Postoperative Patient-Specific Gait Prediction of THA Patients based on Discrete Mechanics and Optimal Control

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Summary

For the patients after total hip arthroplasty (THA), their gait patterns are essential for functional-based surgical planning, but it is impossible to measure the postoperative gait kinetics before surgery. With the goal of improving THA surgical planning, this study predicted patient-specific gait patterns combining the DMOC and the musculoskeletal dynamics modeling. The predicted joint kinematics were in agreement with the experimental data in the postoperative stage.

Introduction

THA has been widely used in treating patients with hip joint diseases. However, abnormal gait patterns, possibly resulting from sub-optimal cup positioning, remain a common functional disorder after surgery. Predictive gait simulations can provide postoperative gait kinetic functions, which are not typically considered in conventional surgical planning. The discrete mechanics and optimal control (DMOC) method has been proven to be an efficient procedure for human motion prediction [1]. However, existing algorithms are still based on generic human models, and cannot to achieve patient-specific gait prediction for THA patients. This study established a patient-specific gait prediction framework based on musculoskeletal dynamics modeling and DMOC theory, and applied it in designing acetabular cup orientation.

Methods

Four patients who had undergone THA for avascular necrosis (males, 31-44 years old, BMI = 26.76 ± 0.81 kg/m^3) were recruited. The computed tomography data were collected to personalize the muscle paths around the hip joint. Motion tracking was conducted for the gait kinematics measurement.

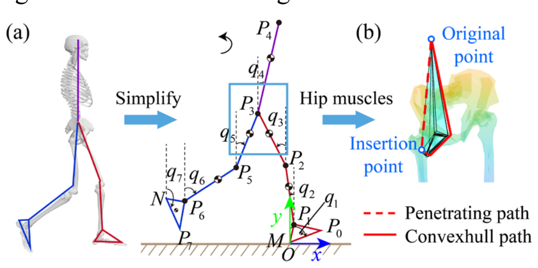

Figure 1: (a) Simplified biped model; (b) Convexhull wrapping model of muscle paths.

The patient-specific gait biodynamics were analyzed using a seven-link biped model, where the foot-ground constraints were defined by the positions of the heel and toe (Fig. 1a-b). Then, the prediction of gait trajectories was formulated as a constrained optimization problem. Using discrete mechanics and optimal control for constrained system (DMOCC), the Lagrange-d'Alembert equations was discretized. Afterwards, while evaluating the hip muscle forces via static optimization method, the muscle moment arm was determined based on the convexhull muscle wrapping algorithm [2]. And a criterion was proposed to ensure that the muscle wrapping path stays outside the underlying bone geometries (Fig. 1c).

Results and Discussion

The optimal gait trajectories and joint kinematics are presented in Fig. 2. The predicted kinematics results for the hip and knee joints were highly correlated with the postoperative experimental data, validating the feasibility of the proposed framework. However, the foot geometry limited the accuracy of ankle kinematics. Moreover, the peak extension/ flexion angle of the hip joint on the dysplastic side was smaller than that on the healthy side, highlighting that the gait asymmetry caused by pain can be considered in this model. Through the calculation of hip reaction forces, the designed acetabular cup orientation ($\beta_{ant} = 17.18\,\text{deg}$) was close to the optimization result in Ref. [3].

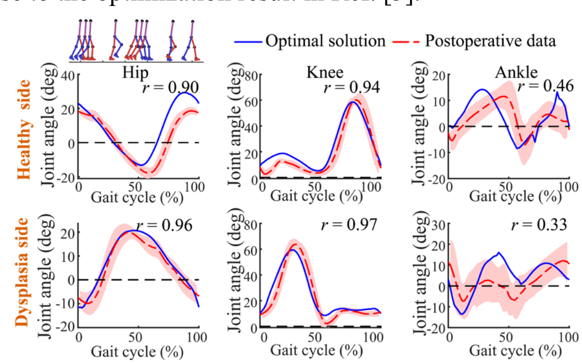

Figure 2: Comparison of the joint angles during a gait cycle.

Conclusions

This study proposed a framework for predicting optimal gait trajectories, achieving postoperative gait prediction compatible with patient-specific musculoskeletal modeling, which can be used in functional-based THA surgical planning.

Acknowledgments

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