Long-Term Performance of Ceramic and Metal Femoral Heads on Conventional Polyethylene in Young and Active Patients

A Matched-Pair Analysis

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Background: Ceramic femoral heads produce less wear of the opposing polyethylene than do metal femoral heads in wear simulation studies. This is a matched-pair analysis of the wear of ceramic and metal femoral heads on conventional polyethylene in uncemented total hip replacements in young, active patients at a minimum of fifteen years of follow-up.

Methods: From June 1989 to May 1992, thirty-one matched pairs of alumina ceramic or cobalt-chromium metal femoral heads were identified. Patients were matched on the basis of age, sex, body weight, diagnosis, and activity level. The mean age was 55 ± 9 years (range, twenty-three to sixty-five years) at the time of surgery. All procedures were performed with a posterolateral surgical approach by a single surgeon using press-fit Ranawat-Bernstein femoral stems, Harris-Galante-II acetabular cups, GUR 4150 conventional polyethylene (sterilized in argon), and 28-mm-diameter femoral heads. Wear measurements were performed by two independent observers using the computer-assisted Roman software.

Results: The average duration of follow-up was 17 ± 1.7 years (range, fifteen to twenty years). The mean Hospital for Special Surgery hip scores (and standard deviation) in the ceramic and metal groups were 39 ± 4 and 40 ± 3 at the time of final follow-up. The University of California Los Angeles activity score at the time of the final follow-up was 6 ± 2 for both groups. The mean wear rates for the ceramic group and the metal group were 0.086 ± 0.05 mm/yr and 0.137 ± 0.05 mm/yr, respectively ($p = 0.0015$). There was one reoperation in the ceramic group because of distal femoral osteolysis. There were three failures in the metal group, requiring isolated liner exchange in two hips and revision of the acetabular component in one hip because of wear-induced osteolysis and/or loosening that caused symptoms. Five hips in the ceramic group and six hips in the metal group had radiographic evidence of acetabular or femoral osteolysis, but none were symptomatic.

Conclusions: Ceramic femoral heads produced significantly less wear on conventional polyethylene liners at the time of long-term follow-up than did metal heads in this matched-pair analysis of young and active patients with uncemented fixation.

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

Wear-related failures are one of the leading causes of revision total hip arthroplasty[1,2]. Ceramic femoral heads were introduced as potentially superior material compared with metal femoral heads[3]. Ceramic femoral heads are more scratch-resistant, have superior wettability, and are chemically inert with enhanced biocompatibility[4,5]. Alumina ceramic coupled with conventional ultra-high molecular weight polyethylene (UHMWPE) has been used in total hip arthroplasty since the 1970s[4]. Although the introduction of the new generation of ceramic composites (BIOLOX delta;

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TABLE I Clinical Results of Ceramic and Metal Heads Showing Similar Preoperative and Postoperative Scores*

	Ceramic			Metal			
	Mean and Stand. Dev.	Range	95% CI	Mean and Stand. Dev.	Range	95% CI	P Value
HSS score							
Preop.	21 ± 5	13-38	19-23	21 ± 5	14-30	20-23	1
Postop.	39 ± 4	24-40	37-40	40 ± 3	28-40	39-40	0.27
UCLA score							
Postop.	6 ± 2	4-10	6-7	6 ± 2	4-10	5-7	1

*HSS = Hospital for Special Surgery, UCLA = University of California Los Angeles, and CI = confidence interval.

TABLE II Comparative Radiographic Data on Ceramic and Metal Heads Showing Similar Component Orientation with Significantly Less Wear in the Ceramic Group

	Ceramic	Metal	P Value
Anteversion *(deg)*			1
Mean and stand. dev.	11 ± 4	11 ± 5	
Range	5-18	4-19	
Inclination *(deg)*			1
Mean and stand. dev.	37 ± 5	37 ± 4	
Range	27-48	29-44	
Wear *(mm/yr)*			0.0015
Mean and stand. dev.	0.086 ± 0.05	0.137 ± 0.05	
Range	0.004-0.19	0.03-0.25	
Radiographic osteolysis *(no. of hips)*	5	6	1
Revision or reoperation for osteolysis and/or loosening*	1†	3‡	0.6

*Although the difference was not significant, there were more revisions in the metal group. †Reoperation. ‡Revisions.

CeramTec, Plochingen, Germany) has greatly reduced the risk of fracture and further increased the use of ceramic femoral heads[4], this study is focused on the first generation of alumina ceramic heads.

Despite the convincing evidence of decreased wear of ceramic femoral heads against UHMWPE in the laboratory compared with metal femoral heads[5-7], we are not aware of any long-term clinical studies comparing the two in the setting of uncemented implant fixation. To our knowledge, this is the first long-term comparative in vivo wear analysis of ceramic and metal femoral heads against UHMWPE in young, active patients with uncemented total hip replacements. Our hypothesis was that ceramic femoral heads would have lower wear rates, improved clinical outcomes, and better survivorship.

Materials and Methods

From 1989 to 1992, ceramic femoral heads on polyethylene and metal femoral heads on polyethylene were randomly used in uncemented total hip arthroplasties for active patients under the age of sixty-five years. During that period, ninety-one alumina ceramic femoral heads (CeramTec) and 157 cobalt-chromium metal heads (DePuy, Warsaw, Indiana), all 28 mm in diameter, were implanted and followed prospectively for a minimum of fifteen years. Of this cohort, thirty-one pairs of alumina ceramic and metal femoral heads (in forty-nine patients) were matched on the basis of age (within two years), sex, body weight (within 5 lb [2.25 kg]), diagnosis, and activity level (within a 1-point difference on the activity score of the University of California Los Angeles [UCLA] scoring system). All patients were selected from a prospective institutional database. There were no significant differences between these matched pairs.

There were thirty-seven men and twelve women. The average duration of follow-up was 17 ± 1.7 years (range, fifteen to twenty years). The mean age was 55 ± 9 years (range, twenty-three to sixty-five years) at the time of surgery. Thirteen patients had bilateral total hip arthroplasty. Five patients with bilateral total hip arthroplasty had a ceramic femoral head on one side and a metal femoral head on the other side, which were matched to one another. The remaining eight patients with bilateral total hip arthroplasty had a ceramic femoral head (two patients) on both sides or metal bearings (six patients) on both sides. One surgeon (C.S.R.) performed all procedures via a posterolateral surgical approach. All femoral components were uncemented Ranawat-Burstein stems (RB; Biomet, Warsaw, Indiana). Acetabular components were Harris-Galante II (HG II, Zimmer, Warsaw, Indiana) until May 1991, and Ranawat-Burstein RingLoc (Biomet) after that time. Both types of acetabular

UHMWPE liners were ram-extruded and machined using GUR 4150 resin and sterilized in argon gas.

The Hospital for Special Surgery (HSS) hip score and the UCLA activity score were used for clinical analysis. Anteroposterior and lateral hip radiographs were assessed for any evidence of periprosthetic osteolysis and/or loosening[8,9]. The acetabular cup anteversion and inclination angles were measured on the latest follow-up pelvic images using EBRA software (Einzel-Bild-Roentgen-Analysis; University of Innsbruck, Innsbruck, Austria)[10].

Wear measurements were performed on the initial anteroposterior pelvic radiographs at a minimum of one year after the index procedure, to eliminate the effect of the bedding-in period[7], and at the time of the latest follow-up. Two independent observers (M.M. and G.G.K.) analyzed polyethylene wear using the computer-assisted Roman software (version 1.70), which uses a concentric circles technique developed by Livermore et al.[11]. In patients with a revision, the wear rates were calculated from radiographs made just prior to revision surgery.

Statistical Methods

A paired Student t test was performed to analyze the statistical differences in continuous data between the ceramic and metal groups. To account for the cluster effect in five patients with bilateral total hip replacements (one side with ceramic and one side with metal components), a linear mixed-effect model with a random effect for person was used to allow two wear rates of the same patients to be correlated with each other. Interobserver reliability of the two observers was evaluated using a one-way random intraclass correlation coefficient. Two-tailed p values of <0.05 were considered significant.

Source of Funding

No external funding was received for this study.

Results

No significant difference was detected between the mean preoperative or postoperative HSS and UCLA scores in the ceramic and metal groups (Table I). The mean acetabular cup anteversion and inclination angles in both groups were within the safe zone with no significant difference (Table II). However, the mean wear rate (and standard deviation) was 0.086 ± 0.05 mm/yr for the ceramic group, which was significantly less than that in the metal group (0.137 ± 0.05 mm/yr; $p = 0.0015$) when adjusted for the random effect of

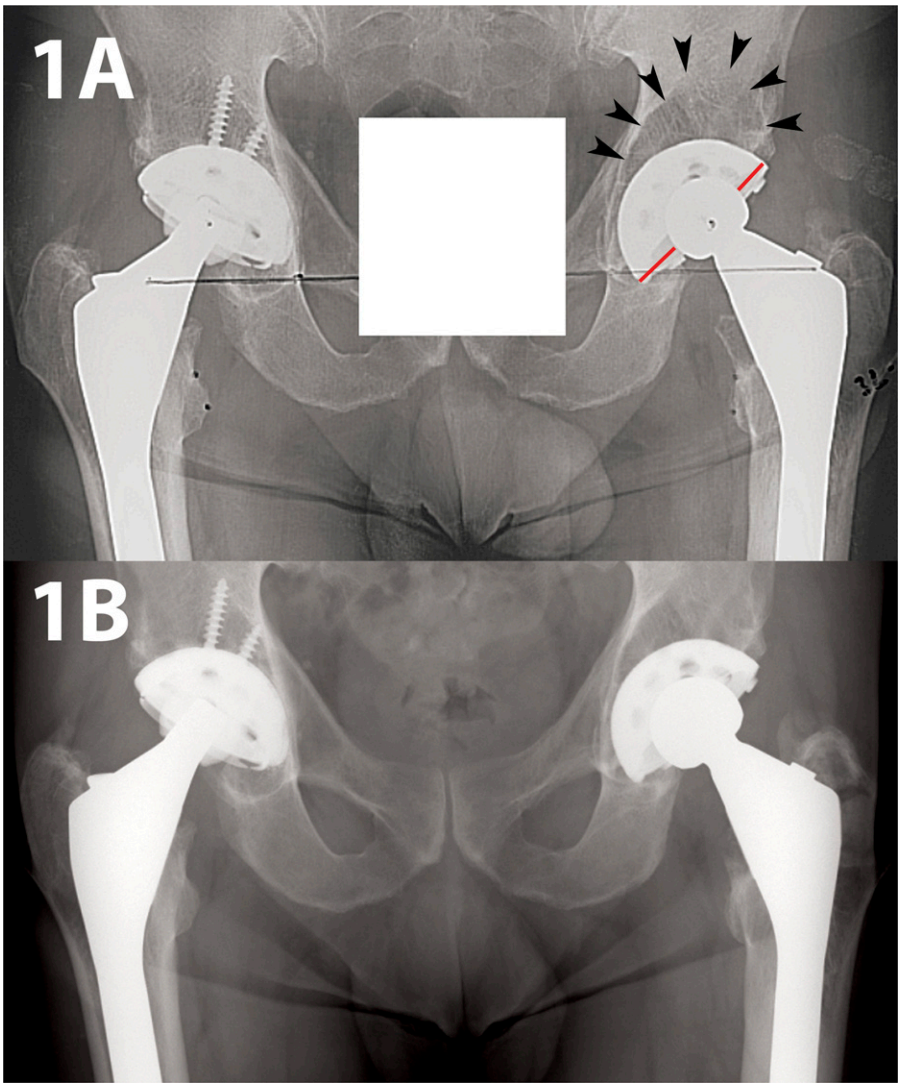

Fig. 1

Figs. 1-A and 1-B Anteroposterior pelvic radiographs of a patient who had bilateral total hip arthroplasty, with ceramic components on the right side and metal on the left side. **Fig. 1-A** The metal side was revised with a liner exchange fourteen years postoperatively for pain resulting from substantial osteolysis (black arrowheads) and a wear rate of 0.17 mm/yr. Note the migration of the head (red lines). **Fig. 1-B** The ceramic side had a wear rate of 0.09 mm/yr after eighteen years.

TABLE III Wear Analysis and Revision Rate for Five Patients with Bilateral Total Hip Arthroplasty (Ceramic on One Side and Metal on the Other Side)

	Ceramic Side	Metal Side
Radiographic follow-up* *(yr)*	19 ± 1.2	17 ± 2
Wear* *(mm/yr)*	0.09 ± 0.04	0.14 ± 0.08
Revision for osteolysis and/or loosening	0	2

*The values are given as the mean and the standard deviation.

patients with bilateral total hip replacements. Interobserver reliability was 0.75 (95% confidence interval [CI], 0.63 to 0.84).

There were no revisions in the ceramic group for osteolysis and/or loosening; however, one patient required a prophylactic strut graft for femoral osteolysis that was distal to the tip of the implant. This distal osteolysis was due to the noncircumferential proximal porous coating of the stem. Five hips in the ceramic group had radiographic evidence of acetabular or femoral osteolysis, none of which was symptomatic (Table II).

There were three failures in the metal group, requiring revisions for symptomatic loosening due to wear-induced osteolysis. Of the three revisions, two were isolated liner exchanges and one was an acetabular component revision. Six hips in the metal group had radiographic evidence of acetabular or femoral osteolysis, but none were symptomatic.

The wear analysis in the subgroup of five patients with bilateral total hip arthroplasty, with a ceramic femoral head on one side and a metal femoral head on the other, demonstrated a significantly higher mean wear rate on the metal side compared with the ceramic side (Table III). Two of these patients had revision of the metal side for wear and osteolysis (Figs. 1-A and 1-B).

Discussion

Ceramic femoral heads are more scratch-resistant with better wettability and improved wear characteristics compared with metal femoral heads in the laboratory setting[3,5,6]. A hip simulator in vitro study using a serum-based solution showed substantial reduction in polyethylene wear of up to fourfold in ceramic heads compared with metal heads[5]. Although studies have shown very low wear rates of ceramic on UHMWPE compared with historical reports of metal on UHMWPE[12-16], there is no long-term head-to-head clinical comparison of the two. Moreover, there are several confounding factors such as type of fixation (cemented versus press-fit components), design of the acetabular cup (modular versus all-polyethylene shells), properties of the polyethylene (UHMWPE or highly cross-linked polyethylene [HCLPE]), and various head sizes. The aim of the present study was to avoid these confounding factors by using a matched-pair wear analysis and comparative radiographic assessment of ceramic and metal femoral heads on UHMWPE in uncemented total hip replacements in young, active patients at a minimum of fifteen years of follow-up.

The mean ceramic wear rate in this study was 0.086 mm/yr, which is below the 0.1 mm/yr threshold for osteolysis[1,12,13]. Moreover, the ceramic wear rates were significantly less than that for the metal control group (0.137 mm/yr), with a 37% decrease in wear for alumina heads compared with the metal control group. These findings are consistent with other published studies[5,13,17-21]. Kim et al.[20] reported average wear of 0.07 mm/yr in 114 uncemented hips utilizing 28-mm alumina heads against UHMWPE. The ten-year survivorship in that study was 97.8% for the osteonecrosis cohort, with a mean age of fifty-one years. Similarly, Zichner and Willert[22] reported linear wear rates of <0.1 mm/yr in 63% of ceramic heads compared with 26.8% of metal heads. Hernigou and Bahrami also reported better volumetric wear data for 32-mm alumina heads than for 32-mm metal heads[21]. In a recent Norwegian registry study of metal-backed acetabular components with UHMWPE, metal heads had a higher relative risk of revision (hazard ratio, 1.8) than alumina heads at twenty years of follow-up[15]. In our cohort, radiographic osteolysis was more prevalent in the metal-on-polyethylene group, and was consistent with the rates of 5% to 24% that have been reported in other studies[23-25].

The results for ceramic femoral heads in young patients with cemented cups showed higher wear rates and lower survival rates than those for uncemented cups[14,26]. Haraguchi et al.[14] reported a mean wear rate of 0.15 mm/yr and fifteen-year survivorship of 75.3% ± 10.2% for alumina ceramic heads against ethylene oxide gas-sterilized polyethylene in cemented total hip replacement. Similarly, Hasegawa et al.[26], in a retrospective case series of ceramic-on-polyethylene articulations in young patients (mean age, fifty-four years), reported mean wear rates of 0.1 mm/yr and ten-year acetabular component survival of 75%. Urban et al.[4] reported a mean wear rate of 0.034 mm/yr for cemented total hip replacements with 32-mm alumina heads at a minimum of seventeen years.

The use of HCLPE and ceramic heads is increasing. Short-term to mid-term clinical results of HCLPE are equal to or better than those for UHMWPE[12,27-31], with an 87% lower risk of osteolysis[32]. Wroblewski et al. reported low wear rates, ranging from 0.022 to 0.019 mm/yr, in a long-term follow-up study of cemented total hip replacements with 22-mm alumina heads articulating against chemically cross-linked polyethylene[19]. Kim et al. showed that mean wear rates for 28-mm alumina heads on HCLPE were 0.05 ± 0.2 mm/yr in a young cohort of patients with osteonecrosis[33].

The main strengths of this study include the matched-pair and long-term follow-up of ceramic-on-polyethylene and metal-on-polyethylene components in young and active patients. All patients were randomly selected to receive ceramic or metal femoral heads. All procedures were done by a single surgeon by means of one approach, using the same femoral

component, 28-mm femoral heads, and uncemented acetabular components. The weakness of this study is the relatively small number of patients. However, they were matched on the basis of several parameters and the numbers were sufficient to reach significance. Although two types of acetabular components were used during the study period, both polyethylene liners were UHMWPE with similar properties[34,35].

In conclusion, the results of this matched-pair analysis of young and active patients who were followed for a mean duration of seventeen years confirm the findings of previous short-term studies in which ceramic femoral heads were found to impart a clinical advantage over metal components, with lower rates of wear and subsequent osteolysis and/or loosening. It remains to be seen whether the longevity of newer ceramics and highly cross-linked polyethylene will match the clinical performance of first-generation ceramic femoral heads on UHMWPE. ■

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References

1. Amstutz HC, Campbell P, Kossovsky N, Clarke IC. Mechanism and clinical significance of wear debris-induced osteolysis. Clin Orthop Relat Res. 1992 Mar;(276):7-18.

2. Bozic KJ, Kurtz SM, Lau E, Ong K, Vail TP, Berry DJ. The epidemiology of revision total hip arthroplasty in the United States. J Bone Joint Surg Am. 2009 Jan;91(1):128-33.

3. Boutin P. [Total arthroplasty of the hip by fritted aluminum prosthesis. Experimental study and 1st clinical applications]. Rev Chir Orthop Reparatrice Appar Mot. Apr-May;58(3):229-46.

4. Urban JA, Garvin KL, Boese CK, Bryson L, Pedersen DR, Callaghan JJ, Miller RK. Ceramic-on-polyethylene bearing surfaces in total hip arthroplasty. Seventeen to twenty-one-year results. J Bone Joint Surg Am. 2001 Nov;83(11):1688-94.

5. Clarke IC, Gustafson A. Clinical and hip simulator comparisons of ceramic-on-polyethylene and metal-on-polyethylene wear. Clin Orthop Relat Res. 2000 Oct;(379):34-40.

6. Bozic KJ. Femoral and acetabular component utilization in the United States. Read at the Thirty-Ninth Open Meeting of The Hip Society; 2011 Feb 19; San Diego, CA.

7. Wroblewski BM, Siney PD, Dowson D, Collins SN. Prospective clinical and joint simulator studies of a new total hip arthroplasty using alumina ceramic heads and cross-linked polyethylene cups. J Bone Joint Surg Br. 1996 Mar;78(2):280-5.

8. Harris WH, McCarthy JC Jr, O'Neill DA. Femoral component loosening using contemporary techniques of femoral cement fixation. J Bone Joint Surg Am. 1982 Sep;64(7):1063-7.

9. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res. 1976 Nov-Dec;(121):20-32.

10. Beaulé PE, Krismer M, Mayrhofer P, Wanner S, Le Duff M, Mattesich M, Stoeckl B, Amstutz HC, Biedermann R, EBRA-FCA for measurement of migration of the femoral component in surface arthroplasty of the hip. J Bone Joint Surg Br. 2005 May;87(5):741-4.

11. Livermore J, Ilstrup D, Morrey B. Effect of femoral head size on wear of the polyethylene acetabular component. J Bone Joint Surg Am. 1990 Apr;72(4):518-28.

12. 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 Oct;87(10):2323-34.

13. Dumbleton JH, Manley MT, Edidin AA. A literature review of the association between wear rate and osteolysis in total hip arthroplasty. J Arthroplasty. 2002 Aug;17(5):649-61.

14. Haraguchi K, Sugano N, Nishii T, Sakai T, Yoshikawa H, Ohzono K. Analysis of survivorship after total hip arthroplasty using a ceramic head. Clin Orthop Relat Res. 2001 Oct;(391):198-209.

15. Hallan G, Dybvik E, Furnes O, Havelin LI. Metal-backed acetabular components with conventional polyethylene: a review of 9113 primary components with a follow-up of 20 years. J Bone Joint Surg Br. 2010 Feb;92(2):196-201.

16. Sychterz CJ, Engh CA Jr, Young AM, Hopper RH Jr, Engh CA. Comparison of in vivo wear between polyethylene liners articulating with ceramic and cobalt-chrome femoral heads. J Bone Joint Surg Br. 2000 Sep;82(7):948-51.

17. Langton DJ, Sprowson AP, Mahadeva D, Bhatnagar S, Holland JP, Nargol AV. Cup anteversion in hip resurfacing: validation of EBRA and the presentation of a simple clinical grading system. J Arthroplasty. 2010 Jun;25(4):607-13.

18. Wroblewski BM, Siney PD, Fleming PA. Low-friction arthroplasty of the hip using alumina ceramic and cross-linked polyethylene. A ten-year follow-up report. J Bone Joint Surg Br. 1999 Jan;81(1):54-5.

19. Wroblewski BM, Siney PD, Fleming PA. Low-friction arthroplasty of the hip using alumina ceramic and cross-linked polyethylene. A 17-year follow-up report. J Bone Joint Surg Br. 2005 Sep;87(9):1220-1.

20. Kim YG, Kim SY, Kim SJ, Park BC, Kim PT, Ihn JC. The use of cementless expansion acetabular component and an alumina-polyethylene bearing in total hip arthroplasty for osteonecrosis. J Bone Joint Surg Br. 2005 Jun;87(6):776-80.

21. Hernigou P, Bahrami T. Zirconia and alumina ceramics in comparison with stainless-steel heads. Polyethylene wear after a minimum ten-year follow-up. J Bone Joint Surg Br. 2003 May;85(4):504-9.

22. Zichner LP, Willert HG. Comparison of alumina-polyethylene and metal-polyethylene in clinical trials. Clin Orthop Relat Res. 1992 Sep;(282):86-94.

23. Soto MO, Rodriguez JA, Ranawat CS. Clinical and radiographic evaluation of the Harris-Galante cup: incidence of wear and osteolysis at 7 to 9 years follow-up. J Arthroplasty. 2000 Feb;15(2):139-45.

24. Valle AG, Zoppi A, Peterson MG, Salvati EA. Clinical and radiographic results associated with a modern, cementless modular cup design in total hip arthroplasty. J Bone Joint Surg Am. 2004 Sep;86(9):1998-2004.

25. Tompkins GS, Jacobs JJ, Kull LR, Rosenberg AG, Galante JO. Primary total hip arthroplasty with a porous-coated acetabular component. Seven-to-ten-year results. J Bone Joint Surg Am. 1997 Feb;79(2):169-76.

26. Hasegawa M, Ohashi T, Tani T. Poor outcome of 44 cemented total hip arthroplasties with alumina ceramic heads: clinical evaluation and retrieval analysis after 10-16 years. Acta Orthop Scand. 2001 Oct;72(5):449-56.

27. Ranawat AS, Tsailis P, Meftah M, Koob TW, Rodriguez JA, Ranawat CS. Minimum 5-year wear analysis of first-generation highly cross-linked polyethylene in patients 65 years and younger [Epub ahead of print]. J Arthroplasty. 2011.

28. Sayeed SA, Mont MA, Costa CR, Johnson AJ, Naziri Q, Bonutti PM, Delanois RE. Early outcomes of sequentially cross-linked thin polyethylene liners with large diameter femoral heads in total hip arthroplasty. Bull NYU Hosp Jt Dis. 2011;69(Suppl 1):S90-4.

29. Kuzyk PR, Saccone M, Sprague S, Simunovic N, Bhandari M, Schemitsch EH. Cross-linked versus conventional polyethylene for total hip replacement: a meta-analysis of randomised controlled trials. J Bone Joint Surg Br. 2011 May;93(5):593-600.

30. Digas G, Kärrholm J, Thanner J, Malchau H, Herberts P. Highly cross-linked polyethylene in cemented THA: randomized study of 61 hips. Clin Orthop Relat Res. 2003 Dec;(417):126-38.

31. Jacobs CA, Christensen CP, Greenwald AS, McKellop H. Clinical performance of highly cross-linked polyethylenes in total hip arthroplasty. J Bone Joint Surg Am. 2007 Dec;89(12):2779-86.

32. Kurtz SM, Gawel HA, Patel JD. History and systematic review of wear and osteolysis outcomes for first-generation highly crosslinked polyethylene. Clin Orthop Relat Res. 2011 Aug;469(8):2262-77.

33. Kim YH, Choi Y, Kim JS. Cementless total hip arthroplasty with alumina-on-highly cross-linked polyethylene bearing in young patients with femoral head osteonecrosis. J Arthroplasty. 2011 Feb;26(2):218-23. Epub 2010 May 8.

34. Faris PM, Ritter MA, Pierce AL, Davis KE, Faris GW. Polyethylene sterilization and production affects wear in total hip arthroplasties. Clin Orthop Relat Res. 2006 Dec;453:305-8.

35. Meding JB, Keating EM, Davis KE. Acetabular UHMWPE survival and wear changes with different manufacturing techniques. Clin Orthop Relat Res. 2011 Feb;469(2):405-11.