FRONTSIDE VS. BACKSIDE WEAR IN AN ACETABULAR COMPONENT WITH MULTIPLE SCREW HOLES

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Introduction: In a modular acetabular component, wear debris may be generated at the articulating surface, between the femoral head and the polyethylene liner, or at the back surface, between the liner and the metal shell. Backside wear at the liner/shell interface has been associated with micromotion of the liner and the presence of screw holes [1, 2]. Huk and colleagues have previously hypothesized that backside wear may be a factor leading to focal osteolytic lesions at the bone-implant interface [1]. However, to date backside wear and its relationship to the presence of screw holes has not been well quantified. Similarly, the effect of screw holes on wear at the articulating surface has not been explored. Consequently, the primary goal of this study was to investigate frontside and backside wear using a sliding-distance coupled finite element approach that has been shown to simulate wear at the articulating surface [3]. This research explored the hypothesis that backside nonconformity plays as important a role in the total wear of a modular acetabular component as the presence of multiple screw holes.

Materials and Methods: Three-dimensional finite element models were created from design drawings of a commercially-available acetabular component with 28 mm inner and 54 mm outer diameters. Shell models included a 4 mm-radius polar fenestration and either zero, two, or eight screw holes with 6.4 mm radii. The acetabular system was modeled using up to 43,664 brick elements to represent the femoral head, the polyethylene liner, and the metal shell (Fig. 1). Frictional sliding contact was modeled at the polished, nonconforming head-liner and liner-shell interfaces. The liner was also modeled as perfectly conforming with the metal shell. The locking mechanism was simulated in the models by applying displacement boundary constraints to selected liner nodes at the rim and the equator. The three-body contact problem was solved using LS-DYNA3D (LSTC, Livermore, CA). A previous study demonstrated the convergence and accuracy of the contact solutions [4]. The Paul load curve (peak 3010 N) was applied in 14 quasistatic steps at 15° of anteversion and 40° of inclination [5]. Although the magnitude of the joint force changed as a function of time, the direction of the load remained constant to simulate the duty cycle of previous *in vitro* testing [6]. Incremental sliding distance at the backside was based on the arc length distance traversed by liner nodes in contact with the shell between load steps. Initial wear rates were computed using Archard's law with a wear coefficient of 10.656 10^{-7} $mm^3N^{-1}m^{-1}$, assuming 10^6 cycles per year [3].

Results: Contact area, contact stress, and wear at the liner/shell interface were more sensitive to liner/shell conformity than the presence of screw holes (Table 1). For example, increasing the conformity of the back surface decreased the linear wear by 67% in the No Hole design; in contrast, adding two screw holes to the No Hole design increased the linear wear by only 9%. Wear rates for the Two Hole and Eight Hole designs were not substantially different, because the additional screw holes fell outside the region of primary liner-shell load transfer. Backside linear and volumetric wear rates were three and four orders of magnitude less, respectively, than wear estimates at the articulating surface (Table 2). This discrepancy was primarily attributed to the difference in maximum sliding distances at the articulating surface (measured in mm) versus the back surface (measured in μm).

Discussion: Our results show frontside wear to be substantially larger than backside wear, underscoring the primary importance of frontside wear considerations for design purposes. This is the first study in which backside wear has been quantified and explicitly compared with frontside wear using metrics established for the articulating surface. Our results also suggest that the presence of screw holes does not substantially increase abrasive backside wear when compared with the effects of backside nonconformity. This study also demonstrates that an abrasive wear model, in conjunction with the finite element method, can be an effective tool by which to quantitatively evaluate design variables and their hypothesized effects on initial backside wear rates. Due to limitations of the wear theory, the conclusions of this study are applicable to a polished backside interface with homogenous tribological properties. Such conditions may not apply in the vicinity of screw holes with sharp edges, where focal wear has been clinically observed [2].

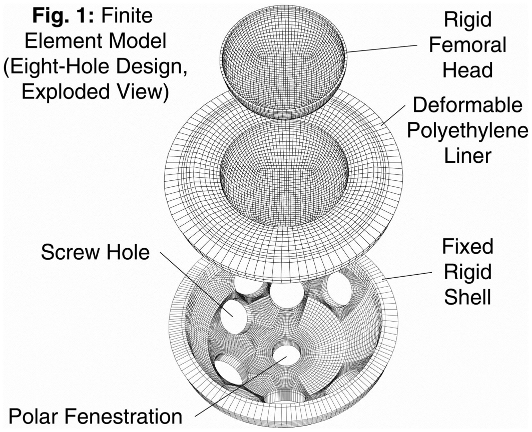

Fig. 1: Finite Element Model (Eight-Hole Design, Exploded View)

Table 1. Summary of Backside (Liner/Shell) Interface Results

Design	Shell	Contact Area	Contact Stress	Linear Wear	Volumetric Wear
No Hole	NC	574	10.01	3.36×10^{-4}	4.17×10^{-2}
No Hole	C	2395	7.86	1.37×10^{-4}	6.65×10^{-2}
Two Hole	NC	531	11.09	3.65×10^{-4}	4.22×10^{-2}
Two Hole	C	2247	9.14	1.18×10^{-4}	5.55×10^{-2}
Eight Hole	NC	487	11.09	3.58×10^{-4}	3.92×10^{-2}
Eight Hole	C	1711	9.54	1.35×10^{-4}	5.23×10^{-2}

Table 2. Summary of Frontside (Head/Liner) Interface Results

Design	Shell	Contact Area	Contact Stress	Linear Wear	Volumetric Wear
No Hole	NC	559	16.88	0.229	39.0
No Hole	C	499	13.44	0.212	38.6
Two Hole	NC	573	16.95	0.227	39.0
Two Hole	C	524	12.21	0.193	38.6
Eight Hole	NC	561	16.97	0.226	37.4
Eight Hole	C	518	12.74	0.200	38.5

Abbreviations for Tables 1 & 2: Maximum Contact Area (mm^3), Maximum Contact Stress (MPa), Initial Linear Wear Rate (mm/year), and Volumetric Wear Rate (mm^3/year). C = Conforming Shell; NC = Nonconforming Shell.

Simulation of long-term wear at the articulating surface has included adaptive remeshing to account for the substantial geometric changes at the head-liner interface during the wear process. Due to the relatively small backside wear rates, adaptive remeshing at the back surface may not be as critical as at the articulating surface. Long-term changes in backside nonconformity are more likely to occur due to creep rather than wear, as was suggested by the results of a recent investigation by Williams et al. [2], which demonstrated progressive changes to liner-shell relative motion during an *in vitro* examination of five designs loaded for up to 10^7 cycles. In the current study, the sensitivity of our results to changes in conformity illustrates the importance of accounting for long-term geometric changes at the back surface of the component during simulations of backside wear.

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References: [1] Huk *et al.*, JBJS (76-B), 1994; [2] Williams *et al.*, J Arthroplasty (12), 1997; [3] Maxian *et al.*, J. Biomech (29), 1996; [4] Kurtz *et al.*, J. Biomech, In Press, 1998; [5] Weightman *et al.*, J. Lubrication Technology, April, 1972. [6] Cournoyer et al., 1997 ORS: 839.

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