Dislocation Potential in Conventional and Dual Mobility Hip Joint Couples

INTRODUCTION:
Studies have indicated that the shallow Ultra High Molecular Weight Polyethylene (UHMWPE) acetabular socket or the socket with no head center inset can significantly increase the risk of hip joint dislocation.\(^1\)\(^2\)\(^3\) A previous study suggested the rim loading model in UHMWPE socket and metal femoral head can generate dislocation force component.\(^4\)\(^5\)\(^6\) Recently there has been renewed interest in dual mobility articulations due to the excellent stability.\(^7\) (Fig. 1) The outer bearing couple of the dual mobility articulations are comprised of the UHMWPE femoral head and metal acetabular socket while inner bearing is the locked conventional metal-poly construct. The acetabular socket is also featured by an anatomically shaped head inset wall. The purpose of this study was to theoretically compare the dislocating force between conventional metal head on UHMWPE socket articulations and the poly head on metal socket articulations used in the outer bearing of a novel dual mobility cup under direct loading.

METHODS:
Sixty 3-D CAD model assemblies were consisted of CoCr and UHMWPE femoral heads and their corresponding 10mm thick generic UHMWPE and CoCr acetabular sockets with five different head center inset heights of 0, 0.5, 1, 1.5 and 2mm for each of six head diameters of 22, 28, 32, 36, 40 and 44mm. The head and socket bearing clearance was line to line. The head center inset sizes were comprised of the femoral cylindrical shell extension of the acetabular bearing. Models were developed within Pro/Engineer Wildfire v2.0 (Parametric Technology Corporation, Waltham, MA). These models were subsequently imported into ANSYS Workbench v11.0 (ANSYS Inc., Canonsburg, PA). Geometric, load, boundary condition symmetry enabled mesh generation and finite element analysis were performed on one-half of the assembly model. Each socket was auto-meshed by an element sizing of 0.76mm. The femoral head was auto-meshed with a 2.5mm size. The kinetic coefficient of friction of 0.02 was applied between the acetabular sockets and the femoral heads. The backside of the acetabular socket was constrained in all degrees of freedom to simulate the complete fixation. The nonlinear elastic modulus of UHMWPE, processed with 30KGray gamma sterilized in nitrogen atmosphere obtained from experimental data, was selected for acetabular and femoral bearings. The elastic modulus of CoCr femoral head and acetabular bearings were 220GPa. The Poisson’s ratios were .49 and .32 for polyethylene and CoCr respectively. The joint load of 2,446N was applied through the femoral head center to the mid point between the spherical edge and rim edge of the UHMWPE bearing. The joint load level was obtained from peak load by three times average body weight of 815.3N. The femoral head was constrained except for the loading direction. The reaction forces against the femoral head to prevent the femoral head from dislocating out of liner bearing were obtained in the FEA analysis. This force was in the opposite direction but equal in value to the dislocating force. The femoral head reaction force was recorded as dislocating force from FEA results. (Fig. 2)

The result trends were verified by the physical testing of actual UHMWPE acetabular liners which were 30KGray sterilized in nitrogen. One 28mm ID liner with 0mm head center inset and one 28mm ID liner with 1.5mm head center inset were fixed in the corresponding shells which were mounted in the fixture secured on the MTS testing machine (MTS Bionix 858, Eden Prairie, MN). A 28mm CoCr head was mounted on the main axial actuator and was seated in liner ID at mid point level of inset wall. The interface between head and liner ID was lubricated by bovine serum. There was an additional side actuator mounted on the MTS table applying horizontal load against the acetabular shell fixture peaked at 2,446N with 50N/s ramping. When femoral head actuator was under positional control, the reaction force or dislocating force against the head was recorded.

RESULTS:
The highest dislocating force was 1,269N per 2,446N of rim loading force for the 0mm head center inset in poly cup with 22mm CoCr femoral head or the case of easiest to dislocate. The lowest dislocating force was 17.7N per 2,446N force for the 2mm inset in CoCr cup with 44mm poly head which therefore was least likely to dislocate. The average DF decreased by 78% from metal head- poly cup couple to poly head - metal cup couple. The dislocating force decreased as the inset wall and head size increased in all material cases. The dislocating force distribution curves are shown. (Fig. 3) Two data points of physical testing of actual 28mm ID liners with 0 and 1.5mm inset wall heights were consistent with the trend of dislocating force curve from FEA.

DISCUSSION:
The study suggests that not only the head center inset, head size but also the bearing material combinations can affect the dislocating force component. The dislocating force can be reduced in same 44mm head diameter and 2 mm head center inset from 7% of rim loading force of conventional metal head - poly socket to 0.7% of rim loading force of poly head - metal socket. This is a 10 fold decrease in dislocation potential for the rim loading condition. This loading condition is more prominent when hip joint undergoes separation which has been observed during the gait after total hip arthroplasty. It could further reach the pure rim loading mode when acetabular cup is in excessive vertical position. In those conditions, all variables found in this study may play the important rules to maintain joint stability. This study suggested that the dislocating force is likely caused mainly by the wedge effect of deformed acetabular bearing. The function of the inset wall allows the femoral head to be separated from the spherical bearing surface. The stiffened cup rim reduces the deformation. Both help to reduce the cup wedge effect. This study suggested the larger femoral head has the advantage of reducing the dislocating force and this effect is more effective when combining with the socket inset wall and stiffened socket rim combinations. The result of this study should provide the guidance to improve acetabular cup design for better joint stability.

REFERENCES: