by three synergistic kinematic changes that drove the knee medially. After gait retraining to learn the predicted modifications, the patient achieved reductions of 32 to 55%. The kinematic and kinetic changes achieved by the patient were generally in agreement with the optimization predictions. The main difference was in the post-training pelvis coronal tilt.



**Figure 1:** a) Nominal, b) Predicted, and c) Post-training gait motion. The moment of the patient’s ground reaction force vector about his knee center was significantly decreased.

When the cost function weights were calibrated to the patient’s toe out gait motion, the predicted adduction torque peaks were in excellent agreement with the patient’s experimental peaks (Fig. 2a). When the same weights were used to predict the patient’s experimental peaks for wide stance gait, the agreement was again excellent (Fig. 2b). Finally when the same weights were used to predict how HTO wedge angle would affect the patient’s post-surgery adduction torque peaks, the results were in good agreement with published data (Fig. 2c; Bryan *et al.*, 1997).

While these initial results are encouraging, application of the method to additional patients is needed to evaluate and refine it further prior to clinical implementation.



**Figure 2:** Optimization predictions of the internal abduction torque curve for a) Toe out gait, b) Wide stance gait, and c) high tibial osteotomy using the patient-specific cost function weights.

## REFERENCES

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## ACKNOWLEDGEMENTS

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