Subject-specific Musculoskeletal Simulation of Hip Dislocation Risk in Activities of Daily Living

+[1]Rasmussen, J; [2]Bichler, R; [3]Torholm S; [4]Renkawitz T, [5]Roel Wirix-Speetjens [3]Dendorfer, S
+[1]Aalborg University, Aalborg, Denmark, [2]BMW Group, Munich, Germany, [3]AnyBody Technology, Aalborg, Denmark, [4]Departement of Orthopedic Surgery, Regensburg University Medical Center , Germany, [5]Materialise, Leuven, Belgium.
jr@me.aau.dk

INTRODUCTION:

Hip arthroplasty patients suffer the risk of joint dislocation [1] and many of the dislocations appear during normal daily activities [2]. As a preventive measure, patients are typically advised to avoid certain movements, typically those involving combinations of large hip flexion angles and/or rotations, for instance deep squats, high steps or mounting bicycles. The causality of dislocation, however, is not well understood because the actual dislocation event is not observable in an experiment. Thus, modeling appears to be the only viable approach to understanding the problem. Recent literature [3] operates with the kinematic concept of jumping distance as a dislocation risk indicator, where the design of the prosthesis determines the migration of the femoral head from the acetabular cup necessary to lose the support of the cup when a given reaction force is carried by the joint, i.e. a kinematic point-of-view.

The contribution of this paper is a new kinetic approach based on the observation that the dislocation of the hip requires a resulting force in the movement direction. Thus, we can state our research question: "Under which circumstances can a dislocating force occur?"

We shall undertake this investigation using an individualized model of a particular activity of daily living that is important to many patients and may influence the design of the most common environments for human activity: the ingress movement into an automobile.

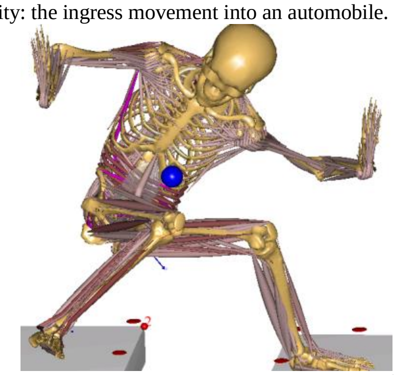

Fig. 1: The musculoskeletal ingress model in the middle of the movement.

METHODS:

A motion capture experiment was performed to record the ingress motion of a healthy male. The experimental environment was a mockup of a BMW Z4 roadster allowing for line-of-sight for the cameras at normally inaccessible locations. Dynamometers and force platforms recorded the interface forces between the human body and the environment. The marker trajectories and force data were stored in a C3D file and subsequently imported into the AnyBody Modeling System version 4.2 (AnyBody Technology, Aalborg, Denmark). The hip and pelvic region of the test subject was MRI scanned at the Medizinisches Versorgungszentrum (Regensburg, Germany) and the images were processed to bony geometries by Materialise (Leuven, Belgium) using the Mimics software, into which a virtual implantation of a hip prosthesis was performed. Informed consent was obtained from the test subject prior to the experiment and the protocol was approved by the local ethics committee of the Technical University of Munich.

By means of geometry morphing based on radial basis functions, the musculoskeletal lower extremity model in the AnyBody Modeling System [4] was fitted to the subject-specific geometry. This process relocates muscle insertion points and bony surfaces to correspond to the subject-specific anthropometry. An experienced surgeon placed a model of a total hip prosthesis (32 mm head diameter) in left side of the virtual model.

The musculoskeletal model proceeded to compute detailed movements of bones and joints in addition to detailed assessments of muscle forces in a musculoskeletal model with a high resolution, comprising more than 1000 individually activated muscle elements (Fig. 1). Subsequently, the model was inspected for risk of impingement and the resulting hip joint reaction forces were controlled for stability in the sense that joint reactions pointing out of the cup will dislocate the joint.

RESULTS:

The kinematic analysis reveals several situations of bony and prosthetic impingement in the ingress movement, a couple of which are illustrated in Fig. 2. Bony Impingement occurs between the section surface of the femur and the edge of the acetabulum. Prosthetic impingement occurs between the neck of the prosthesis and the rim of the cup.

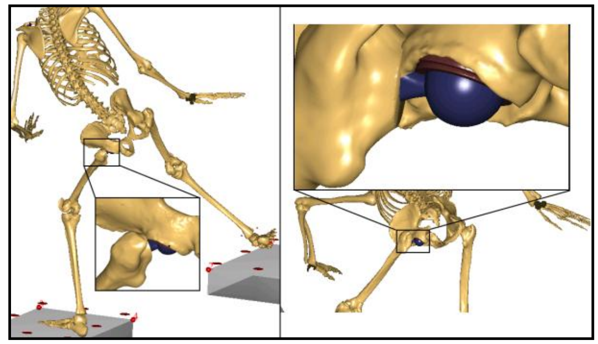

Fig. 2: Two of several cases of impingement during the ingress motion (muscle omitted for clarity). Left: Collision between the sectioned surface of the femur and the rim of the acetabulum. Right: Collision between the neck of the prosthesis and the rim of the cup.

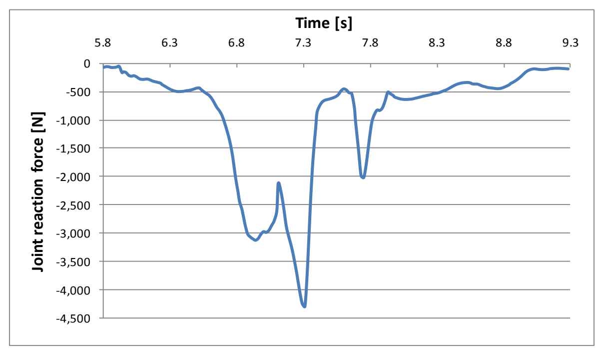

Fig. 3: Joint reaction forces directly into the cup. Positive values are instable.

The joint reaction forces (Fig. 3) are negative and therefore stable throughout the ingress movement, i.e. they always point into the convexity of the acetabular cup.

DISCUSSION:

It is obvious from the results that the recorded movement for a healthy individual cannot be reproduced by a total hip patient without risk of dislocation due to impingement.

The kinetic analysis reveals that, when impingement is disregarded, no dislocation risk exists because the net joint forces are always pointing into the acetabular cup.

This study was based on a healthy individual. Physiognomy as well as motion patterns may vary for a given total hip patient and may influence the result.

REFERENCES:

[1] SOONG ET AL., 2004, J Am Acad Orthop Surg 12, 314-321.
[2] WOO ET AL., 1982, J Bone Joint Surg Am, 64, 1295-1306.
[3] SARIALI ET AL., 2009. Acta Orthopaedica 80(3), 277–282.
[4] KLEIN HORSMAN ET AL, 2007, Clinical Biomechanics 22, 239–247.