INTRODUCTION: Over the past several decades, metal-backed acetabular components have varied in the design of the rim. Currently, most acetabular components have a polyethylene (PE) liner with some form of rim that overlaps the edge of the metal shell and prevents metal-on-metal impingement. However, fracture of the rim of PE liners has been reported (1,2). Also, severe wear damage in the form of delamination or fracture near the rim on the inner periphery of acetabular liners has been observed. The objective of this work was to investigate the relationship between rim geometry, conformity, and loading conditions to provide a clearer understanding of when acetabular hip components may be susceptible to PE failure in the rim region.

METHODS: A 3-dimensional finite element model of an acetabular component was developed using ANSYS finite element software. The model consisted of a rimmed PE liner (8mm thick), a femoral head/neck (28mm diameter), and a metal shell. The liner was meshed with 20-node brick and 15-node wedge elements (Figure 1). A symmetry boundary condition was used to reduce the total degrees of freedom. A quadrilinear material model with an initial slope of 922 MPa was used to define the PE stress-strain relationship (3) and Poisson’s ratio was taken as 0.46. The PE was modeled in the as-irradiated (in air) condition with a 0.2% yield stress, $\sigma_{ys}$, of 14.9 MPa. The femoral head and shell were modeled as rigid bodies and surface-to-surface contact elements were used in all interface regions. A convergence study was conducted to ensure sufficient mesh density, yielding a model with approximately 15,000 degrees of freedom.

![Figure 1: Representative finite element model with nominal rim thickness. The shell is in contact with the backside of the liner and thus not visible in this image.](image)

A sensitivity analysis was performed using three variables; rim thickness, liner-shell conformity, and direction of loading. Three rim thickness conditions (thick, nominal, and thin) were evaluated, where the thick and thin rim conditions were +/- 1mm relative to the nominal condition (2.4mm), respectively. Two conformity conditions were evaluated. The dome-supported condition was defined by perfect conformity between the hemispherical regions of the liner and shell. In the rim-supported condition, the liner was not in contact with the shell at the apex of the component, but rather, was supported by the rim feature. A 1500N load (3000N total load) was applied through the femoral head at 55° and 75° off the centerline the liner. The 55° loading angle corresponds to a clinically desirable loading direction and approximates the direction of loading used in mechanical wear simulators. The 75° loading angle represents an undesirable inclination angle, but one that can occur clinically. A total of 12 conditions (3 rim thicknesses, two conformities, two loading directions) were compared on the basis of the predicted maximum von Mises stress and its location.

RESULTS: For the dome-supported cases, the maximum stress occurred at the articulating surface between the femoral head and PE liner near the periphery. For the rim-supported cases, the maximum stress occurred at the outer surface of the liner, near the underside of the rim. Figure 2 shows that, for the dome-supported condition, increasing the direction of loading from 55° to 75° increased the maximum von Mises stress by more than 50%, for all rim thicknesses. However, altering the loading direction for the rim-supported condition resulted in at most an 8% increase in stress. Increasing or decreasing the rim thickness changed the stress by at most 10% from the nominal condition for the dome-supported condition, regardless of loading direction. For the rim-supported condition, reducing the rim thickness by 1mm increased the maximum stress as much as 30%. Changing from the dome-supported condition to the rim-supported condition increased the maximum stress by 65-100% for the models loaded at 55° and by 16-32% for the models loaded at 75°.

![Figure 2: Maximum von Mises stress as affected by rim thickness, conformity (dome vs. rim), and loading direction (55° or 75°). The 0.2% offset yield stress ($\sigma_{ys}$) is indicated.](image)

DISCUSSION: The substantial increase in maximum von Mises stress predicted by increasing the loading angle supports the importance of proper in vivo implant orientation. Additionally, the results raise the question as to whether traditional in vitro wear simulators rigorously challenge the critical design features at the periphery of the liner of metal-backed acetabular components. With respect to the variables of loading direction and rim thickness, all of the rim-supported conditions exceeded $\sigma_{ys}$ of the PE (Figure 2). For the dome-supported condition, in the loading direction of 75°, the predicted maximum stress was near $\sigma_{ys}$. The results suggest that certain combinations of rim thickness, conformity, and loading direction may accelerate PE failure near the periphery of the articulating surface or of the rim. However, given a dome-supported condition, the rim thickness has minimal effect on the maximum von Mises stress. Thus, it may be possible to minimize this dimension to maximize range of motion.


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