

Reduction of Osteolysis with Use of Marathon Cross-Linked Polyethylene

A Concise Follow-up, at a Minimum of Five Years, of a Previous Report*

By Rudi G. Bitsch, MD, Travis Loidolt, BA, Christian Heisel, MD, Scott Ball, MD, and Thomas P. Schmalzried, MD

Investigation performed at the Joint Replacement Institute, Los Angeles, California

Abstract: We previously reported wear data at a minimum of two years following thirty-four total hip replacements with a Marathon cross-linked polyethylene liner and twenty-four replacements with a conventional (gamma-sterilized-in-air) Enduron polyethylene liner. In this current study, with sequential five-year radiographs, wear rates were determined with use of linear regression analysis. The Marathon polyethylene had average wear rates of 15.4 mm³/yr and 8.0 mm³/million cycles. The Enduron polyethylene had average wear rates of 55.5 mm³/yr and 29.9 mm³/million cycles. The adjusted volumetric wear rate of the Marathon polyethylene was 73% lower than that of the Enduron polyethylene ($p = 0.001$). Osteolysis developed in eight of the twenty-four hips with an Enduron liner but was not apparent in any hip with a Marathon liner.

Level of Evidence: Therapeutic Level III. See Instructions to Authors for a complete description of levels of evidence.

Background

The occurrence of periprosthetic osteolysis¹ has been related to the amount and size of polyethylene particles generated from the bearing surfaces of the implant². Cross-linking of ultra-high molecular weight polyethylene has been shown to markedly reduce wear in laboratory tests and clinical studies³⁻⁵. Concerns have been expressed, however, that the smaller average size of the cross-linked polyethylene wear particles could lead to osteolysis⁶ despite a lower wear rate⁷.

We previously compared the wear rate at a minimum of two years after total hip replacements with a Marathon cross-linked polyethylene liner with the wear rate after replacements with a conventional polyethylene (Enduron) liner⁸. We are updating that previous report after more than five years of clinical experience.

Methods

Two of the patients with a Marathon liner (DePuy, Warsaw, Indiana) in the original study⁸ did not return for follow-up, leaving thirty-two hips in thirty-two patients for evaluation.

There were ten men and twenty-two women, with an average age of sixty years (range, twenty-six to eighty-eight years) at the time of the operation. The average body mass index was 30.5 kg/m² (range, 21.3 to 41.4 kg/m²). The patients were followed for an average of sixty-nine months (range, sixty to eighty-three months). The comparison group consisted of twenty-four hips in twenty-four patients with a conventional gamma-sterilized-in-air polyethylene liner (Enduron; DePuy). There were eleven men and thirteen women with an average age of seventy-four years (range, forty-six to eighty-five years) in this group. The average body mass index was 27.3 kg/m² (range, 18.6 to 35.2 kg/m²). These patients were followed for an average of seventy months (range, sixty to ninety-three months). Patient activity was assessed postoperatively with use of a computerized two-dimensional accelerometer (StepWatch Activity Monitor; Cyma, Seattle, Washington)⁹.

Linear penetration and volumetric wear were measured on serial anteroposterior radiographs of the pelvis with use of the edge-detection-based computer algorithm of Martell and Berdia¹⁰. A linear regression analysis was done to determine femoral head penetration and volumetric wear over five years for each hip. The slope of the linear regression line represents the penetration or wear rate, and the intercept point on the ordinate

*Original Publication

Heisel C, Silva M, dela Rosa MA, Schmalzried TP. Short-term in vivo wear of cross-linked polyethylene. *J Bone Joint Surg Am.* 2004;86:748-51.

Disclosure: In support of their research for or preparation of this work, one or more of the authors received, in any one year, outside funding or grants of less than \$10,000 from the Piedmont Fund of the Los Angeles Orthopaedic Hospital Foundation and a research grant in excess of \$10,000 from the Stiftung Orthopädische Universitätsklinik Heidelberg. In addition, one or more of the authors or a member of his or her immediate family received, in any one year, payments or other benefits in excess of \$10,000 or a commitment or agreement to provide such benefits from a commercial entity (DePuy Orthopaedics). Also, a commercial entity (DePuy) paid or directed in any one year, or agreed to pay or direct, benefits of less than \$10,000 to a research fund, foundation, division, center, clinical practice, or other charitable or nonprofit organization with which one or more of the authors, or a member of his or her immediate family, is affiliated or associated.

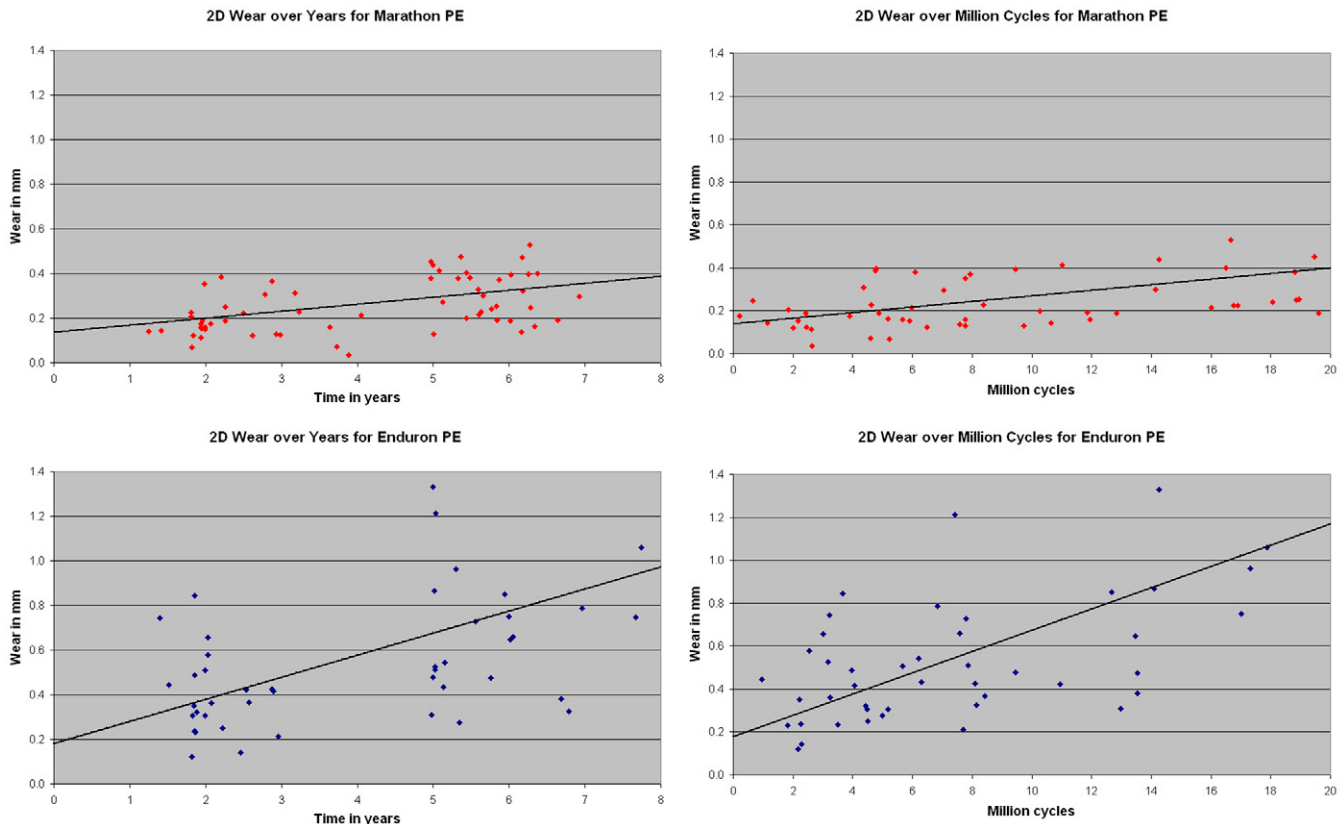


Fig. 1

Linear regression analyses of femoral head penetration over time (left) or per million cycles (right). Marathon polyethylene is analyzed in the upper figures and Enduron polyethylene, in the lower figures. 2D = two-dimensional, and PE = polyethylene.

axis represents the displacement of the femoral head due to bedding-in (creep and other conformational changes without removal of material from the bearing surface)¹¹. The data in both study groups were generated three times by two different observers who were blinded to the type of polyethylene that had been used.

Serial anteroposterior and lateral radiographs were evaluated for the presence of osteolytic lesions by three orthopaedic surgeons who were also blinded to the type of polyethylene. The presence of osteolysis was assessed in the fourteen zones in the femur described by Gruen et al.¹² and the six zones in the acetabulum described by DeLee and Charnley¹³. A lesion was not considered to represent osteolysis unless all three surgeons agreed on the diagnosis.

The differences between the two patient groups were evaluated with use of a Student *t* test or a Mann-Whitney *U* test as required for different types of data. A *p* value of ≤ 0.05 was considered significant.

Results

After a mean duration of follow-up of 5.8 years (range, 5.0 to 7.7 years), no hips had been revised for any reason. There were no mechanical failures of any bearing surface.

The average femoral head penetration (true wear rate, slope of the linear regression line) was 0.031 mm/yr (range, 0.004 to 0.196 mm/yr; standard deviation = 0.047 mm/yr; 95% confidence interval = 0.009 to 0.053 mm/yr) in the hips with a

Marathon polyethylene liner and 0.104 mm/yr (range, 0.020 to 0.410 mm/yr; standard deviation = 0.094 mm/yr; 95% confidence interval = 0.066 to 0.148 mm/yr) in the hips with an Enduron polyethylene liner. The wear rate (femoral head penetration) in the Marathon group was 71% lower than that in the Enduron group ($p = 0.003$). The adjusted femoral head penetration was 0.013 mm/million cycles (range, 0.003 to 0.159 mm/million cycles; standard deviation = 0.029 mm/million cycles; 95% confidence interval = 0.007 to 0.026 mm/million cycles) in the Marathon group and 0.056 mm/million cycles (range, 0.014 to 0.208 mm/million cycles; standard deviation = 0.045 mm/million cycles; 95% confidence interval = 0.037 to 0.076 mm/million cycles) in the Enduron group; this represented a 76% reduction in the Marathon group ($p = 0.023$) (Fig. 1).

The average volumetric wear rate was 15.4 mm³/yr (range, 0.2 to 88.3 mm³/yr; standard deviation = 15.9 mm³/yr; 95% confidence interval = 8.0 to 22.9 mm³/yr) in the hips with a Marathon polyethylene liner and 55.5 mm³/yr (range, 5.6 to 259.0 mm³/yr; standard deviation = 54.1 mm³/yr; 95% confidence interval = 30.9 to 80.2 mm³/yr) in the hips with an Enduron polyethylene liner. The volumetric wear rate in the hips with a Marathon liner was 72% lower than that in the hips with an Enduron liner ($p < 0.001$). The adjusted wear rates were 8.0 mm³/million cycles (range, 0.2 to 55.7 mm³/million cycles; standard deviation = 15.0 mm³/million cycles; 95%

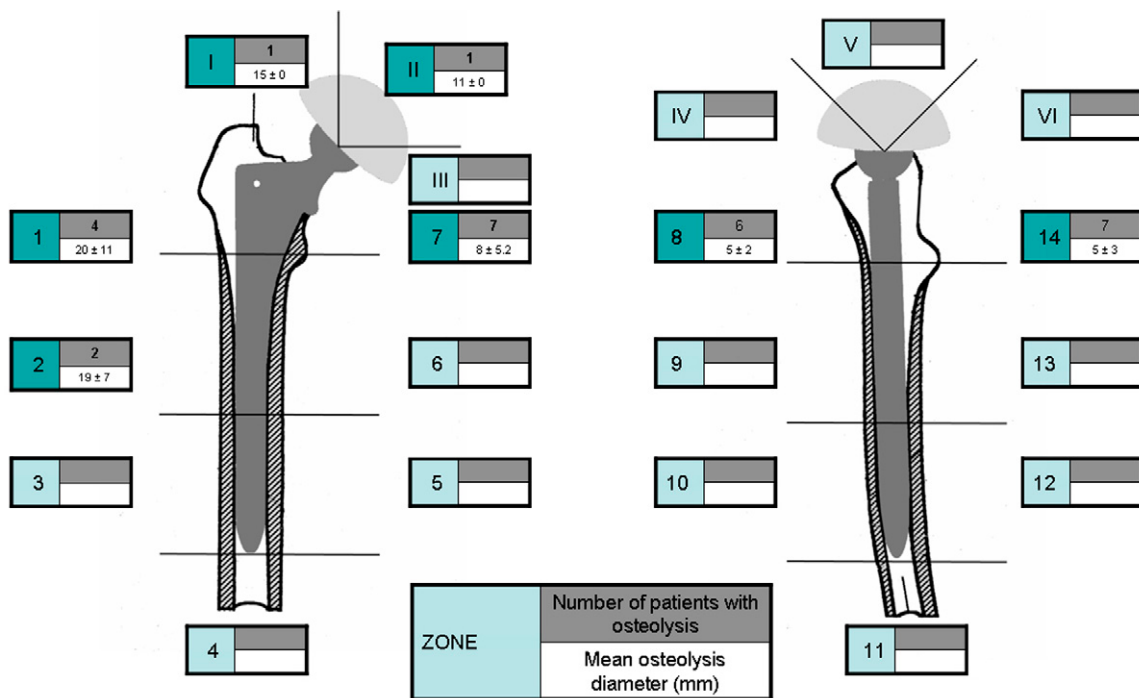


Fig. 2

Location of the osteolytic lesions, according to the zones described by Gruen et al.¹² and by DeLee and Charnley¹³, in the patients with an Enduron polyethylene liner. The number of patients with osteolysis and the mean diameter of the lesions are displayed.

confidence interval = 1.0 to 15.0 mm³/million cycles) and 29.9 mm³/million cycles (range, 4.4 to 131.3 mm³/million cycles; standard deviation = 28.7 mm³/million cycles; 95% confidence interval = 17.5 to 42.3 mm³/million cycles), respectively, a 73% reduction in the Marathon group ($p = 0.001$).

There was a slightly higher average displacement of the femoral head due to bedding-in in the Enduron group. The difference was not significant ($p = 0.435$) (Fig. 1). Hips with a Marathon polyethylene liner showed an average displacement of the femoral head due to creep and other conformational changes without removal of material from the bearing surface (intercept point on the ordinate) of 0.139 mm (range, 0.006 to 0.364 mm; standard deviation = 0.102 mm; 95% confidence interval = 0.067 to 0.212 mm), whereas the hips with the Enduron polyethylene liner had an average bedding-in of 0.171 mm (range, 0.027 to 0.634 mm; standard deviation = 0.170 mm; 95% confidence interval = 0.091 to 0.251 mm).

The mean activity of the patients with the Marathon liner was 1.86 million cycles/yr (range, 0.76 to 3.91 million cycles/yr; standard deviation = 0.94 million cycles/yr; 95% confidence interval = 1.42 to 2.30 million cycles/yr). This was slightly lower than the mean activity of the patients with the Enduron liner, which was 1.98 million cycles/yr (range, 0.63 to 4.30 million cycles/yr; standard deviation = 0.88 million cycles/yr; 95% confidence interval = 1.60 to 2.36 million cycles/yr) ($p = 0.683$).

Negative wear data were seen in the wear calculations of seven patients in the Marathon group and in three in the Enduron group. These cases were excluded from the calculation of mean values.

Osteolysis

Osteolysis was not radiographically apparent to any of the three observers in any of the thirty-two hips with a Marathon liner.

Eight of the twenty-four hips with an Enduron liner demonstrated osteolysis in at least one zone. Classic, scalloped osteolytic lesions were seen in proximal Gruen zones 1, 2, 7, 8, and 14 in four, two, seven, six, and seven hips, respectively, with an Enduron polyethylene liner (Fig. 2). Pelvic osteolysis was seen in zone I in one hip and in zone II in another hip in the Enduron group.

The Enduron liners in the hips with osteolysis showed an average femoral head penetration of 0.178 mm/yr (range, 0.023 to 0.410 mm/yr; standard deviation = 0.123 mm/yr; 95% confidence interval = 0.075 to 0.281 mm/yr) and an average volumetric wear rate of 105.2 mm³/yr (range, 29.8 to 259.0 mm³/yr; standard deviation = 75.0 mm³/yr; 95% confidence interval = 42.3 to 167.8 mm³/yr). The linear wear rate was approximately 2.7 times higher and the volumetric rate was approximately 3.5 times higher than the values for the Enduron liners in the hips without osteolysis, which had an average femoral head penetration of 0.066 mm/yr (range, 0.020 to 0.185 mm/yr; standard deviation = 0.041 mm/yr; 95% confidence interval = 0.044 to 0.089 mm/yr) ($p = 0.010$) and an average volumetric wear rate of 29.8 mm³/yr (range, 5.6 to 64.5 mm³/yr; standard deviation = 18.6 mm³/yr; 95% confidence interval = 19.5 to 40.2 mm³/yr) ($p = 0.004$).

The mean activity of the patients with osteolysis was 2.28 million cycles/yr (range, 0.63 to 4.31 million cycles/yr; standard deviation = 1.25 million cycles/yr; 95% confidence in-

terval = 1.23 to 3.32 million cycles/yr). This was only slightly higher than the mean activity of the remaining patients in the Enduron group, which was 1.83 million cycles/yr (range, 0.93 to 2.83 million cycles/yr; standard deviation = 0.59 million cycles/yr; 95% confidence interval = 1.47 to 2.13 million cycles/yr) ($p = 0.426$).

Discussion

Our previous radiographic study demonstrated, at a minimum of two years postoperatively, wear rates of 53.3 mm³/million cycles for Enduron liners and 15 mm³/million cycles for Marathon liners, a 72% reduction for the Marathon liners⁸. The wear rates of both types of polyethylene were lower in the five-year study: 29.9 mm³/million cycles for the Enduron liners and 8.0 mm³/million cycles for the Marathon liners, which was also a 73% reduction for the Marathon liners. The five-year femoral head penetration rate of 0.104 mm/yr for the Enduron liners is at the lower end of what has been reported with this type of polyethylene¹⁴⁻¹⁶, although there was a wide range of measured wear in both groups.

Engh et al. reported a reduction in the mean wear rate of 95% for Marathon liners compared with Enduron liners (0.01 ± 0.12 mm/yr compared with 0.19 ± 0.12 mm/yr)¹⁷. McKellop et al. found a reduction in the mean wear rate of up to 85% for Marathon liners in hip simulator tests and reported that the reduction was dependent on the roughness of the bearing partners⁵. The percent reduction is a function of the comparison material, which was not irradiated in either the wear simulator study by McKellop et al. or the clinical study by Engh et al. Our comparison is probably the most clinically relevant because most "conventional" polyethylene has been sterilized with gamma irradiation in air, as was the Enduron polyethylene used in the arthroplasties that we studied.

Prostheses with a linear penetration rate of 0.2 mm/yr are categorically associated with an increased risk for osteolysis over ten years^{18,19}. The three orthopaedic surgeons in our study independently recognized periprosthetic osteolysis in eight of the twenty-four hips with an Enduron liner, which had a mean linear penetration rate of 0.178 mm/yr. Osteolysis was not observed in any of the hips with a Marathon liner. A linear penetration rate of 0.031 mm/yr (a volumetric wear rate of 15.4 mm³/yr), which was the mean for the Marathon liners, is categorically associated with a very low risk of osteolysis over twenty years^{9,16,20} and is consistent with the results of other medium-term studies of cross-linked polyethylene^{18,19}.

There was a wide range of wear and activity data in both groups because of the randomness of the patient selection. The aim of the study was to obtain a representation of all patients

who receive a total hip replacement, and we did not exclude any patient on the basis of body mass index, age, or activity level.

A unique aspect of our study method is the quantification of individual patient activity and the reporting of an adjusted wear rate—i.e., the wear per million cycles for a 70-kg patient weight. Quantitative activity assessment with adjustment for both patient activity and weight was the best available means with which to compare these cohorts. Commonly matched variables, such as gender, age, diagnosis, and Charnley class, are actually surrogates for the more fundamental variable: the amount of use of the implant. Our method more directly assesses that fundamental variable.

The limitations of radiographic assessment of small amounts of wear with the method used in our study have been recognized¹⁰ and are not unique to our study. In the study by Engh et al., 32% (twenty-four) of seventy-six hips with a Marathon polyethylene liner had negative wear rates¹⁷. Methodological limitations related to image quality, patient positioning, and muscle tone can contribute to outlier data, including apparently negative wear^{21,22}. With a properly powered study, however, such spurious results have little impact on the calculation of mean head penetration rates. We tried to optimize the accuracy of the method by not analyzing any radiographs in the early postoperative period to avoid evaluating patients with poor muscle tone, by having all radiographs performed by the same radiology technician, and by using standardized patient positioning and the same imaging system.

In summary, compared with Enduron polyethylene that was sterilized with gamma irradiation in air, Marathon polyethylene had a 73% reduction in the adjusted volumetric wear rate. Osteolysis was observed in eight of the twenty-four hips with an Enduron liner but in none of the thirty-two hips with a Marathon liner. Concerns about an increased risk of osteolysis due to smaller particles from cross-linked polyethylene were not realized at the time of this medium-term follow-up. We will continue to follow this cohort of patients. ■

Rudi G. Bitsch, MD
Christian Heisel, MD
Stiftung Orthopädische Universitätsklinik,
Schlierbacher Landstrasse 200A, 69118 Heidelberg, Germany

Travis Loidolt, BA
Scott Ball, MD
Thomas P. Schmalzried, MD
Joint Replacement Institute at Orthopaedic Hospital,
2400 South Flower Street, Los Angeles, CA 90007.
E-mail address for T.P. Schmalzried: schmalzried@earthlink.net

References

- Harris WH. The problem is osteolysis. *Clin Orthop Relat Res.* 1995;311:46-53.
- Green TR, Fisher J, Matthews JB, Stone MH, Ingham E. Effect of size and dose on bone resorption activity of macrophages by in vitro clinically relevant ultra high molecular weight polyethylene particles. *J Biomed Mater Res.* 2000;53:490-7.
- Muratoglu OK, Merrill EW, Bragdon CR, O'Connor D, Hoeffel D, Burroughs B, Jasty M, Harris WH. Effect of radiation, heat, and aging on in vitro wear resistance of polyethylene. *Clin Orthop Relat Res.* 2003;417:253-62.
- Oonishi H, Kadoya Y. Wear of high-dose gamma-irradiated polyethylene in total hip replacements. *J Orthop Sci.* 2000;5:223-8.

- 5.** McKellop H, Shen FW, DiMaio W, Lancaster JG. Wear of gamma-crosslinked polyethylene acetabular cups against roughened femoral balls. *Clin Orthop Relat Res.* 1999;369:73-82.
- 6.** Fisher J, McEwen HM, Tipper JL, Galvin AL, Ingram J, Kamali A, Stone MH, Ingham E. Wear, debris, and biologic activity of cross-linked polyethylene in the knee: benefits and potential concerns. *Clin Orthop Relat Res.* 2004;428:114-9.
- 7.** Campbell P, Shen FW, McKellop H. Biologic and tribologic considerations of alternative bearing surfaces. *Clin Orthop Relat Res.* 2004;418:98-111.
- 8.** Heisel C, Silva M, dela Rosa MA, Schmalzried TP. Short-term in vivo wear of cross-linked polyethylene. *J Bone Joint Surg Am.* 2004;86:748-51.
- 9.** Schmalzried TP, Shepherd EF, Dorey FJ, Jackson WO, dela Rosa M, Fa'vae F, McKellop HA, McClung CD, Martell J, Moreland JR, Amstutz HC. Wear is a function of use, not time. *Clin Orthop Relat Res.* 2000;381:36-46.
- 10.** Martell JM, Berdia S. Determination of polyethylene wear in total hip replacements with use of digital radiographs. *J Bone Joint Surg Am.* 1997;79:1635-41.
- 11.** Sychterz CJ, Engh CA Jr, Yang A, Engh CA. Analysis of temporal wear patterns of porous-coated acetabular components: distinguishing between true wear and so-called bedding-in. *J Bone Joint Surg Am.* 1999;81:821-30.
- 12.** Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res.* 1979;141:17-27.
- 13.** DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res.* 1976;121:20-32.
- 14.** Pedersen DR, Callaghan JJ, Johnston TL, Fetzter GB, Johnston RC. Comparison of femoral head penetration rates between cementless acetabular components with 22-mm and 28-mm heads. *J Arthroplasty.* 2001;16(8 Suppl 1):111-5.
- 15.** Sychterz CJ, Engh CA Jr, Shah N, Engh CA Sr. Radiographic evaluation of penetration by the femoral head into the polyethylene liner over time. *J Bone Joint Surg Am.* 1997;79:1040-6.
- 16.** Dowd JE, Sychterz CJ, Young AM, Engh CA. Characterization of long-term femoral-head-penetration rates. Association with and prediction of osteolysis. *J Bone Joint Surg Am.* 2000;82:1102-7.
- 17.** Engh CA Jr, Stepniewski AS, Ginn SD, Beykirch SE, Sychterz-Terefenko CJ, Hopper RH Jr, Engh CA. A randomized prospective evaluation of outcomes after total hip arthroplasty using cross-linked marathon and non-cross-linked Enduron polyethylene liners. *J Arthroplasty.* 2006;21(6 Suppl 2):17-25.
- 18.** Dorr LD, Wan Z, Shahrardar C, Sirianni L, Boutary M, Yun A. Clinical performance of a Durasul highly cross-linked polyethylene acetabular liner for total hip arthroplasty at five years. *J Bone Joint Surg Am.* 2005;87:1816-21.
- 19.** Manning D, Chiang PP, Martell JM, Galante JO, Harris WH. In vivo comparison wear study of traditional and highly cross-linked polyethylene in total hip arthroplasty. *J Arthroplasty.* 2005;20:880-6.
- 20.** Schmalzried TP, Callaghan JJ. Wear in total hip and knee replacements. *J Bone Joint Surg Am.* 1999;81:115-36.
- 21.** Martell JM, Berkson E, Berger R, Jacobs J. Comparison of two and three-dimensional computerized polyethylene wear analysis after total hip arthroplasty. *J Bone Joint Surg Am.* 2003;85:1111-7.
- 22.** McCalden RW, Naudie DD, Yuan X, Bourne RB. Radiographic methods for the assessment of polyethylene wear after total hip arthroplasty. *J Bone Joint Surg Am.* 2005;87:2323-34.