Biomechanical evaluation of acetabular component polyethylene stresses, fracture risk, and wear rate during press-fit implantation

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Introduction: Potential acetabular component deformation ranging from 0 to 0.57 mm (diametrical) during press-fit implantation has been reported in recent studies [1, 2]. These deformations occur as a consequence of rim loading along the anterior-superior and posterior-inferior margins of the acetabulum [2], resulting in two-point pinching between the ischial and ilial columns [1]. This pinching may result in a slight incongruency between the contacting surfaces, which can alter the contact stresses, in turn affecting PE wear [3].

The objectives of the current study were to: 1) examine the effects of pinching (two-point cup deformation) on PE volumetric wear rate and fracture risk; and 2) compare the behavior of an insert already in clinical use to a proposed thinner insert.

Materials and Methods: A standard total hip prosthesis was implanted into 2 mm under-reamed polyurethane bone foam blocks with two areas relieved on opposite sides [1]. Two different PE liner sizes were compared: 36 and 40 mm (36E and 40E), with corresponding head sizes. The PE thicknesses for the 36E and 40E liners were 5.9 mm and 3.8 mm, respectively. A shell diameter of 50 mm was utilized for both designs. Caliper measurements of the shell and liner diameters were taken before and after impaction.

FE models of the same cup designs with the two different PE liner thicknesses used in the bone foam experiment were generated. The model was validated against experimental measurements. Line-to-line (“no pinch”) reaming and 2 mm under-reaming press fit (“pinch”) conditions of the acetabulum were examined by applying pinch deformations from the above bone foam experiments. Additional deformations of up to 0.55 mm were also simulated. The cups were subsequently loaded to 3 kN with relevant femoral head rotations (Fig. 1) [4]. Two sets of boundary conditions were applied to the backside of the shell: fully fixed or fixed only at the points of pinch.

A previously validated hybrid material model for X3 PE was applied to the PE inserts [5,7] in order to determine molecular chain stretch and characterization of the multiaxial failure behavior. The contact and effective stresses in the insert were also determined. The ratios of volumetric wear between the various cup designs were computed [3]. Simulator-measured volumetric wear rate for 36E inserts (3 mm3/106 cycles) [6] was used to estimate volumetric wear rates.

Results: The bone foam block experiments produced shell pinch deformations of up to 0.28 mm. The molecular chain stretch values for the no pinch and 0.28 mm pinch cases ranged from 1.00018 to 1.00035 (unity implies zero chain stretch) for the two insert sizes (36E and 40E) and did not exceed the failure threshold of 2.3 for X3 (smooth specimen) [7]. The effects of backside shell boundary conditions (fully fixed or partially fixed) had insignificant effects. In the presence of 0.28 mm pinching, the peak contact stress increased from 4.8 to 13.0 MPa for the 36E insert and from 4.0 to 13.0 MPa for the 40E insert (Table 1). The estimated volumetric wear rate differed between the “pinch” and “no pinch” scenarios and also between 36E and 40E inserts with pinching (Table 1 and Fig. 2). The larger head size resulted in a slight increase in the estimated volumetric wear rate from 3.0 to 3.3 mm3/106 cycles with no pinch. For the 36E insert, the volumetric wear rate was estimated to increase from 3.0 to 5.2 mm3/106 cycles, in the presence of 0.28 mm diametrical pinching. The corresponding volumetric wear rate for the 40E insert was estimated to increase from 3.3 to 5.6 mm3/106 cycles. At 0.55 mm of pinch, the wear rate was estimated to be 7.6 and 11.7 mm3/106 cycles for the 36E and 40E inserts, respectively.

Discussion: The estimated wear rates were comparable to those measured in hip simulator studies [6]. Even in the presence of pinch, the estimated wear rates for both the historical thicker (36E) and proposed thinner (40E) liners were low compared to conventional PE (46 mm3/106 cycles for 32E N2 Vac). These data suggest that use of highly cross-linked PE may allow for thinner inserts, hence larger femoral heads, while averting additional acetabular bone resection and improving joint stability [8]. However, further investigation of other cup and head geometries is required to verify this. The findings demonstrate that under similar loading conditions, pinching increased the insert stresses. The molecular chain stretch results suggest that PE fracture is highly unlikely, while the estimated volumetric wear rates are likely to be low compared to conventional PE. This study assumed that the amount of pinching was similar for the 36E and 40E inserts and did not relax under gait load application. This represented a worst-case scenario as it is expected that the visco-elastic response of the surrounding bone would reduce the amount of pinch.


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