A MULTI-SCALE STUDY OF THE HIP JOINT MECHANICS: INFLUENCE OF INERTIAL FORCES

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INTRODUCTION

Development of multi-scale model of human gait must face the double proposition to integrate communication between the different scales of analysis and to translate a dynamic reality into a history of static loads. The idea to translate forces from body movement analysis into tissue model loads was already presented [Adouni, 2014]. However, the representation of inertial loads into static loads at a specific time point is poorly addressed. Hence, the goal of this study was to evaluate the influence of inertial forces on cartilage load calculations in a deformable hip joint model.

METHODS

A multi-scale approach combined a musculoskeletal rigid body (RB) model of the entire human body with a deformable Finite Element (FE) model of the hip joint. The RB model consisted in 12 segments animated through the trajectories of 21 markers during a volunteer gait (67 kg body-weight). Foot-ground contact forces were recorded. An inverse dynamic problem was solved, and forces developed in coupled muscle actuators were estimated.

At the organ-tissue scales, a hip joint FE model was used [Sánchez, 2014]. The model included the joint ligaments, the acetabular and femoral cartilages, and the labrum. Bones were linear elastic, and cartilage tissues were considered as hyperelastic Neo-Hookean materials, with material parameter values taken from [Anderson, 2008]. The boundary loads on the FE model were automatically extracted from subject motion analysis through the RB model.

In order to convert the RB dynamics into an equivalent static problem for the FE simulations, the pelvis was fixed, and a distribution of d'Alembert inertial forces was applied to the femur elements as body forces.

Two time-points of the gait were selected: swing phase with no reaction forces on the ground and monopodalic right stance position. The influence of inertial forces on the FE calculations was studied, in addition to that of body weight and muscle forces, leading to four simulation cases.

RESULTS AND DISCUSSION

Preliminary results of the study are reported. The model of the right swing successfully converged, while it was only possible to analyze the right stance up to about 20% of the global load. Minimum principal strain distributions at the femoral cartilage in the four cases are displayed in Figure 1.

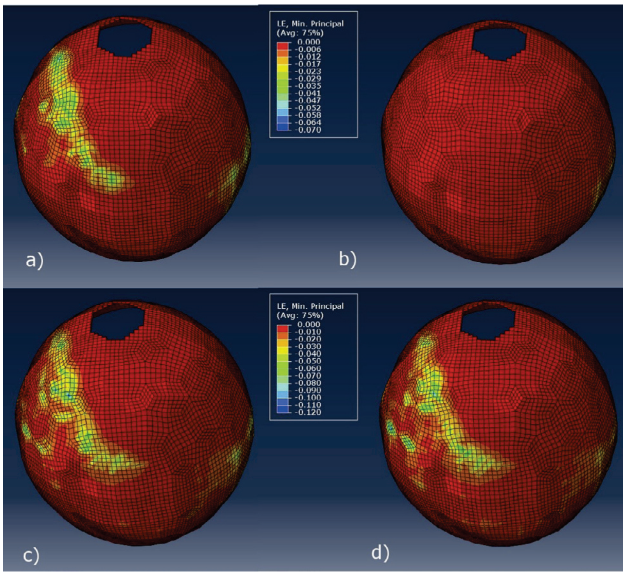

Figure 1: Distributions of minimum principal strains on the femoral head are displayed. a) right swing without Inertia, b) right swing with Inertia, c) right stand without Inertia, d) right stand with Inertia.

During the swing phase, the overall relieve of cartilage loads with the inertial forces was more realistic than the load predicted without these forces. Preliminary results in the stance phase already show load distributions similar to experimentally measured contact stress distributions [Henak, 2013]. While inertial forces did not affect this distribution, they globally increased the loads transferred to key tissues such as the labrum (Fig 2).

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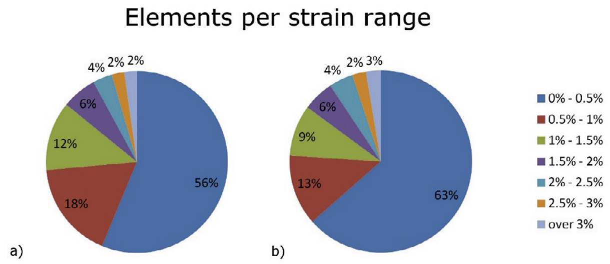

Figure 2: Percentage of elements per strain range in the labrum, with (a), and without (b) inertial forces

Body dynamics were successfully translated into a history of static loads for FE calculations. Results suggest that the analysis of cyclic cartilage loads during gait requires full multiscale coupling, including inertial loads.

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