INTRODUCTION: One potential limitation with uncemented, hemispherical metal-backed acetabular components is the stress shielding of bony structures due to the mismatch in elastic modulus between the metal backing and the periprosthetic bone [1-3]. Previous researchers have suggested that wear-resistant, flexible acetabular cups fabricated from UHMWPE or from other polymer composites may provide more physiologic load transfer to the periprosthetic bone [1-3]. In vitro studies have also shown that improved load transfer may be achieved with non-hemispherical cup designs that do not engage the entire periacetabular bone surface [3].

An alternative design to the hemispherical metal-backed cups is a horseshoe-shaped acetabular component, which replicates the bony anatomy. One such device, the Cambridge cup, has shown clinically successful outcomes at five years follow-up [1]. This study examined the Cambridge cup from a biomechanical and structural perspective, using high-resolution computational models of the bilateral hip.

METHODS: A 3-D finite element (FE) model of the natural bilateral hip was generated based on the geometry and material properties of a 45 year-old female donor hip with no known bone disorder (ScienceCare Anatomical, Phoenix, AZ). One mm thick slice images of the hip (523 slices total; 0.781 mm x 0.781 mm resolution), along with a European Spine Phantom were obtained using a computed tomography (CT) scanner. The protocol was approved by an Institutional Review Board. Linear brick elements were used to model the pelvic, sacral, and femoral trabecular bone, while linear shell elements were used to model a 1 mm thick cortical shell around the pelvis (TrueGrid, XYZ Scientific Applications, Inc., Livermore, CA). The final mesh consisted of 139,616 brick elements and 26,776 shell elements, with 154,533 nodes. Non-homogeneous, isotropic, linear elastic material properties were assigned to the trabecular bone based on the QCT data and reported density-modulus relationships [4].

A Cambridge cup FE model (266,690 brick and 27,408 shell elements, 294,409 nodes) was also constructed by incorporating a 54.5 mm O.D. horseshoe-shaped cup (Figs. 1 and 2) and a large diameter (45 mm) femoral head. The cup consisted of a 3 mm thick bearing surface of UHMWPE, interlocked with a 1.75 mm thick backing of 30% carbon-fiber reinforced polybutyleneetherphthalate (CFR-PBT; 16.6 GPa modulus) [1]. The six pegs on the backside were designed to provide initial mechanical stability. The uncemented cup was assumed to be perfectly bonded to the surrounding bone. A conventional metal-backed hemispherical cup hip model (177,696 brick and 25,246 shell elements, 195,426 nodes) was also developed to provide baseline results. The implant consisted of a 4 mm thick CoCr alloy backing and 8 mm thick UHMWPE liner with a 28 mm diameter femoral head. A peak joint reaction force of 3 kN was applied through the center of the left femoral head. Distributed nodal pelvic muscles forces were also taken into account [5]. Periprosthetic stress and strain fields for the natural hip, Cambridge cup and metal-backed hemispherical cup pelvis models were compared.

RESULTS: The conventional metal-backed hemispherical cup caused unphysiologic distribution of bone stresses in the superior roof and unphysiologic strain transfer around the acetabular fossa (Fig. 3). In contrast, the Cambridge cup produced periacetabular stresses and strains, which were modified from the natural hip but were more physiologic than the conventional hemispherical design. Stresses in the superior acetabular roof with the Cambridge cup, directly underneath the central bearing region, were greater than with the conventional hemispherical design. The peak liner stresses in the Cambridge cup (max. principal stress: 1.2 MPa; von Mises stress: 4.5 MPa) were much lower than the reported tensile and yield strengths of 50 MPa and 25 MPa, respectively. They were also comparable to the liner stresses in the CoCr-backed hemispherical cup (max. principal stress: 1.2 MPa; von Mises stress: 9.7 MPa).

Fig. 3: Min. principal stress (top) and von Mises strain (bottom) distributions around the left acetabulum (natural hip: left; hemispherical cup model: middle; Cambridge cup model: right). Note the unphysiologic loading of the fossa in the hemispherical cup model.

DISCUSSION: The current metal-backed hemispherical cup design produced unphysiologic strains around the acetabular fossa, which has been observed in vitro and suggested as a possible mechanism for decreased implant stability [3]. Conversely, the Cambridge cup produced semi-lunar periprosthetic stress distributions, consistent with contact regions measured in vitro [3]. In spite of the 3 mm UHMWPE liner in the Cambridge cup, the resultant bearing stresses did not exceed the tensile or yield strengths for UHMWPE. Instead, the liner stresses were comparable, if not lower than those for the hemispherical cup (8 mm liner), a likely consequence of the larger femoral head for the Cambridge cup (45 mm vs. 28 mm). These analyses provide a better understanding of the biomechanics of the reconstructed acetabulum and suggest that long-term fixation in the pelvis may require a change in component geometry to substantially influence the magnitude and regional distribution of trabecular bone stresses and strains around the acetabulum.


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