INTRODUCTION:
Current ceramic-on-ceramic total hip replacement (THR) bearings range from 28-36mm diameter. It is advantageous to increase the diameter to improve stability and reduce the risk of dislocation. It is also advantageous that an increase in bearing diameter is achieved without increasing acetabular bone resection. The present study employs computational modelling to investigate whether an acetabular cup could be produced with a bearing diameter up to 48mm but with no increase in cup outer diameter. Such a design takes advantage of recent developments in transformation toughened ceramic materials.

The potential to assemble the cup components prior to surgery was also considered. Incomplete liner seating has been identified in 16% of operations in a multi-surgeon study, and this could be prevented by pre-assembly under standard, clean, controlled conditions, which would be impossible in surgery. Preventing insert-cup separation may also avoid bearing squeaking, as the insert would remain fully supported and unable to resonate throughout the gait cycle.

A finite element analysis (FEA) design study was conducted to derive the geometry and assembly technique for a modular ceramic bearing acetabular cup with reduced thickness but sufficient strength to avoid fracture in-vivo, validated with in-vitro mechanical tests.

METHODS:
A finite element model of the acetabular cup was created using ANSYS 11 Explicit FE Software (ANSYS Inc, Canonsburg, PA). The cup components were modelled under axial assembly and burst test loads, that is, pressing the ceramic bearing insert into a titanium shell. This was a non-linear analysis as a result of contact between the components at a taper interface, and elasto-plasticity assigned to the titanium material. Linear elastic properties relating to a Zirconia Toughened Alumina composite were applied to the ceramic material.

Five different bearing insert and shell geometries were modelled, starting from an existing implant design, to reach a design with increased bearing diameter but acceptable component stress. These designs were modelled under standard burst test conditions.

RESULTS AND DISCUSSION
Modification of the bearing insert and titanium shell component geometry was predicted to reduce the peak ceramic stress by 20%, despite increasing the bearing diameter by 4mm without increasing the outer diameter. Titanium shell stresses were predicted to increase but remain well below the material’s yield point. Radial deformation was also predicted to be within acceptable levels, to prevent equatorial bearing. Predictions of push-out resistance were confirmed by the mechanical tests, in terms of the FE model’s predicted stored energy in the assembled implant compared to the energy required to assemble it in physical tests, as was the measured radial bearing deflection.

Dimensional variation from achievable manufacturing tolerances was predicted to reduce push-out resistance by up to 19% in the worst case, but this was still predicted to be within safe limits.

By applying the assembly load to the insert rim, tensile residual stress in the ceramic component could be reduced dramatically, by up to 8 times. This also gave 50% lower radial deflection of the bearing surface, and a slight improvement in push-out resistance.

With ideal assembly, fracture probability under burst testing was predicted to be of the order of 0.5% at 46kN, the industry standard burst requirement, with an average burst strength (Pf = 50%) of approximately 400kN (Figure 2). For reference, the model predicted mean burst strength for a cup typical of current designs of 300kN, and fracture probability at 46kN of 1.2%. It should be noted that in-vivo, the scenario to cause most concern is dynamic loading with excessive cup opening, which could cause bearing microseparation and edge loading, or impingement of the femoral neck on the insert rim. However, with the reduction in residual tensile stress achieved by the proposed design, fracture under these conditions is likely to be reduced; reduction in residual tension would make the cup more tolerant of poor alignment.

Finally, even in extreme cases of implant alignment, positive pressure was predicted along the full taper interface between the components, implying integrity of the prosthesis and sufficient support to prevent resonance or squeaking.

CONCLUSIONS:
This study suggests that with an improved design which exploits recent transformation toughened ceramic bearing materials, it may be possible to produce preassembled modular acetabular cups with greater stability and integrity in-vivo, which are more tolerant to misalignment in the pelvis, representing an improvement in existing technology.

REFERENCES: