INTRODUCTION:
Clinical studies suggested that the shallow Ultra High Molecular Weight Polyethylene (UHMWPE) acetabular socket liner or the liner with no head center inset can significantly increase the risk of hip joint dislocation from 1.5-2% for liners with head inset design to 11.4-26% head center inset can significantly increase the risk of hip joint dislocation. However recent retrieval study by Tanino at al suggested the neck-liner impingement was not significantly correlated to the dislocation rate but rather, the liner head center inset height showed significance. Our question was, are there any mechanisms other than the impingement may contribute to the dislocation? The purpose of this study was to investigate the dislocating mechanism under direct hip joint loading. Our hypothesis was the liner head center inset can reduce the magnitude of this dislocating force.

METHODS:
Thirty 3-D CAD model assemblies were consisted of CoCr femoral heads and their corresponding 10mm thick generic UHMWPE acetabular bearings 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 liner bearing clearance was line to line. The head center inset was the tangential cylinder 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 cup liner 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 liner bearings and the femoral heads. The backbone of the acetabular liner was constrained in all degrees of freedom to simulate the complete fixation in the shell. The nonlinear elastic modulus of UHMWPE, processed with 30KGray gamma sterilized in nitrogen atmosphere obtained from experimental data, was selected for acetabular liner. The elastic modulus of CoCr head was 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 815.3 N. 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 (DF). The femoral head reaction force was recorded as DF from FEA results. (Fig.1)

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 DF against the head was recorded. (Fig.2)

RESULTS:
The highest DF was 1,269N per 2,446N of rim loading force for the 0mm head center inset with 22mm femoral head or the case of easiest to dislocate. The lowest DF was 171N per 2,446N force for the 2mm inset with 44mm head which therefore was least likely to dislocate. The DF decreased as the inset wall and head size increased. When the inset wall was higher than 1mm, the DF was reduced more than 50%. The head size increased from 22mm to 36mm for 0mm inset wall had the same effect of the inset wall increased from 0 to 0.5mm in 22mm head. But it needed only to be increased to 28mm from 22mm head size for the same effect when inset wall was increased to 1mm from 0.5mm. The DF 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 DF curve from FEA.

DISCUSSION:
The study suggests that the hip joint loading force alone with no torsional load applied can generate a DF component as high as 51% of the loading force. The results confirmed our hypothesis. A head center inset wall above 1mm can effectively reduce this dislocating force to less than 25% of the joint force. The head diameter increase resulted in less DF generation. In addition to the traditional parameters of hip joint dislocation such as impingement, subluxation and head jump distance, this study identified a new intrinsic dislocation force DF induced by the rim-directed joint loading force. It can be the addition to the dislocation torque induced by femoral neck impingement. The liner rim edge loading will be more prominent when hip joint undergoes separation which has been observed during the gait after total hip arthroplasty. Joint force in rim direction can reach high level when acetabular cup is in excessive vertical position. In those conditions, the head center inset design may play an important role to maintain joint stability. The DF is likely caused by the wedge effect between the deformed polyethylene bearing and the femoral head. The function of the inset wall allows the femoral head to be separated from the spherical bearing surface, thus reducing the wedge effect. Our observation of the stabilizing effect trend of the inset wall was consistent with other reported clinical data. However, the increased height of the capture wall also reduces the range of motion. It is therefore necessary to minimize the inset wall height especially for smaller femoral head sizes. This study suggested the larger femoral head has the advantage of reducing the DF and this effect is more effective when combining with the inset wall. The result of this study should provide the guidance to improve acetabular poly liner design for better joint stability.

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REFERENCES: