Ceramic-Ceramic Bearing Decreases Osteolysis

A 20-year Study versus Ceramic-Polyethylene on the Contralateral Hip

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Abstract Although ceramic implants have been in use for many years and they are intended to minimize wear debris it is unknown whether alumina-on-alumina or alumina-on-polyethylene produce less wear and osteolysis. We therefore investigated wear and osteolysis on 28 bilateral arthroplasties (one ceramic-ceramic and the contralateral ceramic-polyethylene) of patients who had survived 20 years without revision and without loosening of either hip. Osteolysis was identified on anteroposterior pelvic radiographs and 3-D volume from CT scans. The number of osteolytic lesions detected with CT scan was higher than with radiographs. The number of lesions was higher on the side with the alumina-PE couple. With a similar length of followup on each side, the surface and the volume of osteolysis were consistently higher on the side with the alumina-PE couple. We found no correlation between the volume of osteolysis and the volume of estimated wear in each couple of friction. Hips with osteolysis had a lower Harris score.

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Each author certifies that his institution has approved the human protocol for this investigation and that all the investigations were conducted in conformity with ethical principles of research.

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Introduction

Periprosthetic osteolysis is regarded as an important factor in the long-term durability of a total hip prosthesis [24] and many studies [1, 23, 24] have suggested osteolysis is related to wear and the number of debris particles. To reduce wear, Boutin [7] reported the use of alumina-on-alumina bearing surfaces in total hip arthroplasty (THA) in 1972. There have been many subsequent reports [3, 4, 9, 12, 18, 19, 25, 31, 32] regarding the use of ceramic total hip systems. In principle ceramics have the potential for low rates of wear compared to metal-on-polyethylene, and in one study alumina-ceramic bearings demonstrated the lowest rates of in vivo wear as compared with metal - polyethylene combination [20]. Although ceramic implants have been in use for many years [7, 8], there have been few reports of osteolysis associated with ceramic bearing surfaces [5, 33] and it is unknown whether alumina-on-alumina has any advantage over alumina-on-polyethylene [34].

Computed tomography is useful for identifying and quantifying osteolysis. Two studies [17, 27] demonstrate a CT scan more accurately identifies the presence, location, and extent of osteolysis than standard radiographs [2]. We therefore investigated osteolysis with CT scan on bilateral arthroplasties (one ceramic-ceramic and the contralateral ceramic-polyethylene) of patients who had survived 20 years.

We asked the following questions: (1) How many lesions of osteolysis could be detected with radiographs and CT scan on both sides? (2) Do the volumes of

osteolysis differ for alumina-on-alumina versus alumina-on-polyethylene in the same patient? (3) Is the volume of osteolysis related to the amount of wear or to the difference between the two bearing surfaces? (4) Does the volume of osteolysis influence hip scores?

Material and Methods

We retrospectively reviewed 28 selected patients (56 hips) with bilateral THA (one ceramic-ceramic, AL/AL and the contralateral ceramic-polyethylene, AL/PE) who underwent surgery between 1981 and 1985. At this time the indications for an AL/AL hip were osteonecrosis or osteoarthritis in patients younger than 55 years. The PE/AL hip was used in patients between 56 and 65 years old. Metal-PE hips were performed when the patients were older than 65 years. During that same time, we performed bilateral THA with the same implants (one ceramic-ceramic, AL/AL and the contralateral ceramic-polyethylene, AL/PE) in 42 patients. For this study we excluded 14 of the 42 patients who did not have their implants a minimum of 20 years due to death (4 patients) or loosening of the implant on one side (6 patients) or both sides (4 patients). The mean age at surgery was 55 years (range, 38–61 years). Nineteen patients were men and 10 patients were women. Alumina cups were implanted in 13 right and 15 left hips. The indication for surgery was osteoarthritis or late-stage osteonecrosis with a substantial amount of flattening of the articular surface. Total hip replacement was a primary procedure in all hips. The minimum followup was 20 years (mean, 22 years; range, 20 to 25 years).

Surgery was performed with a posterolateral approach under general anesthesia. All patients received the same implants. The prostheses were manufactured by Ceraver (Ceraver Osteal, Roissy, France). The stem was made of anodized titanium alloy (TiAl6V4) and was smooth and always cemented. The alumina head was 32 mm in diameter and anchored through a Morse taper. The acetabular component was a polyethylene cup or an alumina cup and was always cemented. Both components were fixed with cement (Palacos G; Heraeus Medical GmbH, Hanau, Germany) containing antibiotics (gentamicin). The alumina acetabular component was a plain cup with grooves on the outer surface, and was cemented.

The cohort was recalled more than 20 years after surgery to determine osteolysis, wear, and function in both hips. Patients were evaluated at the most recent followup with clinical (Harris hip score [13]), radiographic, and CT scan evaluations.

We had available all preoperative and immediate postoperative radiographs which we compared to those at last followup. Absence of loosening of the socket was defined

as no cup migration exceeding 5 mm, no angular rotation exceeding 5°, and no continuous radiolucent line wider than 2 mm [10]. Preexisting cysts or relative areas of osteopenia were not considered to represent osteolysis. Pelvic osteolysis was defined as a new or expanding sharply demarcated lucency adjacent to the cup. Femoral osteolysis was defined as a new or expanding sharply demarcated lucency adjacent to the stem and beginning on the calcar. Each lesion was identified by a member of the radiology department and traced on each radiograph with use of a semiautomated edge-detection module (Photoshop; Adobe Systems, Inc., San Jose, CA). The diameters and areas of the lytic lesions were then calculated from each tracing.

All hips were evaluated with helical computed tomography around the time of the last clinical and radiographic followup. Because the cup had no metal back and the stem was titanium, no metal-artifact-minimizing protocol was necessary. The hips were scanned from 8 cm proximal to the acetabular component to a point distal to the end of the femoral implant. The maximum thickness of the cuts ranged from 1 to 3 mm.

Coronal and sagittal images were subsequently reconstructed from the axial data. These images were compared to preoperative radiographs and to immediate postoperative radiographs. Bone defects present on CT scans that were not evident on the postoperative radiographs were defined as new lesions. Bone defects seen on the CT scan and on preoperative or immediate postoperative radiographs were defined as preexisting lesions and were not further evaluated.

To calculate the volume of the osteolysis lesions were identified in the department of radiology and traced on each axial cut with use of a semiautomated edge-detection module (Photoshop). The areas of the lytic lesions were then calculated from each tracing by determining the number of pixels per square millimeter. The volume between adjacent cuts was calculated by averaging the areas between adjacent cuts multiplied by the thickness of the cuts. Summation of the volumes on each of these cuts was used to determine the total volume of bone loss due to lysis [17, 27].

The technique used for measurement of polyethylene wear and creep was adapted from a 3-D technique previously described [14, 15] used both for measurement and accuracy. By comparison with the initial postoperative and long-term followup films, measurement of the femoral head penetration within the cup could be made. All measurements were made from a standard frontal and lateral view. Creep was evaluated with the method described by Williams et al. [37]. For each patient, penetration against time was measured on radiographs performed at different times in vivo. A line of best fit between these different

points was traced. The intercept with the Y axis allows evaluation of creep. Linear wear was evaluated as the difference between penetration and creep. The volume of polyethylene wear generated by the femoral head displacement with time was calculated by a mathematical formula [16, 21] that measured the volume of a cylinder created by femoral head displacement from its original position in the cup.

Measurement of the wear on radiographs is difficult in AL/AL bearing surfaces, as it is not possible to distinguish the edge of the femoral head from the articulation surface of the acetabular component on the radiographs. We therefore used an indirect technique to measure alumina wear. The indirect measurement of liner wear was based on the amount of decentering of the femoral head from the socket on the AP and lateral radiographs. This method measures the distance between the center of the femoral head and the acetabular convexity on the equator of the acetabular both on AP and lateral radiographs. The center of the femoral head can be determined from the inferior part which is outside the cup. Then, using trigonometry as previously described [14, 15], the amount of linear and volumetric wear can be estimated with a formula that predicts wear volume by using overlapping geometric shapes. The accuracy of this method was evaluated on radiographs of five retrieved implants obtained from other patients with a similar followup (24 years). Equatorial and true polar two-dimensional roundness traces were taken with a Mitutoyo Roundtest RA300 machine (Mitutoyo France, Roissy, Paris) which has an accuracy of 0.01 μm and records both full and partial circles. We found a mean rate of wear of 5 μm per year for the femoral head and 5 μm per year for the acetabular socket. This corresponded to a decentering of 0.3 mm after 24 years (12 μm per year) on radiographs. The accuracy of the radiographic method to measure decentering was 25%.

We used a Mann-Whitney U test for two independent samples to compare the mean volumes of osteolysis. A Kruskal-Wallis test for multiple independent samples was used to assess whether the lesion volume differed according to the bearing surfaces. We also used chi square analysis for comparison of the number of osteolytic lesions between groups. We used Pearson's correlation to assess the relationship between wear and osteolytic lesion volume.

Results

The number of lesions detected with CT scan was higher ($p = 0.03$) than with radiographs. In ceramic-polyethylene hips, 35 new lesions (15 acetabular lesions and 20 calcar lesions) were identified on radiographs in 20 of the 28 (70%) ceramic-polyethylene hips. Four hips had no evidence of pelvic osteolysis on the plain radiographs or the helical CT scan. The other 24 hips had evidence of pelvic osteolysis on the CT scans. Five hips had no evidence of femoral osteolysis on the plain radiographs or the helical CT scan. The other 23 hips had evidence of femoral osteolysis on the CT scans. In ceramic-ceramic hips, 15 hips had no evidence of pelvic osteolysis on the plain radiographs or the helical CT scan. The other 13 hips had evidence of pelvic osteolysis on the CT scans; three of them had evidence on plain radiographs as well, and the remaining 10 had no evidence on plain radiographs. Thirteen hips had no evidence of femoral osteolysis on the plain radiographs or the helical CT scan. The other 15 hips had evidence of femoral osteolysis on the CT scans, but also only two showed clear osteolysis on radiographs.

The diameter, surface, and volume of osteolysis were consistently higher in the side with alumina-PE couple (Table 1). The maximum mean diameter of the lesions seen

Table 1. Diameter, surface and volume of osteolysis measured with radiograph and CT scan

Measurement	Imaging	Hip	Mean (range)	P value
Maximum diameter (mm)	Radiograph (acetabulum)	PE-AL	25 (0–35)	0.02
		AL-AL	3 (0–10)	
	CT scan (acetabulum)	PE-AL	35 (0–45)	0.03
		AL-AL	11 (0–28)	
Surface (mm^2)	Radiograph (acetabulum + femur)	PE-AL	298 (0–516)	0.01
		AL-AL	25 (0–59)	
Volume (mm^3)	CT scan (acetabulum)	PE-AL	2970 (0–4258)	0.02
		AL-AL	650 (0–954)	
	CT scan (femur)	PE-AL	590 (0–1240)	0.02
		AL-AL	160 (0–245)	
	CT scan (acetabulum + femur)	PE-AL	3560 (0–5498)	0.02
		AL-AL	650 (0–1199)	

on the pelvis was greater with CT scan than with radiographs, was greater for the PE-alumina friction than for the AL/AL couple with a greater underestimation on radiographs for the AL-AL hips than for the AL-PE hips (Table 1). The AL/AL hips had less ($p = 0.02$) surface of osteolysis on the radiographs and less volume of osteolysis on CT scan than the AL/PE hips. The amount of volumetric bone loss did not correspond ($p = 0.3$) to the radiographic area of lysis. When evaluated on radiographs, the percentage of the mean surface of osteolysis of AL/AL hips represented 8% (25/298) of the surface of osteolysis measured on the PE hips (Table 1). When evaluated on the CT scan the percentage of the mean volume of osteolysis of the AL/AL hips was 18% (650/3560) and higher ($p = 0.02$) when compared with the volume of osteolysis measured on PE hips (Table 1). The radiographs of the AL-AL hips led to a greater underestimation of the surface of the osteolysis than did the measurement in volume with the CT scan.

The difference in osteolysis appeared related more to the difference of bearing surface than the volume of wear. Wear was always less with the AL/AL bearing surface than with PE cups. In PE-AL hips the average linear wear was 0.05 mm per year (range, 0.03–0.09 mm/year) and the average volumetric wear 1274 mm³ (range, 684–1984 mm³). The wear of the AL-AL hips were very significantly lower ($p < 0.001$), with a mean decentring of 13 μ m per year (range, 0.00–0.20 μ m/year) as linear wear for the head and the cup, and average 124 mm³ (range, 0–519 mm³) for the volumetric wear. But there was no correlation between the volume of osteolysis and the volume of wear: Four hips had PE wear despite the absence of osteolysis on the CT scan; six alumina hips had greater pelvic osteolysis than the minimum volume of osteolysis observed on PE hips; Patients with either no evidence of lysis or evidence visible only on the CT scan had similar ($p = 0.24$) penetration or wear in the PE group when compared with patients with lysis detected on both radiographs and the CT scan. As for the patients and the difference in bearing surface, four patients had no pelvic osteolysis on either side using a CT scan; nine patients had osteolysis visible only with a CT scan on the PE side and no osteolysis on the AL/AL side using a CT scan; 2 patients had osteolysis visible both on CT scan and radiographs on the PE side and no osteolysis on the AL/AL side using a CT scan; 8 patients had osteolysis visible both on CT scan and radiographs on the PE side and osteolysis only seen with CT scan on the AL/AL side; 5 patients had osteolysis visible both on CT scan and radiographs on the PE side and osteolysis on the AL/AL side both seen with CT scan and radiographs.

The average Harris hip score for the hips without osteolysis on CT scan was higher ($p = 0.04$) than those with negative radiographs and a positive CT scan, and also higher ($p = 0.03$) than those detected on both radiographs

and the CT scan (97 points, range, 90–98 points versus 94 points, range, 78–97 points versus 88 points, range, 66–98 points, respectively).

Discussion

The theoretical advantages of AL-AL bearings are related to a decrease of wear and osteolysis as compared with polyethylene. However, the comparison between alumina-on-alumina versus alumina-on-polyethylene has not been documented in the same patients. We therefore asked whether the number of lesions and the volume of osteolysis would be different on bilateral arthroplasties (one ceramic-ceramic and the contralateral ceramic-polyethylene). We also asked if the amount of wear observed in our series was relevant and representative of the other data in the literature.

Our study had several limitations such as sample size and selection criteria. We recognize our study population does not represent the general THA population because those patients selected for the CT were those who had already survived 20 years without revision and without loosening of either hip. We selected hips without loosening because in some circumstances it is difficult to evaluate the volume of bone destruction when loosening is associated with osteolysis. Initially, radiolucency forms at the bone-implant interface. As bone loosening occurs, the socket tends to migrate into the radiolucency and measurement of bone resorption is less accurate. Secondly, although we are certain bone defects identified on plain radiographs before THA do not represent osteolysis, we cannot be certain that all defects appearing on CT scans represent THA-induced osteolytic lesions. It is possible that some of the new lesions identified in our study represent preexisting lesions we were unable to identify on plain radiographs. Despite these limitations, this study allows us to make interesting remarks.

One of the goals of this study was to determine the prevalence of osteolysis in patients who had undergone total hip arthroplasty with AL/AL couple. The low incidence of osteolysis observed in this series on radiographs with AL-AL bearing surface is consistent with the results of other reports of AL/AL THA where osteolysis was only researched with radiographs. A low rate of osteolysis has been previously reported in a series of patients with a similar followup [12] and in other reports focusing on young and active patients [3, 11, 31, 32]. However with the CT scan, we were able to detect osteolysis more frequently than previously reported by these authors, but the number of lesions was less than with the PE-AL hip on the other side.

The CT scan also provided more accurate information than did standard radiographs in regard to the volume of

osteolysis. With AL/AL hip, the volume of osteolysis was always lower than with alumina-PE hip when the comparison was made on the same patient. We are not aware of other studies measuring the volume of osteolysis with a CT scan on patients with these bearing surfaces (AL-AL or PE-AL). An interesting observation is that, with these two different bearing surfaces, two lesions of a similar volume of bone loss on CT scan do not appear similarly on radiographs (in different patients). Osteolysis related to the AL-AL friction couple is more difficult to detect on radiographs. The debris particles that could be the cause of osteolysis in this series of AL-AL hips were only alumina or metal (coming from the neck of the stem). One of the questions is whether this difference is related to the volume of osteolysis or the radiographic density of alumina particles (or metal particles) that are present in bone osteolysis making the osteolysis invisible on radiographs, contrary to PE osteolysis where the PE particles are radiographically transparent so the osteolysis becomes visible. This may explain the different observations made on osteolysis with the ceramic-ceramic hips. Borssen et al. [5] described a patient who had severe osteolysis after a ceramic-on-ceramic total hip arthroplasty. Shih et al. [33] reported localized femoral osteolysis in eight (6%) of 134 hips at a mean of 9 years after a hip replacement with a ceramic prosthesis. Other reports suggest that using an AL/AL couple, a near absence of periprosthetic radiographic osteolysis could be expected [3, 12, 31, 32].

In this study we compared wear in PE and alumina implants in the same patients. Wear comparison between

the two bearing surfaces in vivo is difficult and perhaps impossible. There are several reasons for this. With the PE cup, the penetration of the ceramic head is related not only to wear but also to creep. The AL/PE friction couple causes debris only in relation with PE, because in this couple, there is no wear of the femoral head. Creep does not produce debris. However, creep of the PE may cause deformation of a thin layer of cement and may accelerate the passing of debris into the surrounding bone [29]. With an alumina cup there is no creep but it is not possible to distinguish on the radiographs the edge of the femoral head from the articulation surface of the acetabular component and wear is present both on the femoral head and on the cup. We therefore compared each friction couple to the other reports in the literature. There have been only a few studies on the in vivo wear of ceramic-on-polyethylene total hip replacements with a femoral head of 32 mm and with a long followup (Table 2). These have demonstrated a low wear rate even with this diameter of 32 mm, with some as low as 0.03 mm/yr. The average linear wear rate of 0.05 mm/yr in our study is low and consistent with the previously reported ceramic-on-polyethylene wear rates but, correspondingly, does not compare favorably with the wear rates of in vitro studies of AL-AL replacements.

For AL-AL bearing surfaces, most of the data concerning wear have been obtained in vitro on retrieved implants [19, 38] or with studies from a hip simulator. However, we do not know if these studies accurately reproduce what happens in vivo. This is because the wear seen on the femoral heads corresponds to edge wear on the acetabular component, which is different than normal surface-to-surface wear. The result is that wear patches on the femoral head vary somewhat in shape and depth, while edge loss for the acetabular component is difficult to characterize. We looked at the rate of wear of ceramic bearings whose bearing surfaces were made to the same specifications, principally by the same manufacturer (Cera-aver) and at the same period (20 years ago) (Table 3). Boutin and Blanquaert [8] reported a mean rate of wear of 9 μm per year for the femoral head and 6 μm per year for

Table 2. Comparison of similar studies measuring long term polyethylene wear from radiographs in PE/AL hips

Study	Followup (years)	Femoral head (diameter)	Penetration rate (mm/year)
Schuller and Marti [30]	10	32	0.03
Urban et al. [35]	20	32	0.03
Hernigou et al. [current study]	25	32	0.05

Table 3. Comparison of studies measuring wear on AL/AL hip

Study	Method	Cup	Wear head	Cup and head
Boutin and Blanquaert [8]	Retrieved implants (10 years)	6 $\mu\text{m}/\text{year}$	9 $\mu\text{m}/\text{year}$	
Walter [36]	Simulator			6 $\mu\text{m}/\text{million cycles}$
Bos et al. [6]	Retrieved implants (10 years)	5 $\mu\text{m}/\text{year}$	5 $\mu\text{m}/\text{year}$	
Refior et al. [28]	Simulator			1 $\mu\text{m}/\text{million cycles}$
Nevelos et al. [26]	Retrieved implants (10 years)	5 $\mu\text{m}/\text{year}$	5 $\mu\text{m}/\text{year}$	
Lusty et al. [22]	Retrieved implants (2 years)	0.04 mm^3/year	0.1 mm^3/year	
Hernigou et al. [current study]	Retrieved implants (20 years)	5 $\mu\text{m}/\text{year}$	5 $\mu\text{m}/\text{year}$	
	Radiograph measurement			12 $\mu\text{m}/\text{year}$

the acetabular socket with use of the same ceramic-on-ceramic bearing surface as reported in this series. Nevelos et al. [26] reported the same results for hips implanted by Sedel et al. [31] with the same followup. In our series, with the radiographic technique of evaluation, the decentring of the femoral head in AL-AL hips ranged between 0 and 20 μm per year (average 13 μm per year). This correlated to an amount of wear rate of 5 μm per year on the head and on the cup after analysis of five implants (none included in this series). Of course, such a radiographic technique can only be used on hips with a very long followup to allow measurement of decentring. With modern ceramics (provided by Ceraver or other manufacturers [28]), it may be impossible to evaluate wear on radiographs, according to the very low rates observed on simulators.

In conclusion, the first generation of alumina used in our series of patients was an option to achieve a low level of wear rate and osteolysis. Our study supports the continued use of these bearings. The difference in osteolysis appeared related more to the difference of bearing surface than the volume of wear. Our data indicate radiographs underestimate the extent of osteolysis and computed tomography is an interesting method for the comparison of osteolysis between two different bearing surfaces, particularly when wear and creep are difficult to evaluate on radiographs.

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