The effect of variations in component positioning on the dynamics and contact mechanics of ceramic-on-polyethylene total hip replacement

Faezeh. Jahani[1], John. Fisher[1], Ruth. Wilcox[1], David. Barton[1], James. Brooks[2], Alison. Jones[1]

[1]Institute of Medical & Biological Engineering, School of Mechanical Engineering, University of Leeds, Leeds, LS2 9JT, UK. [2]DePuy Synthes Joint Reconstruction, Leeds, UK

Institute of Medical & Biological Engineering

UNIVERSITY OF LEEDS

Introduction

In total hip replacements, it has been shown that the separation of the head from a concentric position within the cup and the edge loading of the cup, can occur in adverse conditions and negatively affect the wear rate of the device [1].

The aim of this study was to develop a tool that can distinguish the severity of the various factors effecting the device performance. Therefore, a novel computational model was developed to study the effect of following factors on the dynamic separation and contact mechanics of the implant during the walking gait cycle:

- Translational mismatch of the rotational centers of the femoral head and cup (Fig 1c).
- Rotational positioning of the cup (Fig 1b).

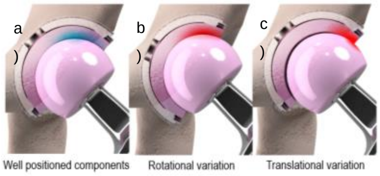

Figure 1: Translational and rotational variation illustration

Materials & Methods

The explicit dynamic model was developed to replicate the action of the Leeds II hip simulator [2], where a spring is applied to the lateral side of the cup. Under high axial loads the head and cup centres are closely aligned. Under low axial load (during swing phase) the spring pushes the cup centre away from the head centre (Fig 2). A 50 N swing phase load was used, representing overall quality of surrounding tissues.

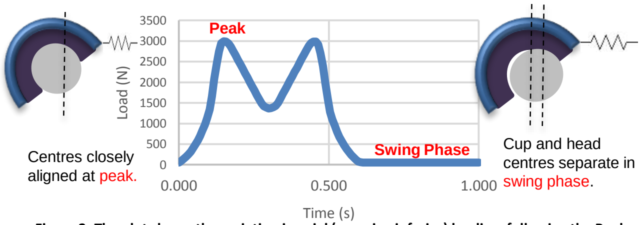

Figure 2: The plot shows the variation in axial (superior-inferior) loading, following the Paul cycle. Schematics show the change in device alignment due to the spring on the medial side.

The geometry of a commercially available ceramic on-polyethylene device (Pinnacle® , DePuy Synthes, Leeds, UK), with a 0.54mm radial clearance, was used (Fig 3). The material properties are listed in Table 1, where values for polyethylene represent the elastic phase of an elastic-plastic material model.

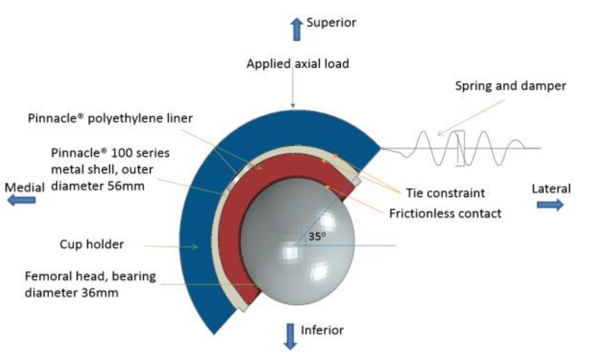

Figure 3: The finite element model assembly, shown as a cut through in the frontal plane.

Table 1: The material properties for each component in the model.

Components	Material	Young's modulus (MPa)	Poisson's ratio	Density (kg/mm³)
Head	Rigid	-	-	4.37×10^{-6}
Cup (elastic-plastic)	Polyethylene	1,000	0.46	9.23×10^{-7}
Shell	Titanium	114,500	0.34	4.43×10^{-6}
Cup holder	Rigid	-	-	8.5×10^{-6}

Materials & Methods

Two cup inclination angles of 35° experimentally (45° clinically) and 55° experimentally (65° clinically) and four levels of translational mismatch were tested. To apply translational mismatch level, the spring was compressed by a fixed amount (Table 2) while the cup was held in place. The cup was then released allowing the medial spring force to take effect, before the Paul cycle axial loading was applied. In each case the spring was critically damped.

Table 2: The input values used to generate the set of cases.

Variable	Implementation method	Values
Translational mismatch level	Spring compression	1mm, 2mm, 3mm and 4mm
Rotational variation	Cup inclination angle	35° and 55°

Results

The highest level of dynamic separation was consistently achieved towards the end of the swing phase of the gait cycle, under each test condition. The dynamic separation increased as the surgical translation mismatch increases (Figure 4). The steeper cup inclination angle produced higher separation for all the translational mismatch levels.

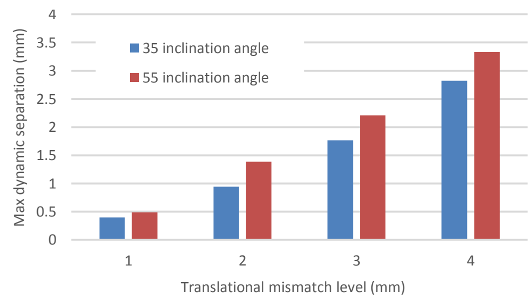

Figure 4: The maximum dynamic separation at the end of swing phase versus surgical translational and rotational mismatch

Oval contact shaped on the edge of the cup was observed when highest mismatch level was used (Figure 5). Substantial plastic deformation was seen in cases where the contact of the cup rim and the femoral head occurred.

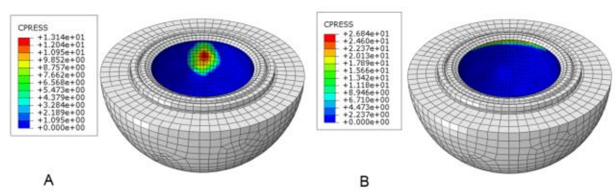

Figure 5: Contact pressure plot on the cup liner at the end of swing phase load, demonstrating the variation in pressure distribution for translational mismatch of 1mm (A) and 4mm (B) conditions (cup inclination angle = 35°).

Discussion & Significance

The finite element model was able to predict medial-lateral separation as it occurred dynamically in the gait cycle.

- When edge loading occurred, the contact pressure was more localized around the rim, which caused a much higher contact pressure over a smaller area and increased plastic strain.
- An increase in translational mismatch level and steeper inclination angle resulted in higher dynamic separation which is in agreement with experimental data [2].
- The results also indicate that a level of translational mismatch level have a more significant effect on dynamic separation than rotational variation [3].

As **edge loading** is a **multi-factorial scenario**, development of this method allows us to investigate on the effect of the **various factors** on the **dynamics** and **contact mechanics** behavior of the device **simultaneously.**

References

[1] Al-Hajjar *et al*, 2010, J. Biomedical Materials Research.
[2] O'Dwyer Lancaster-Jones *et al*, ORS, 2016.
[3] Leng *et al*, 2016, J. IMechE .

DePuy Synthes COMPANIES OF Johnson & Johnson

EPSRC Engineering and Physical Sciences Research Council