Acetabular UHMWPE Survival and Wear Changes With Different Manufacturing Techniques

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Abstract

Background Polyethylene wear may be affected by the type of polyethylene resin, manufacturing technique, degree of thermal stabilization, and sterilization technique.

Questions/purposes We therefore compared femoral head penetration into the PE and cup survival using the same cup system with different PE resins, manufacturing, and sterilization techniques.

Methods Our study group consisted of 1912 THAs performed using the same uncemented cup and identical 28-mm cobalt-chrome heads. The polyethylene varied as follows: Group 1 (94 cups), GUR 4150 resin, ram-extruded, sterilized in air, no barrier packaging; Group 2 (74 cups), same as Group 1 but sterilized in argon; Group 3 (75 cups), Himont 1900 resin, compression-molded bar stock, sterilized in argon, no barrier packaging; Group 4 (620 cups), same as Group 3 except with barrier packing; Group 5 (711 cups), GUR 1050 resin, compression-molded bar stock, sterilized in argon gas with barrier packaging; and Group 6 (338 cups), GUR 1050 resin, compression-molded bar stock, sterilized in argon with barrier packaging, irradiated with 50 kGy, heated below melting temperature, machined,

and finally placed in nonbarrier packaging with gas plasma sterilization. Minimum followup was 2 years (average, 7 years; range, 2–17 years).

Results Femoral head penetration averaged 0.05 mm per year for Groups 5 and 6 and was substantially lower than for Groups 1 to 4. Cup survival was higher at seven years in Groups 3, 4, and 5, and at 10 years in group 4 when compared to groups 1, 2, and 3.

Conclusions We observed lower FHP rates and higher cup survival with polyethylene machined from direct compression-molded bar stock, sterilized in argon gas, with barrier packaging.

Level of Evidence Level III Therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Polyethylene (PE) wear affects survivorship of THAs: PE wear debris causes osteolysis and loosening. PE wear is affected by the type of PE resin [1], the manufacturing technique [1, 6, 18, 19, 23], the addition of calcium stearate [12], the degree of thermal stabilization [11, 12, 17, 21], and the sterilization technique [2, 6, 18, 22]. Thus, in an effort to reduce fatigue damage and wear of the PE in THA, by minimizing PE oxidation during storage, barrier packaging the PE in an inert gas is commonly employed when gamma sterilization is used [13, 18, 22]. In addition, Jacobs et al. in reviewing the early and mid-term clinical results of the so-called highly cross-linked PE reported improved wear resistance in acetabular liners of between 23% and 95% [11].

Faris et al. [6] noted that PE components sterilized with gamma ray irradiation in air and sterilized with gamma ray

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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irradiation in inert gas with machining from ram-extruded bar stock wore at 116% and 111% of the PE wear of the PE manufactured from compression-molded bar stock and sterilized with gamma ray irradiation in argon gas. The same metal shell was used in all cases. However, that study did not address the effect of barrier packaging and cross-linking of the PE.

Using the same cup system as Faris et al. [6], we asked the following questions: (1) Would femoral head penetration (FHP) be affected by cup anteversion, cup abduction, BMI, age, diagnosis, and gender? (2) Would the post-operative clinical hip scores and pain scores be different with different manufacturing techniques of the PE? (3) Would FHP change with different manufacturing techniques of the PE? (4) Would cup survival rates be different with different manufacturing techniques of the PE? (5) Would FHP be different with different manufacturing techniques of the PE if patients were matched according to gender, age, BMI, and diagnosis? (6) Would cup survival differ with different manufacturing techniques of the PE if patients were matched according to gender, age, BMI, and diagnosis?

Patients and Methods

Between January 1969 and March 2009, 8593 primary THAs were performed at our institution. Of these, 2611 THAs in 2200 patients were implanted using the same cup system (RingLoc®; Biomet, Warsaw, IN) based on surgeon preference; we had no uniform indications or contraindications for using this cup system. In all hips, we used 28-mm cobalt-chrome heads and both cemented ($n = 644$) and uncemented ($n = 1967$) stems. Two hundred four patients (245 THAs) were lost to followup, and 335 patients (454 THAs) had less than 2 years of followup. This left 1661 patients with 1912 THAs. The average age of the study group was 62 years (range, 17–96 years; SD, ± 12 years). Forty-eight percent of the study group was male (918 patients) and 52% female (994 patients).

Average followup was 7 years (median, 5 years; range, 2–17 years). One hundred sixty patients (183 hips) died during the study. Two hundred twenty-four (11.7%) hips had simultaneous bilateral procedures, 556 (29.1%) had staged bilateral procedures, and 1132 (59.2%) had unilateral procedures.

The same acetabular cup system was used with both solid cups and ones with screw holes. This was a titanium alloy cup, plasma-sprayed ($Ra = 78 \mu m$) with a peripheral ring used to lock the PE liner. The THAs were divided into six study groups according to PE manufacturing technique. Group 1 (1991–1992) consisted of 94 THAs manufactured from GUR 4150 PE resin, machined from ram-extruded bar stock, sterilized by gamma ray irradiation in air, and placed in nonbarrier packaging. Group 2 (1992–1993) consisted of 74 THAs with the same manufacturing technique as Group 1 except the PE was sterilized in an inert gas (argon) by gamma ray irradiation (no barrier packaging). Group 3 (1993–1995) consisted of 75 THAs manufactured from Himont 1900 resin, machined from compression-molded bar stock (isostatic compression molded PE), sterilized with gamma ray irradiation in argon gas, and placed in nonbarrier packaging (ArCom® PE; Biomet). Group 4 (1995–2001) consisted of 620 THAs with the same manufacturing technique as Group 3 except it was placed in barrier packaging. Group 5 (2001–2004) consisted of 711 THAs manufactured from GUR 1050 resin, machined from compression-molded bar stock (isostatic compression molded PE), sterilized in argon gas with gamma ray irradiation, and placed in barrier packaging with no crosslinking. Group 6 (2004–2007) consisted of 338 THAs manufactured from GUR 1050 resin, machined from compression-molded bar stock (isostatic compression molded PE), sterilized in argon gas with gamma ray irradiation, and placed in barrier packaging with 50 kGy to increase crosslinking of the PE. After this, the PE stock was heated below melting temperature (130°C) and then deformed (diametral compression) into new bar stock, machined, sterilized in gas plasma, and placed in nonbarrier packaging (ArCom XL® PE) (Table 1).

Table 1. Polyethylene manufacturing techniques

Group	Sterilized in	Bar stock	Barrier packaging	Resin	Crosslinked
1 ($n = 94$)	Air	Ram-extruded	No	GUR 4150	No
2 ($n = 74$)	Argon	Ram-extruded	No	GUR 4150	No
3 ($n = 75$)	Argon	ICM*	No	Himont 1900	No
4 ($n = 620$)	Argon	ICM*	Yes	Himont 1900	No
5 ($n = 711$)	Argon	ICM*	Yes	GUR 1050	No
6 ($n = 338$)	Argon	ICM*	Yes then No	GUR 1050	Yes

* Isostatic Compression Molding.

Table 2. Preoperative demographics compared among the six groups

Group	Age (years)*	Body mass index*	% female	% osteoarthritis	% rheumatoid arthritis	% osteonecrosis
1 (n = 94)	59 ± 10	27.8 ± 4.8	48%	85%	2%	7%
2 (n = 74)	55 ± 12	28.2 ± 4.5	44%	80%	0%	14%
3 (n = 75)	53 ± 12	30.4 ± 4.8	44%	85%	1%	9%
4 (n = 620)	59 ± 12	29.8 ± 5.9	45%	83%	1%	7%
5 (n = 711)	65 ± 11 [†]	30.4 ± 5.6	51% [§]	92% [§]	1%	4%
6 (n = 338)	74 ± 7 [‡]	30.2 ± 5.5	59% [§]	92% [§]	0%	3%

* Values are expressed as mean ± SD; [†]p = 0.01; [‡]p < 0.01; [§]p < 0.001.

Table 3. Preoperative and postoperative Harris hip scores and pain scores

Group	Harris hip score		Pain score	
	Preoperative	Postoperative	Preoperative	Postoperative
1 (n = 94)	59.1 ± 15.7 (54.9, 63.3)*	94.3 ± 7.9 (92.2, 96.4)	19.7 ± 9.3 (17.4, 21.9)*	41.6 ± 4.6 (40.5, 42.8)
2 (n = 74)	54.6 ± 14.1 (50.8, 58.5)*	96.7 ± 4.5 (95.3, 98.2)	15.9 ± 7.5 (14.1, 17.8)*	42.9 ± 2.6 (42.1, 43.7)
3 (n = 75)	52.7 ± 11.6 (49.8, 55.7)	95.8 ± 7.1 (93.5, 98.0)	13.9 ± 6.5 (12.4, 15.5)	42.2 ± 3.8 (41.0, 43.4)
4 (n = 620)	52.4 ± 11.1 (51.3, 53.4)	94.8 ± 8.6 (93.8, 95.8)	13.0 ± 6.8 (12.4, 13.6)	42.2 ± 4.9 (41.7, 42.8)
5 (n = 711)	50.1 ± 9.3 (49.3, 50.9)	95.5 ± 6.4 (94.8, 96.2)	11.0 ± 4.6 (10.6, 11.4)	43.1 ± 3.0 (42.8, 43.5)
6 (n = 338)	49.7 ± 11.9 (48.2, 51.1)	94.7 ± 5.8 (93.5, 95.8)	12.8 ± 7.2 (11.9, 13.6)	43.1 ± 2.3 (42.6, 43.5)

Values are expressed as mean ± SD, with 95% confidence interval in parentheses; *p < 0.001; Groups 1 and 2 both had higher preoperative Harris hip scores than the other groups.

No differences were noted among Groups 1 to 4 with respect to age or diagnosis. Group 5 ($p < 0.01$) and Group 6 ($p < 0.001$) had a greater percentage of osteoarthritis hip than Groups 1 to 4. Group 5 ($p = 0.01$) and Group 6 ($p < 0.01$) were older than Groups 1 to 4. Groups 5 and 6 also had a greater ($p < 0.001$) percentage of female patients. No statistical difference was noted in body mass index (BMI) among the six groups (Table 2). Groups 1 and 2 had higher preoperative Harris hip scores (HHS) ($p < 0.001$) and higher preoperative pain scores (less pain) ($p < 0.001$) (Table 3). Average followup was 12.0 years in Group 1, 11.2 years in Group 2, 9.5 years in Group 3, 6.9 years in Group 4, 5.7 years in Group 5, and 3.1 years in Group 6. 45% of the study group was implanted with 8.8 mm of PE, 33% with 10.8 mm of PE, and 7.5% with 11.8 mm of PE. In all, 86% of the study group was implanted with at least 8.8 mm of PE. There was no difference ($p = 0.64$) in the average PE thickness among the six groups. Except for patient matching, all statistical models were adequately powered for probability of a Type 2 error of less than 0.01 (normal = 0.20). The detection limit we observed in the data included differences of 1 point in hip score (continuous data), 5 points in the pain score (the categorical difference of the pain score), and 0.06 mm per year in annual wear (the accuracy of the Martell method) [15, 16].

Because the present data may be confounded by differences in age and gender, and, thus, potential differences

in activity levels, a maximum of 40 patients (40 THAs) were matched according to age, gender, diagnosis and BMI ($\pm 5 \text{ kg/m}^2$). The overall average age in the matched study was 57.9 years (± 10.5). The average BMI was 28.3 kg/m^2 (± 3.7). Each group had 20 males and 20 females. The diagnosis was osteoarthritis in all cases. Because of the reduction of the n-count, the probability of a Type 2 error in this matched analysis was 0.52.

Before 1995, all surgical approaches in this study were posterior without trochanteric osteotomy. After this, two of the surgeons (MAR, MEB) routinely used an anterolateral approach. All hips with anterolateral approaches were treated with trochanteric precautions for 8 weeks. The immediate weight bearing status varied with surgeon. All patients received supervised in-hospital physiotherapy, walking assisted for 6 to 8 weeks with a walker. All patients were mobilized on day 1 postoperatively. No active hip flexion beyond seventy degrees was allowed for 8 weeks. Supervised post-hospitalization physiotherapy varied among patients according to need (outpatient, rehabilitation hospital, or extended care).

The clinical evaluation was performed at 2 months, 6 months, 1, 3, 5, 7, and 10 years, and every 2 to 3 years thereafter by using the HHS. At each visit, we obtained supine AP pelvis and frog lateral hip radiographs.

The five surgeons (JBM, EMK, MAR, PMF, MEB) measured cup anteversion and abduction, along with all

clinical data, at each patient clinic visit; however, the anteversion and abduction used in this study were evaluated by two observers (CF, KED) using the Martell Hip Analysis Suite™ (Orthopedic Research Institute, University of Chicago, Chicago, IL). The average anteversion in Group 1 was $18.6^\circ (\pm 9.53^\circ)$ in Group 1, $16.3^\circ (\pm 6.32^\circ)$ in Group 2, $18.2^\circ (\pm 6.89^\circ)$ in Group 3, $17.7^\circ (\pm 8.5^\circ)$ in Group 4, $20.7^\circ (\pm 8.24^\circ)$ in Group 5, and $15.0^\circ (\pm 6.43^\circ)$ in Group 6. The average anteversion was higher ($p = 0.02$) in Group 5 compared to the other groups. The average abduction was 45.9° in Group 1 ($\pm 7.9^\circ$), $44.9^\circ (\pm 9.0^\circ)$ in Group 2, $45.8^\circ (\pm 6.2^\circ)$ in Group 3, $50.9^\circ (\pm 7.4^\circ)$ in Group 4, $46.8^\circ (\pm 8.3^\circ)$ in Group 5, and $50.3^\circ (\pm 7.2^\circ)$ in Group 6. No differences ($p = 0.51$) in abduction were noted among the six groups.

Femoral head penetration (FHP) rates were measured by two observers (CF, KED) using computer-assisted edge detection with the Martell Hip Analysis Suite™. The accuracy of the Martell method was evaluated by Hui et al. [9] who reported values equal to 0.91 when compared to a coordinate measuring machine. The software calculated wear based on digitized versions of standard radiographs by determining the location of the center of the femoral head and acetabular cup. This allows the software to determine the direction and magnitude of displacement of the femoral head, which indicated the direction and magnitude of the wear. The software uses the convention in which the wear angles are measured from the perpendicular bisector of the tuberosity line, with medial direction being positive. We used the software package's two-dimensional volumetric wear calculations, which are a function of the vector displacements vector and the femoral head size. The most recent followup AP radiograph was compared to the initial postoperative AP radiograph (2 months) to determine overall FHP. No attempt was made to differentiate between the so-called "settling in" phenomenon of the PE liner within the shell versus PE creep or true PE wear. Rather, the total FHP was measured. The two-dimensional linear wear calculation was measured with only two data points. Three-dimensional wear data were not calculated as they have limited clinical value [16].

Chi square analysis was used for preoperative categorical comparisons (gender and diagnosis) among groups. A two-sample *t* test was used for comparison of continuous data (age, anteversion, abduction, and BMI) among groups. We used linear regression analysis (ANOVA) to determine differences in FHP rates by group, including the nuisance effects of age, BMI, gender, anteversion, abduction, bilaterality, and diagnosis. Kaplan-Meier survival (log rank) was used to compare cup survival among the six groups, with failure being defined as aseptic loosening or revision for loosening or PE wear, and the Wilcoxon forward stepwise procedure was used to test for the effects of

covariates such as age, BMI, and gender on survival and linear wear. Activity level, per se, was not, specifically, reported or examined other than according the Harris score. Statistical analysis was performed using the SAS® (SAS Institute Inc, Cary, NC).

Results

Overall, FHP was affected by cup anteversion, age, and BMI. Greater FHP was associated with increased anteversion ($p < 0.001$), increased BMI ($p = 0.02$), and younger age ($p = 0.004$). No association was noted between FHP and abduction ($p = 0.52$), diagnosis ($p = 0.67$), gender ($p = 0.49$).

The average postoperative HHS and pain scores at final followup were 92 and 41, respectively, in Group 1, 91 and 39 in Group 2, 90 and 39 in Group 3, 90 and 39 in Group 4, 91 and 40 in Group 5, and 90 and 38 in Group 6. No difference was noted among groups (Group 1, $p = 0.56$; Group 2, $p = 0.60$; Group 3, $p = 0.13$; Group 4, $p = 0.27$; Group 5, $p = 0.73$; Group 6, reference group) with respect to the final HHS.

FHP did, indeed, change with different manufacturing techniques of the PE FHP averaged $0.122 (\pm 0.125)$ mm per year in Group 1, $0.107 (\pm 0.154)$ mm per year in Group 2, $0.125 (\pm 0.375)$ mm per year in Group 3, $0.059 (\pm 0.226)$ mm per year in Group 4, $0.050 (\pm 0.163)$ mm per year in Group 5, and $0.045 (\pm 0.186)$ mm per year in Group 6. Thus, FHP was less ($p < 0.001$) in Group 4 than in Groups 1, 2, and 3. FHP was less ($p < 0.001$) in Group 5 than in Groups 1, 2, and 3. FHP was less in Group 6 than in Groups 1, 2, and 3 ($p < 0.001$) and in Group 4 ($p = 0.04$).

Cup survival rates were, also, different according to manufacturing techniques of the PE. Eight cups failed in Group 1 (8.5%), five for loosening, three for PE wear; two cups failed in Group 2 (2.7%), one for loosening, one for PE wear; six cups failed in Group 3 (8%), five for loosening, one for PE wear; 11 cups failed in Group 4 (1.8%), nine for loosening, two for PE wear; four cups failed in Group 5 (0.6%), all for loosening; and two cups failed in Group 6 (0.6%), both for loosening. Not all failed cups were revised, however. Cup survival with failure defined as aseptic loosening or revision for loosening or PE wear was higher at 7 years in Groups 3, 4, and 5 and at 10 years in Group 4 ($p = 0.03$) (Table 4). Thus, at 7 years, cup survival was greater for cups machined from direct compression-molded PE as opposed to ram-extruded bar stock.

In the matched group analysis no statistical difference was noted in FHP between the six groups ($p = 0.545$, one way ANOVA). FHP averaged $0.1683 (\pm 0.128)$ mm per year in Group 1, $0.0634 (\pm 0.132)$ mm per year in Group 2,

Table 4. Kaplan-Meier cup survival of the groups

Years	Survival (95% confidence interval)	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
1		1.000 (1.000, 1.000)	0.9859 (0.9042, 0.9980)	1.000 (1.000, 1.000)	0.9939 (0.9832, 0.9982)	0.9984 (0.9888, 0.9998)	1.000 (1.000, 1.000)
3		0.9877 (0.9194, 0.9983)	0.9859 (0.9042, 0.9980)	1.000 (1.000, 1.000)	0.9914 (0.9797, 0.9971)	0.9961 (0.9842, 0.9991)	0.9962 (0.9716, 1.000)
5		0.9877 (0.9194, 0.9983)	0.9859 (0.9042, 0.9980)	1.000 (1.000, 1.000)	0.9914 (0.9797, 0.9971)	0.9961 (0.9842, 0.9991)	
7		0.9712 (0.9194, 0.9983)	0.9859 (0.9042, 0.9980)	1.000* (1.000, 1.000)	0.9914* (0.9797, 0.9971)	0.9961* (0.9842, 0.9991)	
10		0.9491 (0.8920, 0.9931)	0.9541 (0.8166, 0.9896)	0.9286 (0.8030, 0.9864)	0.9720* (0.9172, 0.9904)		
12		0.8154 (0.8498, 0.9844)	0.9541 (0.8166, 0.9896)	0.8844 (0.7332, 0.9699)			
15		0.8154 (0.6381, 0.9128)					

* Cup survival was higher at 7 years in Groups 3, 4, and 5 and at 10 years in Group 4 ($p = 0.03$).

Table 5. FHP comparison between individual groups (Matched Analysis)

Group comparison	p Value
Group 1 versus Group 2	$p = 0.92$
Group 1 versus Group 3	$p = 0.75$
Group 1 versus Group 4	$p = 0.74$
Group 1 versus Group 5	$p = 0.74$
Group 1 versus Group 6	$p = 0.17$
Group 2 versus Group 3	$p = 0.77$
Group 2 versus Group 4	$p = 0.76$
Group 2 versus Group 5	$p = 0.75$
Group 2 versus Group 6	$p = 0.10$
Group 3 versus Group 4	$p = 0.94$
Group 3 versus Group 5	$p = 0.99$
Group 3 versus Group 6	$p = 0.19$
Group 4 versus Group 5	$p = 0.93$
Group 4 versus Group 6	$p = 0.32$
Group 5 versus Group 6	$p = 0.13$

0.194 (± 0.271) mm per year in Group 3, 0.334 (± 0.236) mm per year in Group 4, 0.089 (± 0.445) mm per year in Group 5, and 0.351 (± 0.151) mm per year in Group 6 (Table 5).

Because no cups failed in the matched groups before 5 years, the 5-year survival rate in all six groups was technically 1.000. Thus, we were unable to answer the question as to whether cup survival would differ with different manufacturing techniques of the PE if patients were match according to gender, age, BMI, and diagnosis.

Discussion

PE wear continues to be a major issue in THA as evidenced by the increasing number of reports of so-called highly crosslinked PE [11]. The recent industry trends of sterilization (ethylene oxide, gas plasma, and gamma ray irradiation and inert gas) and quality improvement in packaging methodology have been introduced to minimize PE wear in THA. Radiation and thermal treatment of the PE has also been introduced to minimize wear. We compared the clinical performance and wear results of UHMWPE using the same cup system with different PE manufacturing techniques, resins, and methods of sterilization and determined that wear rates and survival would improved with PE machined from compression molded barstock and sterilized in argon gas with barrier packaging.

We acknowledge limitations to this study. First is the relative short-term followup of Groups 5 and 6 (mean of 5.0 and 3.1 years, respectively). Nevertheless, when all patients were included, differences were confirmed in cup

survival at 7 years in Groups 3, 4, and 5 compared to Groups 1 and 2. In the matched grouping, however, cup survival could not adequately be determined because of the smaller number of cup failures (none) within the first 5 years. Longer followup will be needed to determine whether Group 6, with a highly crosslinked PE, will demonstrate improved survival rates. Second, we made no attempt to differentiate true PE wear from the settling in phenomenon, ie, movement of the PE liner within the shell and the plastic deformation or creep of the PE within the liner. Rather, FHP, which is a combination of all three, was measured comparing the most recent followup radiograph to the baseline radiograph. Unfortunately, the degree of “bedding in,” a combination of creep and movement of the PE within the shell, is extremely controversial and has been speculated to occur between 8 weeks [13] and up to 5 years [11]. Most authors, however, will agree the bedding in phenomenon occurs within the first 24 months [1, 2, 5, 8, 12, 14]. Third, we used a two-dimensional technique to determine wear. The computer edge detection technique of Martell has been extensively studied in the literature and is more than 10 times more reliable than the Livermore technique [10]. The Martell technique will generally measure more wear, however, than radiostereometric analysis [7]. Furthermore, the two-dimensional measurement has been more precise because the AP radiograph is four times more reliable than the lateral radiograph [10]. The three-dimensional technique is likely more accurate and may measure up to 10% more wear as compared to the two-dimensional technique [9]. Thus, the three-dimensional technique has been noted to have limited clinical value [6, 10]. Therefore, only the two-dimensional technique was used in this study. Fourth, our radiographs were taken supine. A report by Garvin et al. [4] noted load bearing did not substantially improve or change the results of measuring wear. Fifth, the patient matching statistical analysis was not adequately powered. Thus, the null hypothesis may be incorrectly accepted. That is, it may be incorrect in stating that no difference in FHP was noted between the 6 groups (underpowered) when, in fact, there may have been significant differences in FHP. Nevertheless, we recognize the benefits of data matching. Because activity level was not specifically evaluated, the age and gender difference between the groups could mean differences in mechanical stress on the acetabular component. ANOVA does not substitute for patient matching. Thus, this portion of the study was included.

In a previous report from our institution, Faris et al. [3] noted the PE components sterilized with gamma ray irradiation in air and sterilized with gamma ray irradiation in inert gas with machining from ram-extruded bar stock wore at 116% and 111% of the PE wear of the PE manufactured from compression-molded bar stock and sterilized with

gamma ray irradiation in argon gas. Our data confirm these findings with longer followup and also add that improved wear rates and cup survival were identified with PE machined from direct compression-molded bar stock, sterilized in argon gas, with barrier packaging. The FHP rates in Group 5 (noncrosslinked PE) and Group 6 (cross-linked PE) were similar at 0.050 and 0.045 mm per year, respectively. One might have expected the wear rate to be substantially less in the latter group. There are at least two possible explanations for this. First, the average followups for these two groups are relatively short (5 years for Group 5 and 3.1 years for Group 6). Longer followup may yield greater differences in the wear rates. Second, both groups had cup PE manufactured with the same resin and machined from compression-molded bar stock.

Other authors have reported on this particular cup system. Puolakka et al. [20] reported on 107 cups implanted with 28 and 32 heads but the PE thickness was not given. The average wear rate was 0.17 mm/year. The PE used was “first-generation” PE (gamma in air sterilization). Cautilli et al. [3] reported on 303 cups with followup between 2 and 5 years. Ti-alloy heads were implanted in all cases. Eleven cups (4%) loosened. The average linear wear was 0.5 mm/year. The PE manufacturing technique was not specifically noted. Isaac et al. [10] reported on 45 cups followed for an average of 7.6 years. 13% of the cups were revised or loosened. No mention was given PE thickness, wear rate, or manufacturing technique (Table 6).

Using the same ring-loc cup system, we observed lower FHP rates and higher cup survival at 7 years postoperative

Table 6. Published reports on the universal RingLoc® cup system

Report	# cups	Followup	FHP	PE* type/ sterilization
Cautilli et al. [3]	303	2–5 years	0.5 mm/year	unknown
Puolakka et al. [20]	107	74 months	0.17 mm/year	Gamma in air
Faris et al. [6]	150	6 years	0.09 mm/year	Gamma inert/ molded
			0.10 mm/year	Gamma inert/ extruded
			0.13 mm/year	Gamma air- extruded
Isaac et al. [10]	45	7.6 years	Not reported	Not reported
Current study	1912	7 years	0.122 mm/year	Group 1*
			0.107 mm/year	Group 2
			0.125 mm/year	Group 3
			0.059 mm/year	Group 4
			0.050 mm/year	Group 5
			0.045 mm/year	Group 6

* See text for description of PE.

with PE machined from compression-molded bar stock, sterilized in argon gas, with barrier packaging.

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