Integration of Functional Pelvic Orientation into Patient-Specific Computational Modeling for Acetabular Cup Positioning

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Introduction

In 1978, Lewinnek et al. proposed a ‘safe zone’ for the position of the acetabular cup as inclination of 40° ± 10° and anteversion of 15° ± 10° [1]. They standardised the position of the pelvis using a jig that orientated the patient parallel to the anterior pelvic plane (APP). His recommended ‘safe zone’ for cup orientation was thus defined relative to the APP. However, the sagittal inclination of the pelvis, relative to the coronal plane of the body, varies significantly between individuals and between the supine, sitting and standing positions [2]. These dynamic variations in sagittal pelvic rotation have a substantial effect on the functional orientation of the acetabulum. Clearly the pelvis cannot be defined as a static reference frame and any proposed ‘safe zone’ must take into account the dynamic behaviour of the pelvis in the sagittal plane, a parameter which is specific to each individual.

Materials and Methods

Finite element models incorporating a titanium shell, ceramic insert, ceramic head and titanium stem were created in SolidWorks (*Dassault Systèmes SolidWorks Corp., France)* and solved using ABAQUS (Dassault Systèmes Simulia Corp., France) to investigate the contact mechanics at the bearing surface of a total hip replacement. The acetabular components were orientated at 40° inclination and 15° anteversion relative to the APP, characterising a well-placed cup as described by Lewinnek et al. [1]. The femoral component was flexed 90° to approximate the position of the femur at the time of “seat-off” when rising from a low chair. A constant radial clearance (40μm), lip radius (1.5mm) and subtended arc angle (160°) were maintained across all sizes of liners. Dry, frictionless contact was assumed for all simulations. The peak load at time of “seat-off” was obtained from in-vivo telemetric implant data [3]. The effects of femoral head size (32mm, 40mm and 48mm) and sagittal pelvic rotation on the contact mechanics and susceptibility to edge-loading were investigated. The sagittal pelvic orientation was adjusted from -30° – 30° in 10° increments, with a positive value of pelvic tilt representing an anterior rotation at the time of “seat-off” (Fig 1).

The two extreme pelvic orientations, -30° and 30°, were then used as separate inputs into a patient-specific, rigid body dynamic simulation of a sit-to-stand event (Optimized Ortho, Australia), and the predicted optimal cup orientations determined.

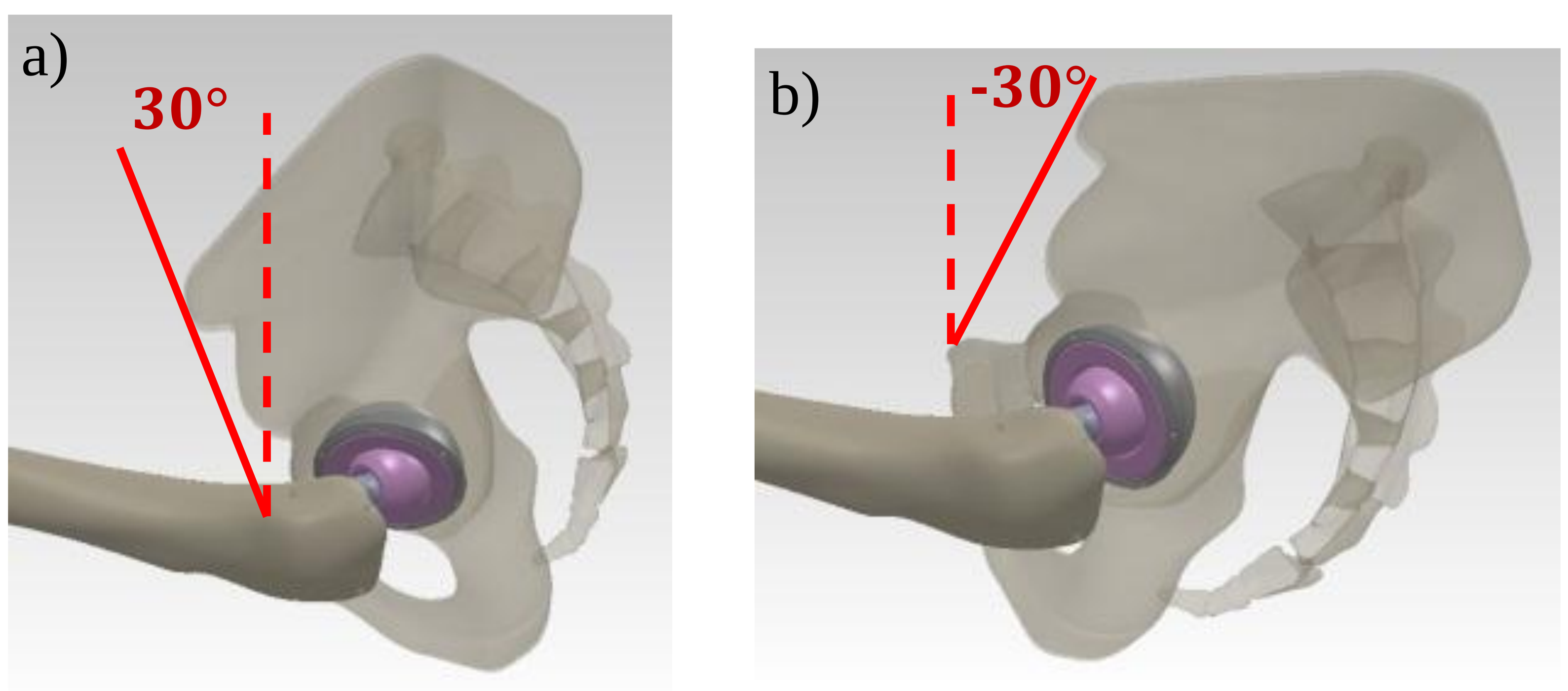

Fig 1. a) An anterior orientation of 30° at time of “seat-off”.
b) A posterior orientation of -30° at time of “seat-off”.

Results

The contact patch at the articulating surface extended over the true edge of the acetabular liner in all simulations with an anteriorly rotated pelvis during “seat-off”, suggestive of edge-loading during this common, everyday activity (Fig 2). A maximum contact pressure of 520MPa was observed during the simulation with a 48mm articulation and a 30° anteriorly rotated pelvis. The dynamic contact patch polar plots, generated by the Optimized Ortho software, predicted edge-loading when the patient was modeled with a 30° anteriorly rotated pelvis at “seat-off” (Fig 3). However, the contact patch was centrally located throughout the same activity when the same patient was run with a 30° posterior rotation of the pelvis.

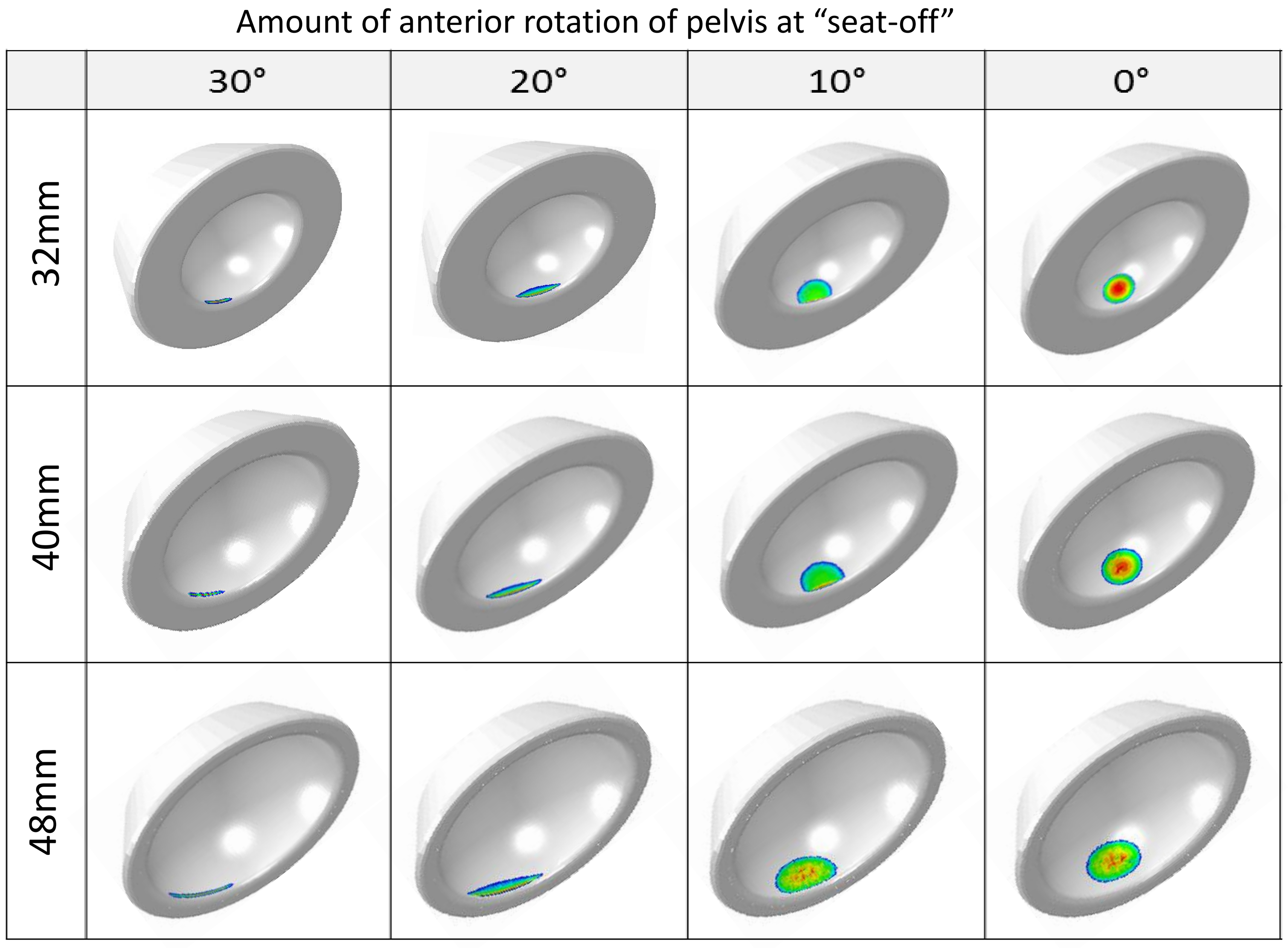

Fig 2. Results of the finite element analysis showing the contact patch passing over the edge of the liner during all simulations with an anteriorly rotated pelvis at “seat-off”.

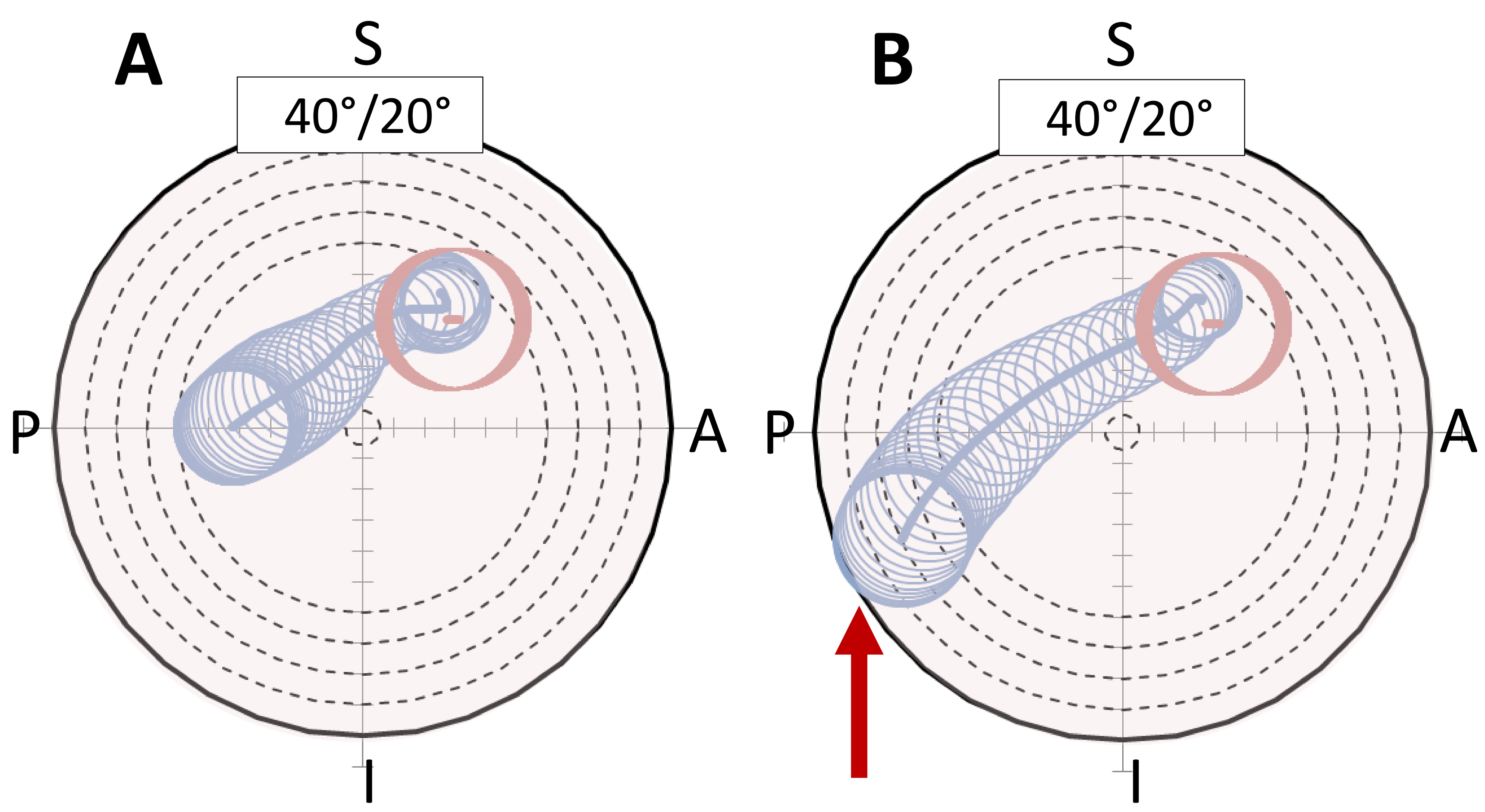

Fig 3. The results of the Optimized Ortho dynamic simulations of the sit-to-stand and step-up events (blue = sit-to-stand). a) The contact patch stays relatively central on the articulating surface throughout the activities when the patient is modeled with a posterior pelvic rotation of -30° at “seat-off”. Conversely, b) suggests posterior edge-loading when the same patient is simulated with a 30° anterior rotation at time of “seat-off”.

Conclusions

1. Variations in sagittal pelvic rotation have a substantial effect on the functional anteversion and inclination of the acetabular cup.
2. Posterior edge-loading can occur in a well orientated cup during a sit-to-stand manoeuvre, even with a 48mm ceramic articulation.
3. Previously defined static ‘safe zones’ might not be appropriate for all patients as they don’t account for the dynamic behaviour of the femur and pelvis.
4. Optimal cup orientation is likely patient-specific and requires a dynamic evaluation incorporating the lumbar spine, pelvis and femur to ensure maximum protection against edge loading, impingement and dislocation.

References

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2. DiGioia, A.M., et al., *Functional pelvic orientation measured from lateral standing and sitting radiographs.* Clinical orthopaedics and related research, 2006. **453**: p. 272-6.
3. Bergmann, G., et al., *Realistic loads for testing hip implants.* Bio-Medical Materials and Engineering, 2010. **20**(2): p. 65-75.