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Effect of Microseparation and Third-Body Particles on Dual-Mobility Crosslinked Hip Liner Wear

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ABSTRACT

Large heads have been recommended to reduce the risk of dislocation after total hip arthroplasty. One of the issues with larger heads is the risk of increased wear and damage in thin polyethylene liners. Dual-mobility liners have been proposed as an alternative to large heads. We tested the wear performance of highly crosslinked dual-mobility liners under adverse conditions simulating microseparation and third-body wear. No measurable increase in polyethylene wear rate was found in the presence of third-body particles. Microseparation induced a small increase in wear rate (2.9 mm^3/million cycles). A finite element model simulating microseparation in dual-mobility liners was validated using these experimental results. The results of our study indicate that highly crosslinked dual-mobility liners have high tolerance for third-body particles and microseparation.

Hip dislocation remains one of the major short-term complications after total hip arthroplasty (THA). This issue has led to the popularity of large head sizes, which increase the distance the head has to translate before dislocation. However, larger head sizes may increase the risk for polyethylene wear and damage in the thinner insert. A dual-mobility polyethylene-bearing design has been reported to have the same resistance to dislocation as a larger head while theoretically retaining the tribological properties of a thicker polyethylene liner comparable to a 28-mm fixed-bearing design [1,2].

The dual-mobility bearing (Fig. 1) consists of a 22- or 28-mm femoral head, which is captive inside a larger polyethylene head. This larger polyethylene head is also free to rotate within a metal shell. Since the inner femoral head is captured within the liner, the outer diameter of the liner is the effective head size resisting dislocation [3,4]. One concern of this design is the potential for wear at 2 bearing surfaces especially in the presence of third-body particles. Another concern is that microseparation between the hip components during the swing phase [5] may adversely affect wear performance [6,7].

Separation of the femoral head from the acetabular liner during the swing phase of walking was first reported for metal-on-polythene hip arthroplasty bearings [5]. Wear simulation experiments indicate that microseparation may generate “stripe” wear in ceramic-on-ceramic articulations [8]. Microseparation has also resulted in greater than 10-fold increase in ceramic-on-ceramic and metal-on-metal bearing wear and can even cause a fracture in a zirconia head [6,7,9,10]. However, despite the greater microseparation reported clinically for metal-on-polyethylene wear, less is known about its potential detrimental effects for this bearing couple [11]. This study was therefore designed to simulate the effects of microseparation using experimental and finite element wear simulation and to test the performance of a dual-mobility bearing under aggressive testing conditions that combined microseparation with third-body wear.

Materials and Methods

Experimental Wear Testing

Dual-mobility THA components, restoration ADM (Fig. 1, Stryker, Mahwah, NJ), with sequentially crosslinked (3MRad of gamma irradiation followed by annealing, repeated for a total of 3 cycles) acetabular liners (X3, Stryker) were divided into 4 groups (N = 3). The control group was subjected to wear testing using the ISO 14242-1 waveform [12]. The microseparation group was subjected to a nominal 0.8 mm lateral microseparation during the swing phase. Third-body particles (1 g/L bone cement particles, ground down using a freezer/mill and sieved to obtain target sizes between 25 and 53 μm) were added to the lubricant in the third-body group. The fourth group was subjected to microseparation combined with third-body particles. Three additional untested liners were soaked in the lubricant to control for fluid absorption. Testing was conducted on a 12-station hip wear simulator

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Fig. 1. Photograph of the anatomic dual-mobility design with mobile acetabular liner.

with microseparation capability (AMTI, Watertown, MA). Microseparation was generated between the head and the shell by engaging lateral force springs and by reducing the vertical force during swing phase to generate a nominal microseparation of 0.75 mm [8]. Bovine serum diluted to a nominal 20 mg/L, supplemented with EDTA and sodium azide, was used as lubricant. Every 500,000 cycles, gravimetric analysis was performed and liner surfaces were imaged at 20× magnification using stereomicroscope. At the end of the wear test, the liners were visually examined for scratches. The depth of visible scratch marks on the surface of the liner was measured by a Starrett 468MXSP-25 spindle head micrometer with an accuracy of ±1.25 μm. The micrometer was mounted on a custom stand to orient the liner perpendicular to a 500 μm diameter measuring probe. The averages of three measurements were taken at each location.

Finite Element Analysis Development

Experimental wear rates for low and highly crosslinked polyethylene hip liners were obtained from a previously reported hip wear simulator study of a fixed-bearing THA design [13]. We repeated our previously described method of computing the wear coefficient for knee wear simulation studies [14,15]. Briefly, a finite element model of the wear simulation of the fixed-bearing design was constructed (MSC.MARC, MSC Software, Santa Ana, CA) to replicate experimental conditions. The femoral head and acetabular shell were simulated as rigid bodies. The polyethylene liner was modeled as a deformable body with previously reported material properties [16]. Contact was simulated between the femoral head and the polyethylene liner with a coefficient of friction of 0.2. Boundary conditions were applied to replicate the axial load (force controlled), and flexion-extension, axial rotation, and abduction-adduction (displacement controlled).

Contact area, contact pressure, and sliding distance were computed. Wear was predicted by using the Archard's classic law for mild wear [17]. Each cycle was divided into 100 increments and wear was computed for each increment and summed over the entire cycle. The surface nodes affected by wear were moved in a direction normal to the articular surface based on the computed material loss at the end of every increment. The MSC.MARC solver adaptively adjusted interior nodes to maintain element quality. The simulation was then repeated in a step-wise manner and the wear was multiplied by the size of each step (50,000 cycles per step) to compute the total wear at the end of 5 million cycles. For comparison with experimental data, computed volumetric wear was converted to gravimetric wear using polyethylene density of 0.97 mm^3/mg. The wear factors for the standard and highly crosslinked polyethylene were then determined by minimizing the difference between predicted wear and experimental wear rate.

The wear factor obtained for highly crosslinked polyethylene was then used to predict wear in a dual-mobility hip component (Restoration ADM (Fig. 2), Stryker). A finite element model of the ADM hip was similarly constructed with the following differences. In the ADM hip, the liner is free to move within the monoblock acetabular shell and therefore contact was simulated between both the femoral head and liner, and the liner and acetabular shell. For the control group, the ISO 14242-1 waveform was used (to replicate experimental loading conditions). For the microseparation group a microseparation of 0.75 mm was additionally simulated replicating experimental conditions. The wear rates predicted for the control and microseparation groups were then compared to experimental wear rates measured in this study.

To study the relative contribution of wear rates from the 2 articular surfaces of the dual-mobility liner, we simulated wear with the liner bonded to the femoral head or with the liner bonded to the acetabular shell. Bonding the liner to the femoral head replicated a condition in which all the relative sliding occurred between the liner and the metal acetabular shell while bonding the liner to the acetabular shell replicated a traditional fixed-bearing condition. We anticipated that wear at the outer bearing surface of the liner would be higher because of the greater sliding distance for the same kinematic rotation and that the experimental wear rate would be somewhere in between the range of predicted wear rate for the 2 bonding conditions. We also studied the effect of microseparation on a low crosslinked polyethylene liner. We first computed the wear coefficient for low crosslinked polyethylene from a previously reported hip wear simulator study of a low

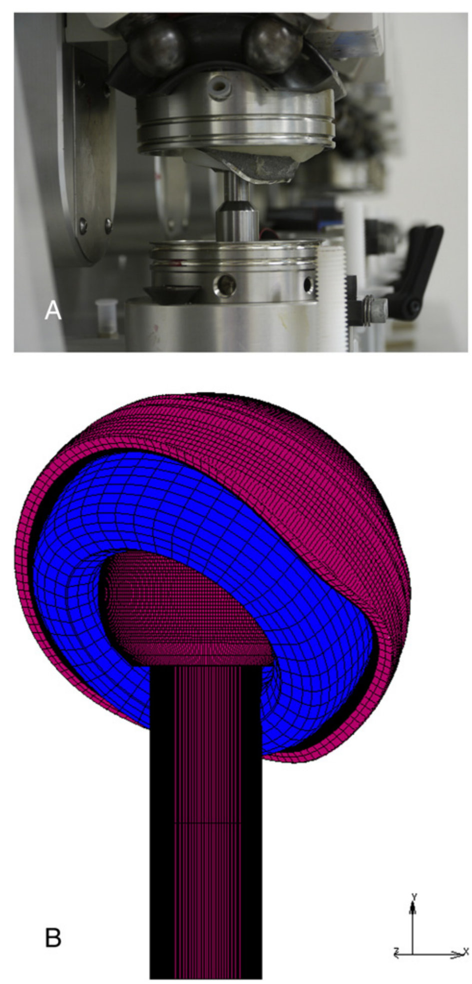

Fig. 2. (A) Photograph of the components mounted in the AMTI hip wear simulator. (B) Finite element model of the anatomic dual-mobility design.