EFFECTS OF IMPLANT DESIGN PARAMETERS ON FLUID INGRESS DURING THA IMPINGEMENT/SUBLUXATION

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INTRODUCTION

Aseptic loosening from polyethylene wear debris remains the leading cause of failure for metal-on-polyethylene total hip implants. Wear is exacerbated by 3rd body debris, leading to femoral head roughening, but the manner by which 3rd bodies gain access to the very closely congruent bearing surface is unknown. One possibility is that ingress of 3rd body debris is facilitated by fluid transport during subluxation. The high prevalence of indentation damage found on the rim of retrieved acetabular liners from femoral neck impingement (Shon W Yong et al., 2005) suggests that subluxation events are frequent. To study subluxation-induced particle ingress, a computational fluid dynamics (CFD) model has been developed to quantify the ensuing fluid motions. The focus of the present study was on the effects of variations in implant design parameters on fluid velocity.

METHODS

CFD model geometry was created using Truegrid v2.1.5, and solutions were obtained using ADINA v8.2. The region of interest for the CFD model was the capsule-enclosed joint space, plus the bearing region between the femoral head and acetabulum (Figure 1). Kinematics for femoral head movement were taken from output data from a finite element model of leg-cross dislocation (Nadzadi ME et al., 2002) from the beginning of hip subluxation (impingement initiation). The leg-cross subluxation event corresponded to ~0.60 mm separation after .012 seconds. Four variables were parametrically studied: femoral head diameter, bevel angle and face width of the chamfer, and thickness of clearance between the femoral head and acetabulum. The baseline case consisted of a 28mm femoral head diameter, 0.1 mm clearance between the femoral head and acetabular component, a chamfer consisting of 25% of the polyethylene liner thickness at an angle of 30º, and fluid modeled as Newtonian and incompressible (viscosity of 1.0 Pa·s (Mazzucco D et al., 2002). Outer capsule boundaries were modeled as rigid with no-slip conditions, and the femoral head was modeled as a moving rigid boundary.

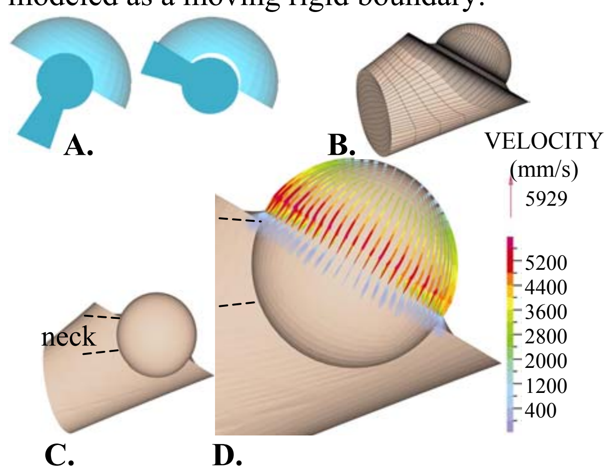

Figure 1. 3D CFD model (frontal view for a right hip). A. Schematic indicating subluxation. B. Outer model view with visible mesh. C. Transparent view of the model with visible femoral head surface. D. Fluid velocity vectors at the beginning of the subluxation for a 28 mm femoral head.

RESULTS AND DISCUSSION

As seen in Figure 1, the subluxation resulted in very high fluid velocity along the entrance to the gap between the femoral head and acetabular cup (maximum 5929 mm/s for a 28 mm head, ~120 times the femoral head velocity). This fluid velocity decreased from the gap entrance to the pole of the cup. Fluid velocity at the beginning of subluxation was compared for three head sizes and three clearance widths along an equatorial line in the model (Figure 2). The greatest ingress velocities were seen on the anterosuperolateral acetabular cup edge (~300º-0º, Figure 2), and lowest ingress velocities were seen posteriorly (~120º-180º). Larger head sizes and smaller gap widths resulted in greater fluid velocity (Figure 2).

Fluid pathlines were calculated by integrating the velocity solutions, to determine sites to which suspended 3rd body particles could be transported during leg-cross subluxation. As an example, fluid initially just outside the entrance to the gap between the femoral head and acetabular cup at point (1) (Figure 3) moved into the gap at the beginning of the subluxation, and moved towards the pole of the cup throughout the subluxation. At the end of the subluxation, the end of the pathline was 11º away from the pole of the cup.

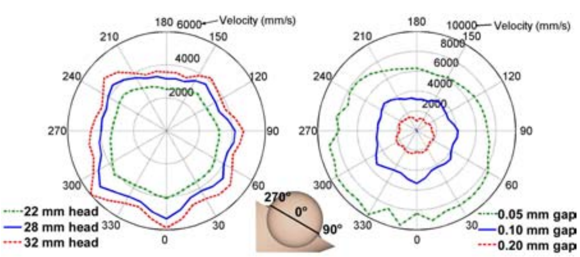

Figure 2. Ingress velocity magnitude at an equatorial line around the femoral head at the entrance to the gap between the femoral head and acetabulum, for the beginning of the subluxation.

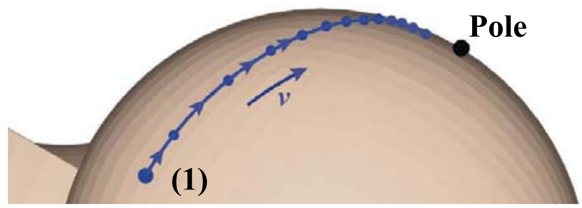

Figure 3. Pathline for fluid beginning at location (1) during the leg-cross subluxation. Each dot along the pathline indicates the position of the fluid for successive time points, in 0.001-second increments, up to the end of the subluxation (0.012 s).

SUMMARY

The data indicate that 3rd body debris suspended in joint fluid could be drawn nearly to the pole of the cup with even very small separations of the femoral head (<0.6 mm). Debris suspended near the entrance to the cup just before the subluxation begins can reach a "latitude" of 79º. Larger head diameters and smaller clearance widths had increased fluid velocity at all points around the entrance to the gap compared to smaller head sizes and larger clearance widths, respectively. Fluid velocity was greatest along the anterosuperolateral cup edge for all head sizes and clearance widths. Although absolute fluid velocity was greater, however, fluid pathlines indicated that suspended debris would reach nominally similar angular positions on the cup with larger head sizes.

REFERENCES

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