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Congruence and Impingement in Total Hip Arthroplasty during Everyday Tasks

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Introduction

Conventional pre-operative planning for total hip arthroplasty mostly relies on the patient radiologic anatomy for the positioning and choice of implants. This kind of planning essentially remains a static approach since dynamic aspects such as the joint kinematics are not taken into account. Hence, clinicians are not able to fully consider the evolving behavior of the prosthetic joint that may lead to implant failures. In fact, kinematics plays an important role since some movement may create conflicts within the prosthetic joint and even provoke dislocations. The goal of our study was to assess the relationship between acetabular implant positioning variations and resultant impingements and loss of joint congruence during daily activities. In order to obtain accurate hip joint kinematics for simulation, we performed an in-vivo study using optical motion capture and magnetic resonance imaging (MRI).

Methods

Motion capture and MRI was carried out on 4 healthy volunteers (mean age, 28 years). Motion from the subjects was acquired during routine (stand-to-sit, lie down) and specific activities (lace the shoes while seated, pick an object on the floor while seated or standing) known to be prone to implant dislocation and impingement. The hip joint kinematics was computed from the recorded markers trajectories using a validated optimized fitting algorithm (accuracy: translational error ≈ 0.5 mm, rotational error < 3°) which accounted for skin motion artifacts and patient-specific anatomical constraints (e.g. bone geometry reconstructed from MRI, hip joint center) (Fig. 1).

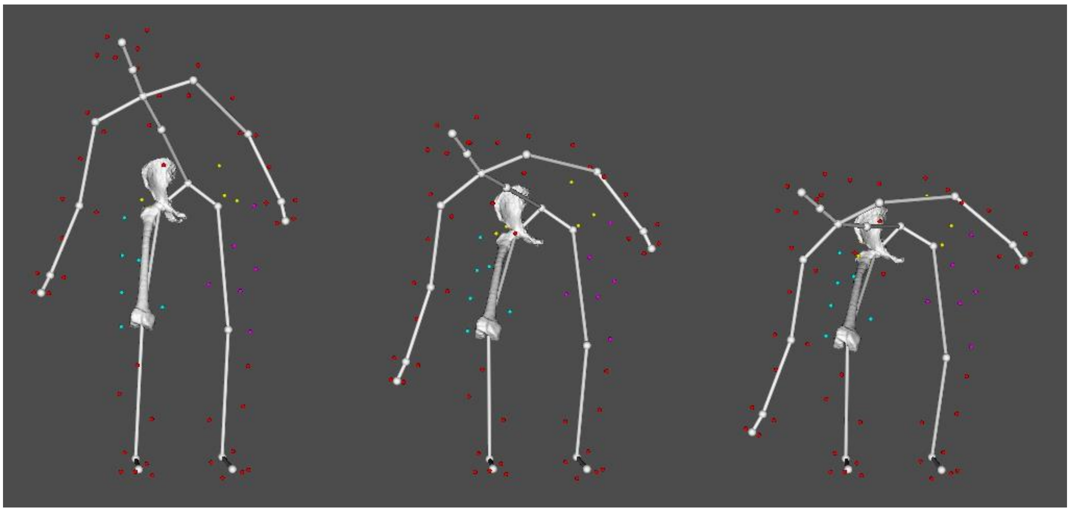

Fig. 1: Examples of computed motion (here the right hip) during the task "pick an object on the floor"

3D models of prosthetic hip joints (pelvis, proximal femur, cup, stem, head) were developed based on variations of acetabular cup's inclination (40°, 45°, 60°) and anteversion (0°, 15°, 30°) parameters, resulting in a total of 9 different implant configurations. Femoral anteversion remained fixed and determined as "neutral" with the stem being parallel to the posterior cortex of the femoral neck. Motion capture data of daily tasks were applied to all implant configurations.

While visualizing the prosthetic models in motion, a collision detection algorithm was used to locate abnormal contacts between both bony and prosthetic components (Fig. 2). Moreover, femoral head translations (subluxation) were computed to evaluate the joint congruence.

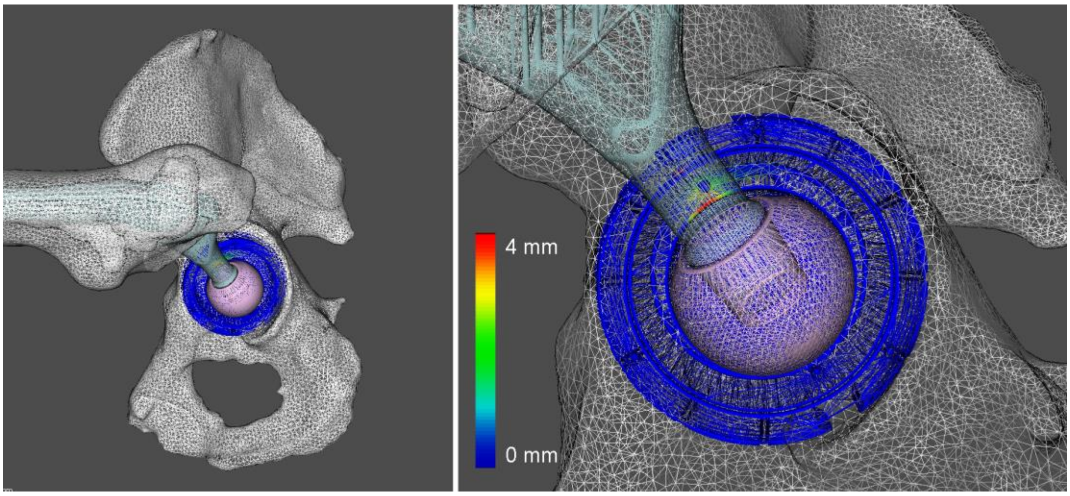

Fig. 2: Simulation of prosthetic hip joint 3D models. The color represents the impingement zone (blue = no collisions, other colors = collisions)

Results

Simulations showed collisions occurring at maximal ranges of motion in the anterosuperior part of the acetabulum. Both prosthetic and bony impingements were observed, especially while lacing shoes and lying down. The more the inclination and anteversion were important, the lower the frequency of impingements was noted (e.g. 23% at 40°/0°, 13% at 45°/15°, 5% at 60°/30°). Subluxations followed the same trend (e.g. 4.0 mm at 40°/0°, 1.5 mm at 45°/15°, 0.2 mm at 60°/30°). They occurred in a posterior direction as a consequence of impingements.

Conclusion

Daily tasks could expose the prosthetic hip to subluxation and impingement located in anterosuperior position. This location could be explained by the high hip flexion required to execute the motions (≥ 95°). Considering the kinematics solely, increasing inclination and anteversion seems to decrease possible conflicts, but mechanical aspects (stress, wear) should also be considered in the definition of ideal cup positioning.