# EFFECTS OF IMPACT LOADING ON ALTERNATIVE BEARING SURFACES AND SUBCHONDRAL BONE OF THA

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**Introduction:** Metal-on-Metal (MOM) and Ceramic-on-Ceramic (COC) articulations have garnered renewed interest in the orthopaedic community. Low amounts of wear, and hence postulated low periprosthetic debris concentrations, form the basis for re-examination of hard-on-hard articulations. However, the new generation of articulations is modular, requiring locking interfaces between the hard bearing insert and the metal shell. Both direct taper locks and interpositional polymer (UHMWPE) locks have been introduced. Proponents of the taper lock designs suggest that the removal of all UHMWPE from the joint is advantageous. Proponents of the composite liner designs suggest that the interposition of an UHMWPE layer, while present to provide a means of locking the insert to the shell, also provides a means of absorbing shock or impact loads on the reconstruction. We proposed the hypothesis that the presence of a UHMWPE layer between a hard bearing and its mating shell would change the overall load transfer to the superior or bone interface side of the shell. That is, we investigated whether UHMWPE possesses mechanical and inertial properties that would be conducive to shock absorption under impact loading conditions. We tested this hypothesis using a state-of-the-art finite element model based on clinically relevant MOM and COC geometries.

**Methods:** Three-dimensional finite element models were constructed using Truegrid (XYZ Scientific Inc.) to represent a 28 mm diameter spherical femoral head contacting a hemispherical multi-layered acetabular socket (Fig. 1). The socket was composed of three parts, including a 7 mm thick acetabular liner, a titanium alloy shell, and a layer of cancellous bone 10 mm thick. The liner consisted of two layers to permit modeling of composite CoCr/UHMWPE design, in which the liner consists of a CoCr bearing surface embedded in an UHMWPE foundation. The properties for different regions of the model were varied to simulate six acetabular designs (Fig. 1, Table 1).

**Table 1**. Summary of Six Contemporary Hip Couples in THA

| Design | Head | Liner |
|---|---|---|
| Conventional-1 | CoCr | UHMWPE |
| Conventional-2 | Alumina | UHMWPE |
| MOM | CoCr | CoCr |
| MOM-UHMWPE | CoCr | CoCr/UHMWPE "Sandwich" |
| COC | Alumina | Alumina |
| COC-UHMWPE | Alumina | Alumina/UHMWPE "Sandwich" |

Head-liner contact was simulated using an explicit finite element software LS-Dyna (LS-DYNA3D: LSTC, Livermore, CA) [1] and zoning studies verified convergence of the contact solutions. The model consisted of 64,000 solid hexahedral elements and 68,786 nodes. An inner radial clearance of 50 μm was simulated between the femoral head and the liner; the interfaces between all of the other components was simulated as displacement compatible. The displacements for the back surface of the subchondral bone layer were fixed in all coordinate directions. The properties for the materials were: Titanium alloy, E=118 GPa, ν=0.3 ρ=4.85g/cc; CoCr alloy, E=200 GPa, ν=0.3 ρ=8.03g/cc; Polyethylene, E=630 MPa, ν=0.46, ρ=0.94 g/cc; Ceramic, E=320 GPa, ν=0.3, ρ=3.9 g/cc; Bone E=500 MPa, ν=0.0, ρ=1.5 g/cc.

The liner was simulated at an inclination of 30°, and a peak joint reaction force of 3,000 N was applied at the center of the femoral head using either quasi-static or dynamic loading history. For the dynamic loading case, an eliptical load history with a 5 ms pulsewidth was used. The peak frequency component for this loading is 100 Hz, which is in line with frequencies observed during accidental overloads for which the benefit of a compliant or shock absorbing layer would be maximized.

**Results:** The dynamic results within the acetabular cups showed that inertial effects within the cups played a relatively small role at the loading rates used here. Contact stress distributions were similar between the quasi-static results and the dynamic (impact loading) results at peak load.

Under dynamic loading conditions, the maximum effective (von Mises) substantially lower than the yield stress of 965 MPa for forged CoCr and the flexural strength for alumina of 500-550 MPa. When comparing the two MOM and COC designs, the inclusion of a UHMWPE layer lowered the stresses at the bearing surface, but also increased the maximum von Mises (effective) stresses, located at the back surface of the metal or ceramic bearing insert (Table 2). Inclusion of an UHMWPE layer in the MOM and COC designs had no substantial influence on the dynamic response of the articulation for the impact conditions studied here.

**Fig. 1.** Exploded View of Finite Element Model

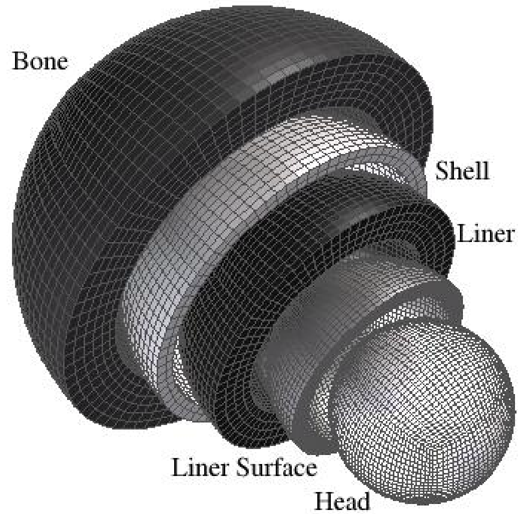


**Table 2.** Summary of maximum contact and von Mises stresses in the liner and bone for 3,000 N joint force with quasistatic and impact loading histories.

| Design | Liner Contact Area ($mm^3$) | | Liner von Mises Stress (MPa) | | Bone von Mises Stress (MPa) | |
|---|---|---|---|---|---|---|
| | Static | Impact | Static | Impact | Static | Impact |
| Conventional-1 | 730 | 704 | 7.6 | 7.7 | 2.0 | 1.8 |
| Conventional-2 | 709 | 704 | 8.0 | 7.8 | 2.0 | 1.8 |
| MOM | 91 | 99 | 45 | 48 | 1.7 | 1.9 |
| MOM-UHMWPE | 143 | 145 | 90 | 94 | 1.7 | 1.8 |
| COC | 67 | 72 | 62 | 72 | 1.7 | 1.7 |
| COC-UHMWPE | 93 | 100 | 127 | 130 | 1.6 | 1.8 |

**Discussion:** Ceramic-on-ceramic components exhibited von Mises stresses of about 25% of their flexural strength, suggesting that structural concerns should be minimal using today's modular ceramic technology. Contact stress decreased in MOM components when an UHMWPE layer was interposed, but this decrease was due to an increase in contact area. Since adhesive/abrasive wear is the primary mode of wear in a MOM couple, increasing the contact area is likely to increase debris production commensurately.

The inclusion of a UHMWPE layer between the metal articulating surface and the metal shell had no effect on the stresses transmitted to the bone. Within the context of changing the effects of dynamic loading on an acetabular reconstruction, the use of an UHMWPE layer cannot be considered to have shock absorbing properties of any clinical relevance.

**References:** [1]Kurtz et al., *J. Biomech.* 31:431-437, 1998.

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