INTRODUCTION: Clinical and laboratory contact mechanics studies of the natural hip joint generally involve a metallic instrumented femoral prostheses interacting with the natural acetabular cartilage [1]. However, the parameters measured using these methods will not represent those existing in a healthy natural joint. Moreover, current technology also does not allow the study of contact mechanics and tribology of the natural hip joint non-intrusively. Thus the only alternative is to utilise analytical or numerical models.

Existing three-dimensional models of the natural hip joint use elastic or hyperelastic material properties to represent cartilage. However, the biphasic nature of the cartilage plays an important role in its tribology and the contact mechanics.

The aims of the present study were to investigate the contact mechanics of the natural hip joint and sought to understand the role of interstitial fluid.

METHODS: A previously developed pelvic model was utilised [2]. Femoral head cartilage was 2 mm thick with no clearance between the two cartilage surfaces since MR images have shown that both the acetabular and femoral head cartilages appear as one with a little or no inter-articular gap [3][4]. The femoral head was assumed to be made up of only cortical bone with properties used for pelvis.

The femoral head bone had 432 six-node linear triangular prism elements (C3D6) and 1872 eight-node linear brick elements (C3D8). Femoral cartilage was made up of 5322 eight-node trilinear displacement and pore pressure reduced integration elements (C3D8R8). The cartilage solid phase was modelled as neo-Hookean [2]. All the other material properties and the type of elements used in the pelvis can be found elsewhere [2].

The femoral head was allowed to move only in the vertical direction with a load of 2000 N applied at the centre of the head (Figure 1). The fluid flow on the acetabular and femoral cartilage surfaces was based on the developing contact [5]. The contact was assumed frictionless and soft contact formulation in ABAQUS was used. Total fluid load support, peak contact and fluid pressure, and contact area were recorded throughout the simulation.

This model could not be validated in a conventional way using experiments. Therefore a simpler three-dimensional poro-hyperelastic model of the hip joint was modelled in this study. In future studies, the acetabulum and femur will be modelled using subject-specific MRI scans. This will give local variable clearances and more realistic localised contact areas, both reducing the load carried by the fluid phase. This will in turn affect the contact stresses and shear stresses which have the potential of inducing lubrication.

SIGNIFICANCE: The high fluid load support predicted by this model was indicative of the effectiveness of biphasic lubrication which along with the lower contact stresses would perhaps aid in protecting the cartilage in the long term. This improved model is a potential tool to aid clinicians, biologists and engineers to understand contact mechanics and joint lubrication, and their long-term implications for the treatment of musculoskeletal diseases of the hip joint.

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REFERENCES:

Table 1: Comparison of two- and three-dimensional cup and ball model for validation

<table>
<thead>
<tr>
<th></th>
<th>Peak Contact Pressure (MPa)</th>
<th>Contact Area (mm²)</th>
<th>Peak Fluid Pressure (MPa)</th>
<th>Total Fluid Load Support (%)</th>
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<td>1.242</td>
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<td>3D model</td>
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<td>Difference (%)</td>
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<td>1.23</td>
<td>1.80</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Figure 1: FE model of natural hip joint

RESULTS: Values of different parameters monitored in the axisymmetric and three-dimensional models are given in Table 1. The contours of fluid pressure after 1 second of loading were similar in both models with a central contact zone of maximum pressure which gradually reduced towards the edges.

Figure 2: The contour of fluid pressure (MPa) on the acetabular cartilage contact surface after 1 second of loading