The Influence of Head Diameter and Wall Thickness on Deformations of Press-fit Cups and UHMWPE Liners

+1 Goebel, P; 1 Kluess, D; 1 Wieding, J; 1 Soufrant, R; 2 Heyer, H; 3 Sander, M; 3 Bader, R
4 Department of Orthopedics, University of Rostock, Germany; 5 Chair of Structural Mechanics, University of Rostock, Germany
paul.goebel@med.uni-rostock.de

INTRODUCTION:
Aseptic implant loosening caused by wear debris, attributed to the friction within acetabular components during gait cycle, is still the most frequently reason for revisions of endoprostheses in total hip replacement (THR) [1]. Impaction of acetabular components could produce additional forces resulting from acetabular cup deformation, which may result in combination with the hip joint loads during gait cycle in increased frictional torque at the articulating joint [2].

Increasing the range of motion and dislocation stability of total hip endoprostheses needs to enlarge prosthetic heads whereby the cup and/or liner thickness decreases. This may have negative effects on the tribological coupling and its wear rate, because deformations of both acetabular cups and liners during press-fit implantation and hip joint loading could occur.

The purpose of this parametric finite-element (FE) study was to analyze deformations of cementless acetabular metal cups resulting from the press-fit implantation into the acetabular bone with regard to different cup wall thicknesses. Transmission of these deformations to the ultra-high-molecular-weight-polyethylene (UHMWPE) liner, which is inserted into the cup after press-fit implantation, was determined by means of several liner thicknesses to enable statement about a changing clearance between head and liner. Subsequently the influence of physiological joint loading to deformations and stresses of the liner was evaluated.

METHODS:
Nine FE models, resulting from combining three cup and liner wall thicknesses (Tab. 1), were used to analyze deformations and stresses after press-fit implantation and hip joint loading. The FE models consisted of a commercial THR, the left hemipelvis and the left proximal femur of artificial bone (Sawbones Europe AB, Malmö, Sweden) (Fig. 1). Bearing components were meshed with linear eight-node hexahedral elements while anatomical structures were discretized with 10-node tetrahedral elements with quadratic interpolation for accurate contact calculation. Additionally, a 2D-surface meshed with quadratic 6-node triangular shell elements was created as cortical layer on top of the outline contour of the pelvis with an average thickness of 1.5 mm [3, 4]. As a consequence of a convergence study, the FE meshes consisted of approximately 78,000 finite elements.

RESULTS:
Evaluation of cup and liner deformation was carried out in a cylindrical coordinate system located in the middle of cup and liner. By means of node paths along the inner rim of cup and liner, radial deformations were circumferentially evaluated and the maximum decrease of inner diameter for every model was computed (Fig. 2). A sensitivity analysis showed the importance of physiological thickness of the cortical layer, being the crucial factor for resulting cup deformation.

Press-fit implantation showed diametric cup deformations of 0.096, 0.034 and 0.014 mm for wall thicknesses of 3, 5 and 7 mm, respectively. Largest deformations of PE liners with thicknesses of 4, 6 and 8 mm occurred at an average of 0.084 ± 0.003 mm with a cup wall thickness of 3 mm. Smallest liner deformation (0.011 mm) was established with highest cup (7 mm) and liner wall thickness (8 mm). The results of liner deformation under physiological joint loading (Tab. 2) showed only little variation to those from press-fit implantation.

All determined von Mises stresses within the liners amounted clearly below the yield stress of 24 MPa for UHMWPE (Tab. 2). During constant head size of 36 mm, when cup wall thickness decreased from 7 to 5 resp. 3 mm, the increase of liner thickness from 4 to 6 resp. 8 mm led the maximum stress reduce about 17 resp. 30 %.

Tab. 2. Maximum diametric liner deformation and stress with regard to several head sizes resulting from different cup and liner thicknesses under physiological joint loading.

![Fig. 1. FE model consisting of total hip replacement and left hemipelvis and femur.](image)

DISCUSSION:
Using thin walled acetabular cups (3 mm) for press-fit implantation resulted in deformations of PE liners which also entailed under loading a reduction of the initial clearance (0.1 mm) about 49 %. Thus, the optimum range for hard-soft pairings (0.10 to 0.15 mm) is impaired, which can have a negative impact on lubrication and wear. Acetabular cups with wall thicknesses ≤ 5 mm should only be used in combination with PE liners > 6 mm to impair the clearance as small as possible.

SIGNIFICANCE:
Recommendations for the combinations of wall thicknesses of metallic press-fit cups and PE liners could be drawn. In addition, the influence of different head sizes on deformations and stresses in the liner under physiological joint loading was analyzed to characterize the consequences of a possible change in clearance.

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REFERENCES: