The Measurement of Creep in Ultrahigh Molecular Weight Polyethylene

A Comparison of Conventional Versus Highly Cross-Linked Polyethylene

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Abstract: Quantification of creep of highly cross-linked polyethylene would enable separation of creep from wear when evaluating femoral head penetration into polyethylene. We compared creep magnitude of a highly cross-linked versus conventional polyethylene in the laboratory. Twelve acetabular liners of each material were tested, 6 of which had a 32-mm inner diameter (ID) and 6 had 28-mm ID. Creep was measured using coordinate measuring machines during loading at 2 Hz without motion to 4 million cycles. Penetration into 32-mm ID conventional liners reached 97 μm versus 107 μm for highly cross-linked material, not significant. Penetration into 28-mm conventional liners was 132 μm versus 155 μm for highly cross-linked material (P = .017). Ninety percent of the creep had occurred by 2.5 million cycles. **Key words:** polyethylene, cross-linking, creep, hip, arthroplasty.

Osteolysis secondary to polyethylene wear debris is the single most common late cause for failure of total hip arthroplasty. Efforts have been made to improve the wear characteristics and durability of ultrahigh molecular weight polyethylene (UHMWPE) used as a bearing surface in total hip arthroplasty. One effort that has shown promise is the development of highly cross-linked UHMWPE. When used in acetabular components, this material has been demonstrated in vivo [1-3] and in vitro [4,5] to reduce wear to very low levels.

In vivo quantification of the wear behavior of UHMWPE generally relies on plain radiographic or radiostereometric analysis (RSA) measurement of penetration of the femoral head into the polyethylene. This penetration consists of bedding-in, creep, and wear.

Acetabular components made using current forms of highly cross-linked UHMWPE with FDA approval were first implanted in 1999. Prospective clinical studies examining the wear performance of components made from highly cross-linked UHMWPE versus conventional UHMWPE using a variety of radiographic methods are ongoing. The ability to determine how much of the total penetration is caused by wear is dependent on knowledge of the creep behavior of the new materials.

The majority of the creep in UHMWPE occurs early in the loading of the material, as demonstrated in both clinical [6-8] and experimental [9] studies.

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Because the new highly cross-linked polyethylene materials receive higher radiation doses and some are melted after irradiation to eliminate detectable free radicals, many have a lower modulus of elasticity ($\sum$) and may have different creep behavior. The silane cross-linked UHMWPE reported by Wroblewski et al [10] had a high (0.2-0.4 mm) penetration rate during the first 18 months, largely attributed to creep, and thereafter had virtually no further penetration for the next 8 years [11].

The purpose of this study was to develop an in vitro model to quantify the creep behavior in 2 groups of acetabular components under conditions of physiological load without motion, one made from conventional UHMWPE and the other from a highly cross-linked polyethylene. The hypothesis was that there would be a substantive increase in the creep magnitude of the highly cross-linked polyethylene material because of the decrease in $\sum$ that results from the additional radiation and melting required to produce the material [5].

Materials and Methods

Twenty-four acetabular cups were studied. Twelve cups were made from GUR 1020, γ-sterilized at 25 to 41 kGy in nitrogen (Sulene, Zimmer Inc, Austin, Tex, formerly Centerpulse Orthopaedics). The other 12 cups were highly cross-linked UHMWPE made from GUR 1050, treated with 95 kGy e-beam irradiation at a temperature of 125°C, followed by melting at 150°C, and terminally sterilized with ethylene oxide (Durasul, Zimmer Inc) [5]. Six conventional and 6 highly cross-linked liners had an inner diameter (ID) of 32 mm, an outer diameter of 50 mm, and a thickness of 9 mm, whereas the other 12 had an ID of 28 mm, an outer diameter of 54 mm, and a thickness of 10.25 mm.

The liners were potted in a fixture using polymethylmethacrylate, so that the external dimensions of the cups would remain fixed. The contours of the articular surface of all components were measured using a MicroVal PFx and a Global Image Model 574 (Brown and Sharpe, North Kingstown, RI) coordinate-measuring machines (CMM) before any load had been applied. The liners were then subjected to cyclical loading and removed at periodic intervals for CMM analysis. The liners were placed in a climate-controlled room for 48 hours before measurement to ensure that the cups had reached both thermal equilibrium and full stress relaxation [12].

The liners were loaded cyclically in a Boston hip simulator (AMTI, Watertown, Mass) to a peak load of 3330 N and a minimum load of 222 N, with no motion of the cup, using a double-peaked Paul [13] curve at 2 Hz. For the first 10 000 cycles, all cups were loaded dry. During the first 10 000 cycles, the cups were taken off the wear simulator 6 times for CMM measurements. It was felt that because the cups were under load for such short periods in the early stages of the study, fluid uptake would have a negligible effect on the creep measurements. After the first 10 000 cycles, all 12 of the cups with a 28-mm ID were loaded in 100% bovine serum diluted with sodium azide and EDTA at 37°C and recirculated. Of the cups with a 32-mm ID, 3 cups of each material were loaded in bovine serum, and 3 cups of each material were loaded in the dry state to quantify whether the amount of creep was affected by the presence of bovine serum. All femoral heads were implant quality chrome cobalt. The study design after the first 10 000 cycles is summarized in Table 1.

Table 1. Study Design After the First 10 000 Loading Cycles

	28-mm ID, Loaded in Bovine Serum	32-mm ID, Loaded in Bovine Serum	32-mm ID, Loaded in the Dry State
Conventional UHMWPE	6	3	3
Highly cross-linked UHMWPE	6	3	3

CMM measurements were taken after 1, 10, 100, 1000, 10 000, 100 000, 250 000, 500 000, 750 000, and 1 000 000 and then at every million cycles out to 4 000 000 cycles. The 28-mm diameter series was continued to 6.2 million cycles.

The geometry of the articulating surface of each liner was determined using the CMM. Between 10 700 and 11 160 articulating surface coordinate data points were taken with the CMM machine and analyzed using custom software. The maximum linear penetration into the articular surface was calculated.

The data were analyzed using a *t* test for independent samples using a commercially available statistics package (STATISTICA 6.1, StatSoft, Inc, Tulsa, Okla) to determine differences in penetration. The results were considered significant at $P < .05$.

Results

The penetration data are given in Table 2. No significant differences in penetration existed by