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Short communication

Effect of cup abduction angle and head lateral microseparation on contact stresses in ceramic-on-ceramic total hip arthroplasty

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ABSTRACT

A finite elements model was developed in order to evaluate the combined influence of the head lateral microseparation and the cup abduction angle on the contact pressure in Ceramic-on-Ceramic Total Hip Arthroplasty. The model's parameters were those used on the Leeds II hip simulator. A 32 mm head diameter and a 30 μm radial clearance was used. The cup was positioned with an abduction angle ranging from 45° to 90°. The medio-lateral microseparation varied from 0 to 500 μm. A load of 2500 N was applied through the head centre. For 45° abduction angle, edge loading appeared above a medial–lateral separation of 30 μm. Complete edge loading was obtained for a 60 μm medial–lateral separation. Under edge loading conditions, the contact area was found to be elliptical. For 45° abduction angle, as the head lateral separation increased, the maximal contact pressure increased from 66 MPa and converged to an asymptotic value of 205 MPa. Both cup abduction and lateral microseparation displacement induced a large increase in the stresses in Ceramic-on-Ceramic THA. However, this increase in contact pressure induced by higher abduction angle, became negligible as the lateral separation increased.

1. Introduction

Experimental studies have shown that femoral head lateral microseparation induces edge loading and increases the wear in ceramic-on-ceramic total hip arthroplasty (CoC THA). This increase may be due to an increase in the contact stresses and also to a modification of the lubrication regime (Sariali et al., 2010a). These theoretical results are consistent with the clinical results (Blumenfeld et al., 2011; Dennis et al., 2001) proving that separation may occur in vivo, inducing consequently an increase in the contact stress for hard-on-hard THA (Mohan et al., 2009).

There are theoretical (D'Lima et al., 2001) and clinical evidences (Brodner (2004); Nevelos et al., 2000) suggesting that cups placed with a high abduction angle may lead to edge loading with or without microseparation. However, to our knowledge there is no reported study about the influence of the cup abduction angle on contact stress in CoC THA under different values of head lateral microseparation.

The aim of this study was to investigate the combined influence of the head lateral microseparation and the acetabular cup abduction angle on the contact pressure.

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2. Material and method

A ball and socket model of a typical CoC THA, was developed in order to predict the contact area and the contact pressure distribution, first under an ideal centered regime and then under microseparation conditions. The effect of the abduction angle and the head lateral displacement on contact area and stresses was investigated.

2.1. Modelling

A 32 mm alumina ball and an equivalent cup with a radial clearance of 30 μm incorporating a metal-backing was used. This value is an average radial clearance for ceramic-on-ceramic THA. Measurements including those of the chamfer of the cup rim were provided by CERAMTEC® (Plochingen, Germany). The cup was first positioned with a 45° abduction angle, and a 0° anteversion angle. Afterwards, the cup abduction angle was varied from 45° to 90° in order to determine its influence on the contact stresses and the contact area.

The material used was Alumina Biolox Forte ceramic for the ball and the cup (Young's Modulus = 380 GPa, Poisson's ratio = 0.23) and Metal (cobalt–chromium alloy) for the backing (Young's Modulus = 210 GPa, Poisson's ratio = 0.3) (Rieker et al., 2001).

For the meshing, a tetragonal element type was used for the metal-back and a hexagonal element type for the liner and the head.

The finite elements analysis was performed with the ABAQUS® software package. A static analysis was used. Two steps were undertaken : in the first step, a lateral displacement of the head was performed, in order to get a lateral microseparation, and then, in the second step a load was applied through the centre of the ball and directed upwards towards the cup. As used in the Leeds II hip simulator, the microseparation was varied from 0 to 500 μm and the load was 2500 N. The boundary conditions were chosen as follows: the external surface of the backing was fixed, the cup was tied to the back and the head was restrained to move only in the vertical direction.

3. Method

The sensitivity of the results to the mesh was studied in the case of a centered model and under 500 μm microseparation conditions. The mesh refinement was increased progressively by doubling the number of elements and the variation in the pressure contact was determined. A compromise between the mesh refinement and the solving duration was decided by fixing at 10% the threshold of significance for a variation in contact pressure according to the mesh.

The contact was modeled with a small-sliding method, using the head as the slave surface. The contact pressure was plotted in the contact area according to the distance from the centre of the contact surface to the top of the head. The values of the contact pressure for the centered model were compared to the values predicted by the Hertz theory (Appendix 1, Equation 1, Equation 2, and Equation 3). The influence of medial–lateral displacement and cup abduction angle on the contact stresses were analyzed.

4. Results

A good convergence of the model was found under both ideal centered conditions and microseparation regime. The results did not vary significantly according to the mesh accuracy above 16,000 elements.

4.1. Contact analysis under 45° cup inclination angle

Under the case of centered loading, the contact area was circular, centered on the top of the head (O) with a radius of 4.6 mm, which was close to the value predicted by the Hertz theory (4.3 mm). Edge loading appeared above 30 μm of medial–lateral separation, which corresponded to 42 μm of axial separation. Complete edge loading was obtained for 60 μm medial–lateral separation (Fig. 1). In the case of edge loading, the contact area was found to be elliptical. As the lateral microseparation increased, the centre of the contact area shifted laterally on the femoral head of a distance that reached a maximal value of 10.4 mm corresponding to a head–rim contact (Fig. 2).

Under the case of centered loading, the maximum contact pressure was found to be 66 MPa, very close to the theoretical value predicted by the Hertz theory (64.4 MPa). As the microseparation increased, the maximum contact pressure increased and converged to an asymptotic value of 205 MPa (Fig. 3). The critical value above which edge loading appeared was found to be 30 μm of medial–lateral separation.

4.2. Influence of cup abduction angle

Edge loading appeared for lower values of lateral microseparation of the head as the cup abduction angle increased (Fig. 4). For a 0 μm head lateralization, there was no edge loading for 65°, whereas edge loading appeared above 75°. Indeed, edge loading was incomplete at a 75° abduction angle and complete for 90°. For 500 μm of head lateralization, the centre of the contact area was shifted laterally at a distance varying from 10.4 mm for 45° cup inclination to −2.5 mm for 90° cup inclination.

As the abduction angle increased, the maximum contact pressure increased. Under centered conditions (no head lateral microseparation), the contact pressure was about 66 MPa for a 45° cup abduction and increased up to 137.2 MPa for a 90° abduction angle. However, this increase in contact pressure, induced by higher abduction angle, became negligible as the lateral microseparation increased (Fig. 3). Indeed, above 240 μm, the contact pressure reached an asymptotic value of about 200 MPa.

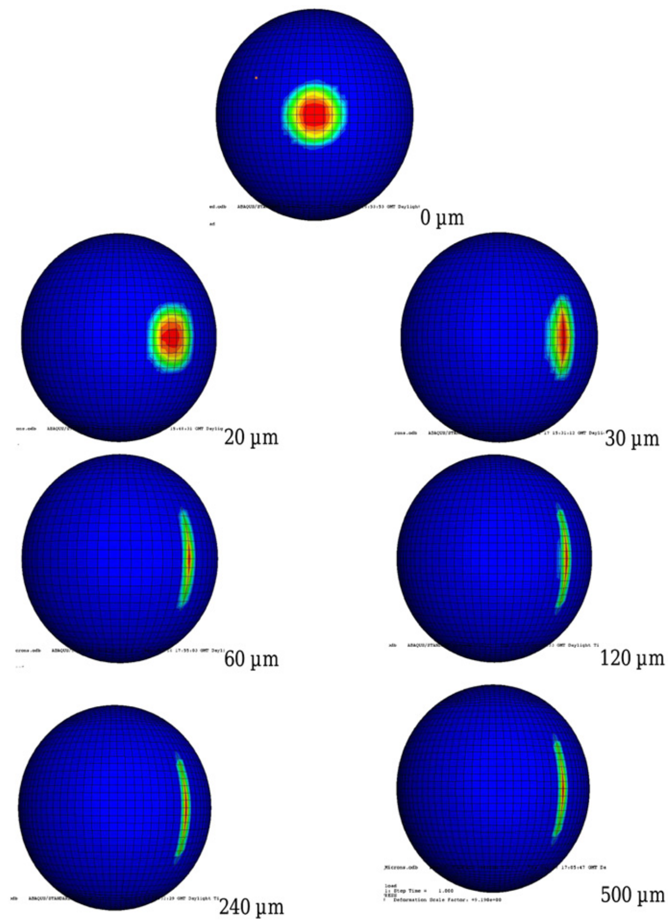

Fig. 1. Contact area shape changed as the microseparation increased. In the case of centred loading, the surface was a circle of 4.6 mm radius, whereas in the case of edge loading the surface converged to an ellipse.

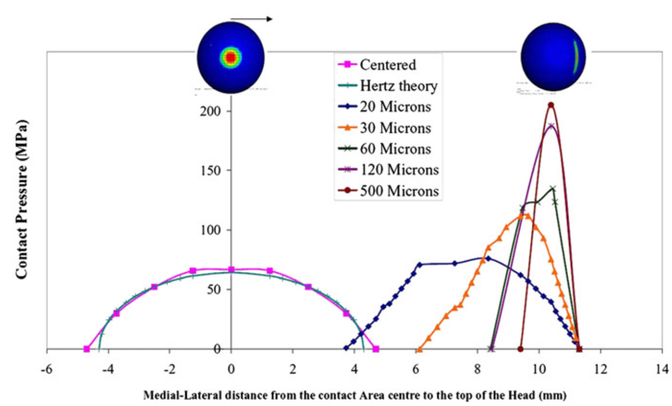

Fig. 2. Pressure distribution was determined according to the distance from the centre of the contact surface to the top of the head (O), which corresponded to the centre of the contact surface under ideal centred conditions.

5. Discussion

Edge-loading started above 30 μm of head lateral microseparation, comparing well with previously reported studies showing