INTRODUCTION:
With the commercial launch of ceramic-on-metal (COM) bearings in total hip replacement (THR), the question arises if problems known from ceramic-on-ceramic (COC) or metal-on-metal (MOM) bearings will play a role in this new approach. COC bearings are at risk for stripe wear, commonly suspected to be caused by steep cup positions and subsequent edge loading [1; 2]. A related complication with MOM bearings especially in hip resurfacing are increased metal ion levels, also connected to steep cup positions and edge loading [3]. In the present study we compared the deformation and stresses in the acetabular cup liner of COM bearings with COC, MOM as well as ceramic-on-polyethylene (COP) bearings using a finite-element (FE)-model, analyzing a variety of head size and implant position. Liner deformation in terms of change in inner diameter as well as peak stresses were evaluated and compared.

METHODS:
The FE-model consisting of a commercial THR, the left proximal femur and a section of the hemipelvis (Figure 1) was created based on our previously published approach [4]. The finite-element-mesh was designed such that anatomical structures were represented with tetrahedral elements with quadratic interpolation. Bearing components were represented with small hexahedral elements for accurate contact calculation. Static load and muscle forces were applied according to the maximum load during the gait cycle. Polyethylene was modelled using a nonlinear definition with isotropic hardening [5], cobalt-chromium was modelled elastic-plastic and ceramic was modelled linear-elastic.

Sensitivity was evaluated considering clearance between head and liner and a mesh convergence study was conducted. As a result of the convergence study, approximately 75,000 finite elements were used. Validity of the model was checked using an experimental setup with artificial bone and strain gauges located at the rim of the liner (Figure 1).

In order to analyze the influence on deformations and stress in the liner, implant material (COM vs. COC vs. MOM vs. COP), head size (28 mm vs. 36 mm) and cup position (45° inclination / 15° anteversion vs. 60° incl. / 0° ante.) were varied using the validated FE-model. Deformation was evaluated along node-paths at the equator of the liner and in the inside at the level of highest deformation. COM resp. COP, COC and MOM bearings were evaluated using von Mises stress resp. minimum principal stress within the liner. All calculations were performed using ABAQUS V6.9ef (Simulia, Providence, RI, USA).

RESULTS:
The experimental validation showed high correlation between the strain measurements and the corresponding FE-results of the circumferential strains. Sensitivity analysis of the ball and liner clearance showed that most stable results were gained with a radial lubrication gap of 50 µm for each bearing.

Liner deformation was evaluated in a cylindrical coordinate system with the origin in the rotation center. Hence, the radial coordinate showed the change in radius resp. diameter of the liner at different levels. We found positive and negative deformation values meaning that the liner diameter was partially widened and partially tightened. A corresponding change in diameter profile is demonstrated in Figure 2. We found that change in head size has a high influence on cup deformation in COM, COC and MOM bearings, most possibly due to decreased liner thickness using bigger heads. The equatorial diameter deformation was raised from +13 µm using a 28 mm head to +84 µm using a 36 mm head in a flat cup position. As regards the polyethylene liner, tightening of the equator by -64 µm was calculated in a flat cup position, while in steep positions the equator widened by +45 µm. Differences in MOM, COC and COM liner deformation were only in sub-micrometer range and not further evaluated.

DISCUSSION:
Deformation of the acetabular cup liner in total hip replacement has an important influence on lubrication, wear and clinical long-term success. With regard to the new bearing couple COM, our goal was to investigate if liner deformation and stresses are significantly different from other bearing couples and how implant position and head size affect these parameters. The deformation occurring during intraoperative impaction and press-fit of the metal shell was not included in this study. Hence, the results are only valid considering the late postoperative phase when the implant is fully integrated in the bone stock without pre-stressed conditions. The FE-analysis showed no significant difference with regard to liner deformation between COM, COC and MOM bearings. However, principal stresses were slightly higher in COM under the same conditions, but lower than COC.

As regards COP, a tightening of the equatorial diameter occurred under physiological loading. This is possibly caused by material flow or creep while the prosthetic head protrudes in the cranio-medial direction, a side-effect that shall be studied in further studies.

REFERENCES: