QUANTIFYING FLUID INGRESS TO THE JOINT SPACE DURING TOTAL HIP IMPLANT SUBLUXATION

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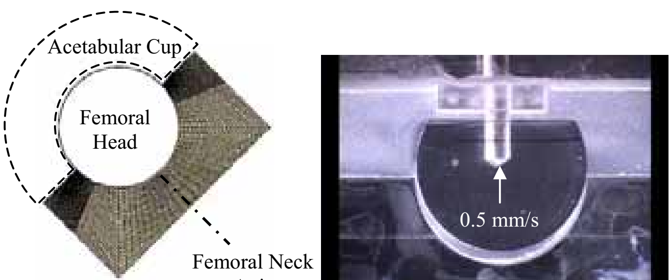
INTRODUCTION

Ingress of 3rd body debris responsible for femoral head scratching and wear acceleration of total hip implants may be facilitated by convective fluid transport during hip subluxation. To study subluxation-induced particle ingress, a computational fluid dynamics (CFD) model has been developed to quantify the associated fluid motions. Validation of the model was performed using particle image velocimetry (PIV), a method of measuring fluid velocity by tracking marker particles in the flow. Two different femoral head displacement events were evaluated using a fully 3D model.

METHODS

A proof-of-concept 2D CFD model (Figure 1A) was first created for comparison with experimental PIV results. The synovial fluid was assumed to be Newtonian and incompressible (viscosity of 1.0 Pa·s [1]). All external surfaces were designated as "no slip" boundaries. The femoral head was moved (subluxed/separated) out of the cup at a speed of 0.5 mm/s. For PIV validation (Figure 1B) marker particles introduced into the fluid were illuminated and their movement recorded with a digital video camera (Sony DCR-VX2000). EdPIV software was used to track particle movement and calculate fluid velocity.



A. B.

Figure 1: **A.** 2D CFD model mesh and **B.** physical PIV setup.

Two distinct head separation events were then studied using a definitive 3D CFD model (Figure 3A). One implemented the medial separation and femoral head superolateral cup edge pivot reported by Komistek et al. during the swing phase of gait [2]. The other implemented lever-out subluxation due to impingement/lever-out about the inferomedial cup edge [3]. Both regimes resulted in a 0.8 mm separation between the femoral head and acetabular cup after 0.6 s.

RESULTS AND DISCUSSION

The results of the PIV validation are shown in Figure 2. The agreement of PIV versus 2D CFD was 85% or better for velocity vector magnitudes in the clearly visualized areas just away from the entrance to the gap between the femoral head and acetabulum. (The fluid velocity at the gap entrance could not be measured accurately with the physical setup because of high fluid velocity at that point.) Additionally, any incidental fluid motion that might have occurred out of the plane of the image would result in lost/inaccurate vectors.

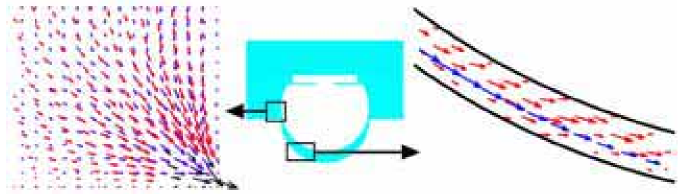
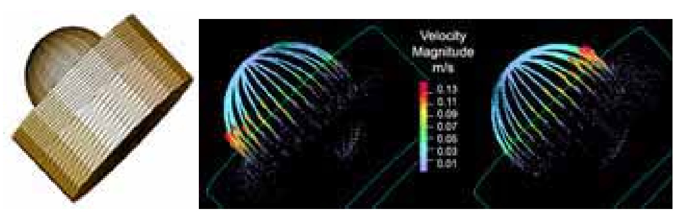


Figure 2: Velocity vectors of the 2D CFD model (red and black) compared to PIV results (blue). CFD velocity vectors shown in red are plotted so that vectors of equal length in the PIV results are equal velocity magnitudes. Black velocity vectors in the left panel, lower right corner, are scaled so that vectors of equal length are 50% greater in the CFD model than PIV.

The 3D CFD results showed markedly different fluid ingress kinematics for swing phase separation versus lever-out subluxation (Figure 3). It was noted that the lever-out femoral head displacement resulted in high velocities at the beginning of the subluxation event at the inferomedial cup edge like that of the gait cycle separation, although at 0.6 s high fluid velocities were located at the superolateral cup edge. The results also suggest that lever-out subluxations may attract debris from multiple locations into the joint space. Dramatic differences in flow patterns suggest that the two subluxation modalities evaluated subject very different regions of the bearing surface to preferential debris embedment, with very different consequences for subsequent head scratching and polyethylene wear acceleration.



A. B. C.

Figure 3: **A.** 3D CFD mesh and flow patterns during **B.** swing phase separation and **C.** lever-out, both at 0.6 s.

REFERENCES

1. Mazzucco D, et al. *J Orthop Res* **20**, 1157-1163, 2002.
2. Komistek RD, et al. *JBJS* **84-A**, 1836-1841, 2002.
3. Nadzadi ME, et al. *J Biomech* **36**, 577-591, 2003.

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