Differentiation between Creep and Wear on Polyethylene

INTRODUCTION

A variety of methods exist clinically to determine the linear penetration of a femoral head into the polyethylene liner [1,2]. While it is generally attributed only to wear, the linear penetration measurement includes both creep (plastic deformation) as well as wear (material removal) [3]. True wear releases small wear particles into the joint space with potential for unfavorable biological responses. Polyethylene creep does not generate particles and is not a clinical concern for modern hip bearings. The objective of this study is to differentiate between polyethylene creep and actual material wear for simulator tested hip bearings.

MATERIALS AND METHODS

A total of four sets of test samples were used in this study. Trident® design (Stryker Orthopaedics, Mahwah, NJ) liners with internal diameters ranging from 28mm to 40mm were used. These polyethylene liners were manufactured from GUR 1020 UHMWPE that was sequentially annealed and irradiated three times and then gas sterilized (X3TM, Stryker Orthopaedics, Mahwah, NJ) [4]. Appropriate diameter cobalt chrome femoral heads ranging from 28mm to 40mm (n=3) were matched with the inserts. A twelve station hip joint simulator (MTS, Eden Prairie, MN) was used with three sets of each size liner (28mm, 32mm, 26mm, 40mm) (n=12). Testing was run at 1 Hz with cyclic Paul curve physiological loading applied axially, at a maximum of 2450 N. Alpha Calf Fraction serum (Hyclone Labs, Logan, UT) diluted to 50% with de-ionized water and 20mMole EDTA was used as a lubricant. Gravimetric and geometric measurements of the acetabular liners and serum replacement occurred every 0.5 million cycles (Mc). Gravimetric measurements were compared against soaked samples to negate weight changes due to fluid absorption. The total test length was 2.0 Mc. Geometric data was taken on the liners using a coordinate measuring machine (CMM) (Wenzel, Wiesthal, Germany). At least 25,000 points were taken across the entire bearing surface at every 0.5 Mc. Maximum linear penetration was calculated from these measured points using Geomagic Qualify Version 10 (Geomagic, Research Triangle Park, NC). The linear penetration attributed to wear was calculated from the measured gravimetric measurements. Finite Element Analysis (FEA) was performed to determine the expected initial bearing contact area and contact stress distribution. FEA models were assembled in Pro Engineer Wildfire 2 (Parametric technology Corp., Needham, MA), followed by analysis with ANSYS Workbench Version 11 (Ansys Inc, Canonsburg, PA).

RESULTS

The finite element analysis confirmed that with decreasing femoral head size, and therefore decreased contact area, there is also a decrease in contact pressure across the bearing surface.

Wear rates were not statistically different between any of the four testing groups. Total mass loss for each group ranged from 1.29 mg to 5.39 mg at 2.0 Mc. This corresponds to approximately 7.7µm to 12.8µm of linear wear. CMM measurements indicate linear penetration between 40.8µm and 89.3µm as shown in Figure 2. The percentage of linear penetration attributed to wear was determined by comparing the geometric measurements (creep and wear) and gravimetric measurement (wear only).

DISCUSSION

Maximum contact pressure inside the acetabular liner exceeded those that have been previously found by researchers to cause significant creep within the material [4]. Using the gravimetric measurements the linear penetration due to wear was calculated and then compared to the actual maximum linear penetration from the CMM data. This comparison showed creep to be solely responsible for as high as 90.6% of the measured linear penetration while actual wear only accounted for as little as 9.4% of the measured linear penetration. No statistical difference was found between any group of head sizes in either actual penetration or creep (p ≥ 0.26 for all groups, respectively). It has been suggested that creep primarily occurs early and minimizes with time [5]. Due to the short duration of this study only a small percentage of deformation was found to be material loss with this highly cross-linked material. The results of this study support the suggestion made previously by clinical researchers that a large percentage of the higher initial linear penetration found in clinical studies is due to creep and not by loss of material [5] and suggests that true material wear for this highly cross-linked material may be even lower than what has been clinically reported.

REFERENCES


Figure 1: Contact pressure as a function of head size

Figure 2: Material loss' contribution to total linear penetration at 2.0 Mc