Ceramic Bearings for Total Hip Arthroplasty Have High Survivorship at 10 Years

James A. D'Antonio MD, William N. Capello MD,
Marybeth Naughton BS

Published online: 15 September 2011
© The Association of Bone and Joint Surgeons® 2011

Abstract

Background Ceramic bearings were introduced to reduce wear and increase long-term survivorship of total hip arthroplasty. In a previous study comparing ceramic with metal-on-polyethylene at 5 to 8 years, we found higher survivorship and no osteolysis for the ceramic bearings.

Questions/Purposes We asked whether ceramic bearings have equal or superior survivorship compared with that for metal-on-polyethylene at longer followup; we also determined survivorship of the implant systems, the presence or absence of radiographic osteolysis, and incidence of device squeaking.

Two authors certify that they (JAD, WNC) have or may receive payments or benefits, in any 1 year, an amount in excess of \$10,000 from a commercial entity (Stryker Orthopaedics) related to this work; two authors certify that they (JAD, WNC) have stock in Stryker Orthopaedics.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent was obtained.

This work was performed at Sewickley Valley Hospital Sewickley, PA, USA; Indiana University School of Medicine, Indianapolis, IN, USA; and Stryker Orthopaedics, Mahwah, NJ, USA.

J. A. D'Antonio (✉)
Greater Pittsburgh Orthopaedics Association, 725 Cherrington
Parkway, Suite 200, Moon Township, PA 15108, USA
e-mail: dantonioja@me.com

W. N. Capello
Indiana University School of Medicine, Indianapolis, IN, USA

M. Naughton
Stryker Orthopaedics, Mahwah, NJ, USA

Methods Five surgeons at five sites have followed 189 patients (216 hips) for a minimum of 10 years and average of 10.3 years (range, 10–12.4 years) comparing alumina ceramic bearings (144 hips) with cobalt chrome-on-polyethylene bearings (72 hips). We determined Kaplan-Meier survivorship of the bearing surface and implant systems and collected radiographic and clinical data.

Results We observed no difference between the control metal-on-polyethylene and the alumina-bearing couple cohorts with regard to bearing-related failures (98.9% versus 99.1%). Revisions for any reason occurred in 10.5% of the control patients and 3.1% of the patients with alumina bearings. All femoral implants remain well fixed (100%), whereas one acetabular component (1%) is unstable in the control group. Osteolysis occurred in 26% of the control patients and in none of the patients with alumina bearings. Squeaking occurred in two of 144 hips (1.4%) of the patients with ceramic bearings.

Conclusions Patients receiving the ceramic-on-ceramic bearings had fewer revisions for any reason and less osteolysis than the control metal-on-polyethylene at 10 years. Our data suggest ceramic bearings continue to provide an option for the young and more active patient and provide for a measure to compare other new alternative bearings that are currently available.

Level of Evidence Level I, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

THA over the past four decades has evolved to provide for pain relief and improved quality of life for a high percentage of patients. Although the incidence of infection

and prosthetic loosening has decreased with improved surgical technique and implant design, polyethylene wear debris and osteolysis became a major limitation to prosthetic survivorship [12, 18, 24]. The extent of osteolysis has been linked to wear rate, which is affected by patient use [12, 36]. The foremost unresolved challenge has been the development of bearing surfaces that can withstand the higher demands of younger and more active patients and a population with greater longevity. New alternative bearings with greater wear resistance have been developed with the promise to reduce wear debris and extend implant longevity [8, 11]. These new low-wear bearings, which include highly cross-linked polyethylenes, metal on metal, and ceramic on ceramic, now have minimum 5-year results and have high survivorship [3, 4, 8, 9, 14, 31].

We previously published the 5- and 8-year results of this prospective randomized study comparing ceramic-on-ceramic bearing implants with metal-on-conventional polyethylene to determine whether the two bearings were at least equivalent in their performance [3, 8]. At 5 years, we reported equivalent Harris hip scores (96% versus 97%) but less osteolysis (1.5% versus 14%) and fewer revisions (2.7% versus 7.5%) in the ceramic cohorts. At 8 years, we reported higher survivorship for patients with ceramic bearings, a lower incidence of osteolysis, one ceramic fracture, and squeaking in three patients (1.5%).

At a minimum followup of 10 years, our primary objective was to confirm whether ceramic bearings are equal or superior to metal-on-polyethylene based on bearing survivorship. Our secondary objectives were the survivorship of implant systems, radiographic presence of osteolysis, and device squeaking.

Patients and Methods

In October 1996, a US Investigational Device Exemption, randomized, controlled noninferiority trial began comparing alumina-bearing couples with a chrome cobalt-on-polyethylene control system. The implant system design and study protocol have been reported [8]. Although all patients received the same femoral stem (Omnifit HA; Stryker Orthopaedics, Mahwah, NJ), there was a randomized one-third chance of receiving one of the three cup designs, two of which had an alumina-on-alumina bearing surface (System I or System II) and one the control (System III) (Fig. 1). The control polyethylene was gamma-sterilized in an inert atmosphere and was not highly cross-linked. Femoral head diameter for the ceramic cohorts was dictated by shell size and 89% were 32 mm or greater (Table 1). Head diameter for the polyethylene controls was left to the discretion of the surgeon and 90% were 28 mm in diameter.

Fig. 1 The cementless components used in the ABC clinical study are shown. System I is a titanium porous-coated acetabular shell, with an alumina ceramic insert and an alumina ceramic femoral head. System II is a titanium arc-deposited, HA-coated acetabular shell, with an alumina ceramic acetabular insert and an alumina ceramic femoral head. The control system (denoted as System III) includes a titanium porous-coated acetabular shell, with a polyethylene acetabular insert and a cobalt-chrome femoral head.

Table 1. Comparison of femoral head size for the three study groups

Head size (mm)	ABC System I	ABC System II	CoCr System III
26	NA	NA	5.5%
28	11.0%	8.6%	90.3%
32	89.0%	91.4%	4.2%

NA = not available.

Five surgeons at five sites enrolled 253 patients (289 hips) and have followed 189 patients (216 hips) for a minimum of 10 years and average of 10.3 years. Before the 10-year anniversary, nine patients (11 hips) have died, 11 patients (11 hips) have been revised, and 44 patients (51 hips) withdrew and were lost to followup (LTF) between 5 and 10 years. Of those LTF, 20 patients (22 hips) opted out of continuing in the study at maximum 5 years and the latest evaluations for the remaining 24 patients (29 hips) occurred at 6 years for six hips; seven years for four hips; 8 years for three hips; and 9 years for 16 hips. There were 16 hips from System I, 20 hips from System II, and 15 hips from System III that were not included in the 10-year cohort. Statistical analysis showed no difference in distribution of demographics of LTF by study group compared with the minimum 10-year cohorts (diagnosis, gender, weight, height, body mass index) (Table 2).

Kaplan-Meier (K-M) survivorship [25] was determined for bearing surface failure (fracture, revision for wear/osteolysis, locking mechanism failure), and end point revision for any reason.

The postoperative radiographs were assessed for standard parameters for cementless implants as recommended by the Hip Society [23] and reviewed by one orthopaedic surgeon (PB) who was not part of the study group. Hips were evaluated radiographically for radiolucent lines and osteolysis in acetabular component zones as described by DeLee and Charnley [10] and in all femoral Gruen

Table 2. Demographics for lost to followup

Demographic	In-study	Lost to followup	p
Number of hips	238	51	
Study group distribution	79:79:80	20:16:15	0.719
Gender (male/female)	156/82	30/21	0.421
Mean age (years) (range)	54.2 (21–75)	53.1 (30–73)	0.416
Height (inches) (range)	68.9 (59–78)	68.1 (60–81)	0.09
Weight (lbs) (range)	189.2 (93–305)	186.9 (118–359)	0.356
Body mass index (kg/m ²) (range)	27.9 (14–46)	28.2 (21–45)	0.834
Diagnosis (AVN, OA, TA)	31:200:7	13:37:1	0.081

In-study = subjects with 10-year followup, were revised, or died; AVN = avascular necrosis; OA = osteoarthritis; TA = traumatic arthritis.

zones [15] on AP and mediolateral radiographs. Implant stability was evaluated according to criteria described by Engh et al. [13]. Radiolucent line was defined as a lucent area in close proximity to the implant encompassing at least 50% of the zone and at least 1 mm in width. Implant migration was defined as prosthetic migration from fixed bony landmarks measured in 0.5-mm increments at each evaluation interval. Osteolysis was recorded for a specific area of bone loss (scalloping) without the presence of a reactive line for all implant zones.

Clinical data and radiographs were collected preoperatively, early postoperatively (at 6–8 weeks), and at every followup thereafter. A composite Harris hip score (HHS) was calculated [17] at each visit. History of squeaking, although not part of the original protocol, was recorded at last followup.

Baseline characteristics were summarized and compared among groups using Wilcoxon rank sum test for continuous data or Fisher's exact test for discrete data. Mean HHS scores preoperatively and 10 years postoperatively were summarized and compared using one-way analysis of variance. Survival probability was estimated using the K-M method. The log rank test was used to test for differences of survival distribution function among three groups. When log rank test indicated there was a statistical difference ($p < 0.05$) in survival distribution function among groups, a Cox proportional hazards model was then used to compare survival among the three groups. Hazard ratios of System I and System II were displayed with System III as a reference. A hazard ratio (HR) of 1 would indicate no difference in risk, whereas a HR less than 1 indicates a lower risk. We performed a worse-case scenario K-M treating all patients lost to followup as failed. SAS software Version 9.2 (SAS Institute, Cary, NC) was used for all data analyses.

Results

K-M survivorship for bearing-related revisions at 10 years postoperatively was similar ($p = 0.152$) for all three systems:

Fig. 2 The K-M survivorship with the end point bearing surface revision is no different for the three study groups at 10 years followup: System I, 100%; System II, 98.6% (90.8%–99.8%); and System III, 98.9% (92.3%–99.8%) (log rank test $p = 0.152$).

System I was 100%, System II 98.6% (90.8%–99.8%), and System III 98.9% (92.3%–99.8%) (Fig. 2). The K-M survivorship at 10 years assuming all patients lost to followup showed no difference ($p = 0.951$) among three cohorts (Fig. 3). We revised one acetabular insert revision in ABC System II at 9.2 years as a result of a fractured ceramic insert. The patient was a 50-year-old woman at surgery with a body mass index of 23.2 kg/m², an acetabular shell with 52-mm outer diameter, 32-mm insert (4-mm ceramic thickness), and acetabular cup inclination of 31°. There were three bearing-related revisions in ABC System III for osteolysis occurring at 4, 10.4, and 11 years after surgery.

K-M survivorship revision for any reason at 10 years postoperatively was similar ($p = 0.027$) for all systems: System I was 97.9% (91.9%–99.5%), System II 95.2% (87.8%–98.2%), and System III 91.3% (83.4%–95.6%) (Fig. 4). In the analysis with System I and System II as independent categorical variables and System III as the reference group to test the HR (relative risk of revision), we found the HR (95% confidence interval) for System I was 0.183 (0.040–0.834) and for System II was 0.394 (0.124–1.257) compared with the control System III

Fig. 3 The K-M survivorship of the bearings, assuming lost to followup were revised, shows no statistical differences among the three groups ($p = 0.951$).

Fig. 4 The K-M survivorship with the end point revision for any reason is significantly different for the three study groups at 10 years followup: System I, 97.9% (91.9%–99.5%); System II, 95.2% (87.8%–98.3%); and System III, 91.3% (83.4%–95.6%) (log rank test $p = 0.027$).

confirming the lower risk for revision for each ceramic cohort. The K-M survivorship (at 10 years) was repeated assuming that all patients lost to followup were revised to test the statistical difference under worst-case conditions and no statistical difference between study cohorts (log rank test $p = 0.617$) was found (Fig. 5).

Six revisions for the 194 implanted hips in the ceramic-on-ceramic Systems I and II were performed (3.1%): two femurs with periprosthetic fracture and subsidence; one socket for recurrent dislocations at 5 years; two for deep joint infection; and one liner for fracture that occurred at 9 years postoperatively. Ten revisions (10.5%) for the control patients (95 hips) included one femur for periprosthetic fracture and one for leg length discrepancy; three acetabular revisions for recurrent dislocations; three for osteolysis; and two cases for deep joint infection (Table 3). In addition, three intraoperative ceramic chips that required intraoperative exchange of the acetabular component occurred at the time of surgery without any subsequent complications.

Fig. 5 The K-M survivorship end point revision for any reason, assuming all lost to followup were revised, shows no statistical differences among the three study groups ($p = 0.617$).

Table 3. Component revisions for original population

Revisions	System I (99 hips)	System II (95 hips)	Control System III (95 hips)	Statistical significance (log rank test)
Acetabular	0	0	3 (3.0%)	0.0695
Femoral	1 (1.0%)	1 (1.1%)	2 (2.1%)	0.8462
Insert/head	0	2 (2.1%)	5 (5.3%)	0.0356
Revision all	1 (1.0%)	1 (1.1%)	0	1.000
Total (revision of any component)	2	4	10	0.0361

All three groups had radiographically stable femoral implants and one acetabular component was unstable (Table 4). Femoral osteolysis in Gruen Zone 1, 7, 8, or 14 was noted in 26% of patients who received the control and in none of the patients who received ceramic Systems I or II ($p < 0.001$). Acetabular osteolysis occurred in 3.5% of controls and in 0% of the ceramic cohorts ($p = 0.105$). Radiolucencies were more commonly found about the microstructured titanium cups ($p = 0.001$) (Table 4).

Mean HHSs in all three groups showed a marked improvement from preoperative status to last followup (Table 5). Squeaking has occurred in two patients (1%); a 66-year-old woman (System I) first noted noise at 6 years with hyperflexion and a 44-year-old man first noted the noise at 5 years. Neither patient can reproduce the squeaking, and the noise is of no clinical importance for these patients.

Discussion

Ceramic bearings were introduced to reduce wear and increase long-term survivorship. Our current study is the

Table 4. Summary of radiographic results at 10 years

Parameter	System I 57	System II 59	System III 56	p
Femoral				
Unstable stem	0	0	0	
Osteolysis proximal femur	0	0	14 (25.5%)	< 0.001
Stem subsidence	0	0	0	
Acetabular				
Cup inclination, mean (range; SD)	48.34 (32–61; $\pm$ 6.7)	49.51 (34–69; $\pm$ 6.80)	47.52 (26–64; $\pm$ 7.2)	0.2487
RL Zone 1	6 (10.5%)	0	4 (7.1%)	0.0238
RL Zone 2	0	0	6 (10.7%)	< 0.001
RL Zone 3	3 (5.3%)	0	3 (5.4%)	0.1926
RL any zone	8 (14.0%)*	0	11 (19.6%)*	< 0.001
Acetabular osteolysis	0	0	2 (3.6%)	0.1047
Unstable cup	0	0	1 (1.8%)	0.3256
Heterotopic ossification $\geq$ Brooker 3	4 (7.1%)	2 (3.4%)	2 (3.6%)	0.6641

* One shell had RL in two zones; RL = radiolucent line.

Table 5. Demographics, clinical performance, less than 10-year followup, and complications

Parameter	ABC System I	ABC System II	Control	p
Demographics				
Number of hips	73	71	72	
Male/female (%)	67:33	72:28	60:40	0.3150
Mean age (years) (range; SD)	54.9 (30–73; $\pm$ 10.86)	54.8 (26–75; $\pm$ 9.8)	53.5 (26–75; $\pm$ 10.18)	0.4398
Mean weight (lbs) (range; SD)	188.6 (93–300; $\pm$ 35.9)	192.4 (93–305; $\pm$ 38.2)	185.4 (99–260; $\pm$ 37.7)	0.7413
Mean height (inches) (range; SD)	69.0 (61–75.3; $\pm$ 3.5)	69.3 (60–76; $\pm$ 3.9)	68.5 (59–75; $\pm$ 3.9)	0.5785
Mean body mass index (kg/m ²) (range; SD)	27.7 (14.2–37.8; $\pm$ 4.1)	28.1 (21.3–46.3; $\pm$ 4.7)	27.7 (18.1–41.7; $\pm$ 5.1)	0.7203
Length of followup	10.3	10.3	10.3	0.4178
Diagnosis	97% OA, 3% AVN	79% OA, 18% AVN, 3% PTA	78% OA, 18% AVN, 4% PTA	0.0014
Clinical performance				
Mean preoperative HHS (range; SD)	50.65 (26.95–78.03; $\pm$ 11.4)	47.86 (28.85–75.23; $\pm$ 10.7)	49.83 (21.35–87.25; $\pm$ 12.6)	0.3741
Mean 10-year HHS (range; SD)	96.80 (48.95–100; $\pm$ 8.0)	96.17 (74–100; $\pm$ 5.9)	96.49 (74.0–100; $\pm$ 5.6)	0.8730
Less than 10-year followup				
Lost to followup	20	16	15	
Died	4	5	2	
Revised before 10 years	2	3	6	
Total	99	95	95	
Complications for total population				
Dislocations	2 (2.0%)	1 (1.1%)	7 (7.4%)	0.0731
Postoperative insert fracture	0	1 (1.1%)	0	0.6574
Intraoperative insert chip	2 (2.0%)	1 (1.1%)	0	0.7756
Squeaking	1 (1.0%)	1 (1.1%)	0	1.0000

HHS = Harris hip score; OA = osteoarthritis; AVN = avascular necrosis; PTA = posttraumatic arthritis.

only prospective randomized and controlled study with minimum 10-year followup comparing the survivorship of ceramic-on-ceramic with metal-on-polyethylene bearings. We previously reported equivalent HHSs but fewer

revisions and less osteolysis comparing ceramic with the control polyethylene bearing [3, 8]. Our primary purpose was to confirm whether ceramic bearings were equal or superior to metal-on-polyethylene based on bearing

Table 6. Comparison of ceramic bearing study results to recent reports on third-generation ceramic implant systems

Citation	Number of hips/patients	Mean followup (years)	Survivorship revision any reason	Survivorship aseptic revision	Survivorship bearing-related failures	Osteolysis/wear	Squeaking
Kress et al. [26]	75 hips/71 patients	10.5	97% at 10 years	99%	100%	1%	NR
Lewis et al. [28]	56 hips/55 patients	8.1	96%	100%	100%	0% C/C = 0.02 mm/year M/P = 0.11 mm/year	0%
Chevillotte et al. [5]	100 hips/92 patients	8.8	96%	98%	NR	0%	6%
Park et al. [33]	112 hips/100 patients	9.6	95%	99%	98%	NR	0%
Lee et al. [27]	88 hips/74 patients	10.9	99%	100%	99%	0%	1%
Murphy et al. [32]	194 hips/173 patients	4.3	96%	99.5%	97%	0%	0%
Lusty et al. [29]	301 hips/283 patients	6.5	96%	99%	NR	0.4%	0.3%
Current study	216 hips/207 patients	10.3	Alumina I: 97.9%; Alumina II: 95.2%; Control: 91.3%	Alumina: 99%; Control: 99%	Alumina I: 100%; Alumina II: 99%; Control: 99%	0% ceramic 25.5% control ($p < 0.001$)	1%

NR = not reported; C/C = ceramic-on-ceramic; M/P = metal-on-polyethylene.

survivorship and our secondary objectives were survivorship of implant systems, radiographic absence of osteolysis, and device squeaking.

Our study has some limitations. First, 44 patients (51 hips [16%]) withdrew before the 10-year anniversary. We have accounted for these patients in the survival analysis by considering them as failures. The possibility that all patients lost to followup were revised is unlikely because at last followup, all were doing well with intact implants. Statistical analysis showed no difference in distribution of patients lost by study group compared with the 10-year cohort indicating that the 10-year patient cohort was representative of the study population. Noninferiority to the control was maintained when looking at revision for bearing failure and at revision for any reason, previously identified as superior for the ceramic group, confirming at least equivalence of the bearing surfaces. Second, we had a single unblinded observer evaluating the radiographs and the evaluation for osteolysis and implant fixation are prone to intraobserver variability. We believe, however, that there is consistency in a single reviewer over a long-term study with an experienced orthopaedic surgeon. Third, 90% of the control subjects had a 28-mm head diameter compared with 11% of the ceramic cohorts. The use of smaller head sizes for the control patients may have influenced the higher dislocation and revision rate for the control patients and is consistent with a report in the literature [1]. However, the use of a 32-mm head size with conventional polyethylene might have resulted in more wear, osteolysis,

and a higher revision rate [12, 18]. Finally, the five surgeons in this study were experienced with the implant systems used and the results may not be similar to a wider, less-experienced surgeon population.

We found the survival of implants with ceramic bearings to be similar to those of other reports in the literature of third-generation ceramic-on-ceramic bearings [5, 26–29, 32, 33] (Table 6). In our study, the survivorship of ceramic bearings (System I 100%, System II 99%) was no different than the control (99%) at 10 years and is similar to ceramic bearing survivorship reported in studies with 4- to 10-year followup. Murphy et al. [32] and Park et al. [33] reported 97% and 98% survivorship; and Lee et al. [27], Kress et al. [26] 99%, and Lewis et al. [28] 100% ceramic bearing survivorship. In our study, there have been no ceramic bearing failures beyond 10 years for either ceramic study group and no pending revisions. However, two additional hips from the control group were revised for osteolysis.

Survivorship of implants in our study with regard to aseptic loosening aseptic is 99% for all three study cohorts (ceramic and controls). This high survivorship of the implants is similar to those of other studies using ceramic bearings with contemporary implant systems [5, 26–29, 32, 33]. Lusty et al. and Park et al. have reported 99% survivorship out to 9.6 years [29, 33] and Lee et al. have reported 100% survivorship at 10.9 years [27].

There is one unstable shell in the control group at 10 years in a patient who has evidence of acetabular osteolysis in Zones 1 and 2 and a radiolucent line of 3 mm

in width in Zone 3. There are no unstable shells or pending failures in the ceramic group at 10 years.

Alumina-ceramic bearings have a history of problems with neck/socket impingement, a potential for fracture, and aseptic loosening [2, 16, 21, 30, 37]. Considering survivorship revision for any reason, our ceramic cohorts had a survivorship of 95% and 98% and is similar to those of recent publications and may reflect improvements in implant design and the material properties of the ceramic [7, 20]. Overall survivorship in recent reports ranges from 95% [33] to 99% [27]. However, the 91% survivorship of our control group was lower with instability (3%) and osteolysis (3%) representing the most common reasons for revision (Fig. 4). The use of smaller head sizes for the control patients may have played a role in the dislocation and revision rate and is consistent with a report in the literature [1]. Periprosthetic osteolysis with conventional polyethylene is reportedly the most common reason for revision surgery with a revision rate as high as 12% at 10 years [18, 19]. A recent report using a highly cross-linked polyethylene followed for 10 years showed no evidence of osteolysis [4]. In our study, at minimum 10 years, radiographic evidence for osteolysis is present in 26% of the control patients with only 3% being revised (Fig. 6A–B) and absent in the ceramic cohorts (Fig. 7). The low incidence of osteolysis in our patients with ceramic bearings is similar to recent reports [26–29, 32, 33]. Chevoillotte et al. found no osteolysis at 8.8 years, whereas Kress et al. reported 1% at 10.5 years [5, 26] (Table 6).

Cox regression analysis with System I and System II as independent categorical variables and System III as the reference group indicated a lower rate of revision for the ceramic groups as compared with the control group when all revisions were considered. In the worst-case analysis for revision for any reason based on assumption that all patients lost to followup were revised, the risk of revision for the ceramic groups is no longer lower than for the control metal/polyethylene group indicating at least comparable results for revision for any reason for the three study groups (Fig. 5).

The etiology of squeaking is believed to be multifactorial and related to patient age and size, surgical technique and implant position, stem design, and metallurgy [6, 22, 29, 34, 35, 38]. The incidence of squeaking in this ceramic study group is 1% and similar to recent reports [5, 26–28, 32, 33]. Chevoillotte et al. [5] reported a 6% incidence of squeaking, whereas Park et al. [33] at 9.6 years and Lewis et al. [28] at 8 years reported 0%. The low incidence in our study is believed to be related to the more rigid stem design and metallurgy used in our ceramic cohorts. This is supported by literature reports of a lower incidence of squeaking comparing stems with the same design and metallurgy with more flexible designs [22, 35, 38]. In both

Fig. 6A–B (A) A 6-week postoperative radiograph of the hip of a 38-year-old woman with a control polyethylene bearing is shown. (B) A 4-year radiograph shows osteolysis in Zones 1, 7, and greater trochanter.

Fig. 7 The patient was 48 years old at the time of implantation. His 12-year postoperative radiograph shows no osteolysis of the ceramic-ceramic bearing.

of the ceramic cohorts (Systems I and II), squeaking has not been a cause of disability, patient dissatisfaction, or need for revision.

Our observations support continued use of ceramic-on-ceramic bearings and provides a level of success at minimum 10 years followup for alternative bearings to compare. Continued clinical followup over the next decade will further measure the value of the hard-on-hard ceramic bearings for THA.

Acknowledgments We thank the investigators who continue to follow our patients in the original ABC study: Benjamin E. Bierbaum, MD, New England Baptist Hospital (Boston, MA); James R. Roberson, MD, Emory Sports Medicine & Spine Center (Decatur, GA); and Robert Zann, MD, Boca Raton Hospital (Boca Raton, FL). We also thank the following individuals for their assistance: Peter Bonutti, MD, Bonutti Clinic, Effingham, IL; the independent radiographic reviewer for the study; and Jianhua Shen MS (Stryker, Mahwah, NJ), for performing the statistical analysis.

References

- Berry DJ, von Knoch M, Schleck CD, Harmsen WS. Effect of femoral head diameter and operative approach on risk of dislocation after primary total hip arthroplasty. *J Bone Joint Surg Am*. 2005;87:2456–2463.
- Boehler M, Knahr K, Plenk HJ Jr, Walter A, Salzer M, Schreiber V. Long-term results of uncemented alumina acetabular implants. *J Bone Joint Surg Br*. 1994;76:53–59.
- Capello WN, D'Antonio JA, Feinberg JR, Manley MT, Naughton M. Ceramic-on-ceramic total hip arthroplasty. *J Arthroplasty*. 2008;23(Suppl 1):39–43.
- Capello WN, D'Antonio JA, Ramakrishnan R, Naughton M. Continued improved wear with an annealed highly cross-linked polyethylene. *Clin Orthop Relat Res*. 2011;469:825–830.
- Chevillotte C, Pibarot V, Carret JP, Bejui-Hugues J, Guyen O. Nine years follow-up of 100 ceramic-on-ceramic total hip arthroplasty. *Int Orthop*. 2010 Dec 21 [Epub ahead of print].
- Chevillotte C, Trousdale RT, Chen Q, Guyen O, An KN. The 2009 Frank Stinchfield Award: 'Hip squeaking': a biomechanical study of ceramic-on-ceramic bearing surfaces. *Clin Orthop Relat Res*. 2010;468:345–350.
- Clarke IC. Role of ceramic implants: design and clinical success with total hip prosthetic ceramic-to-ceramic bearings. *Clin Orthop Relat Res*. 1992;282:19–30.
- D'Antonio JA, Capello WN, Manley MT, Naughton M, Sutton K. Alumina ceramic bearings for total hip arthroplasty: five-year results of a prospective randomized study. *Clin Orthop Relat Res*. 2005;436:164–171.
- D'Antonio JA, Manley MT, Capello WN, Bierbaum B, Ramakrishnan R, Naughton M, Sutton K. Five-year experience with Crossfire highly crosslinked polyethylene. *Clin Orthop Relat Res*. 2005;441:143–150.
- DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res*. 1976; 121:20–32.
- Dumbleton JH, D'Antonio JA, Manley MT, Capello WN, Wang A. The basis for a second-generation highly cross-linked UHMWPE. *Clin Orthop Relat Res*. 2006;453:265–271.
- Dumbleton JH, Manley MT, Edidin AA. A literature review of the association between wear rate and osteolysis in total hip arthroplasty. *J Arthroplasty*. 2002;17:649–661.
- Engh CA, Massin P, Suthers KE. Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. *Clin Orthop Relat Res*. 1990;257:107–128.
- Girard J, Bocquet D, Autissier G, Fouilleron N, Fron D, Migaud H. Metal-on-metal hip arthroplasty in patients thirty years of age or younger. *J Bone Joint Surg Am*. 2010;92:2419–2426.
- 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.
- Hannouche D, Nich C, Bizot P, Meunier A, Nizard R, Sedel L. Fractures of ceramic bearings. *Clin Orthop Relat Res*. 2003;417:19–26.
- Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fracture: treatment by mold arthroplasty: an end-result study using a new method of result evaluation. *J Bone Joint Surg Am*. 1969;51:737–755.
- Harris WH. Wear and periprosthetic osteolysis. *Clin Orthop Relat Res*. 2001;393:66–70.
- Hellman EJ, Capello WN, Feinberg JR. Omnifit cementless total hip arthroplasty: a 10 year average follow-up. *Clin Orthop Relat Res*. 1999;364:164–174.
- Heros RJ, Willmann G. Ceramics in total hip arthroplasty: history, mechanical properties, clinical results, and current manufacturing state of the art. *Semin Arthroplasty*. 1998;9:114–122.
- Holmer P, Nielsen PT. Fracture of ceramic femoral heads in total hip arthroplasty. *J Arthroplasty*. 1993;8:567–571.
- Jarrett CA, Ranawat AS, Bruzzone M, Blum YC, Rodriguez JA, Ranawat CS. The squeaking hip: a phenomenon of ceramic-on-ceramic total hip arthroplasty. *J Bone Joint Surg Am*. 2009;91:1344–1349.
- Johnston RC, Fitzgerald JR, Harris WH, Muller ME, Sledge CB. Clinical and radiographic evaluation of cementless THA. *J Bone Joint Surg Am*. 1990;72:162–168.
- Kabo JM, Gebhard JS, Loren G, Amstutz HC. In vivo wear of polyethylene acetabular components. *J Bone Joint Surg Br*. 1993;75:254–258.
- Kaplan EL, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc*. 1958;53:457–481.
- Kress AM, Schmidt R, Holzwarth U, Forst R, Mueller LA. Excellent results with cementless total hip arthroplasty and alumina-on-alumina pairing: minimum ten-year follow-up. *Int Orthop*. 2011;35:195–200.
- Lee YK, Ha YC, Yoo JJ, Koo KH, Toon KS, Kim HJ. Alumina-on-alumina total hip arthroplasty at minimum 10 year follow-up. *J Bone Joint Surg Am*. 2010;92:1715–1718.
- Lewis PM, Al-Belooshi A, Olsen M, Schemm EH, Waddell JP. Prospective randomized trial comparing alumina ceramic-on-ceramic with ceramic-on-conventional polyethylene bearings in total hip arthroplasty. *J Arthroplasty*. 2010;25:392–397.
- Lusty PK, Tai CC, Sew-Hoy RP, Walter WL, Walter WK, Zicat BA. Third-generation alumina-on-alumina ceramic bearings in cementless total hip arthroplasty. *J Bone Joint Surg Am*. 2007; 89:2676.
- Mahoney OM, Dimon JH. Unsatisfactory results with a ceramic total hip prosthesis. *J Bone Joint Surg Am*. 1990;72:663–671.
- McCalden RW, MacDonald SJ, Rorabeck CH, Bourne RB, Chess DG, Charron KD. Wear rate of highly cross-linked polyethylene in total hip arthroplasty: a randomized controlled trial. *J Bone Joint Surg Am*. 2010;91:773–782.
- Murphy SB, Ecker TM, Tannast M. Two- to 9-year clinical results of alumina ceramic-on-ceramic THA. *Clin Orthop Relat Res*. 2006;453:97–102.
- Park YS, Park SJ, Lim SJ. Ten-year results after cementless THA with sandwich-type alumina ceramic bearing. *Orthopedics*. 2010;33:796.

34. Restrepo C, Matar WY, Parvizi J, Rothman RH, Hozack WJ. Natural history of squeaking after total hip arthroplasty. *Clin Orthop Relat Res.* 2010;468:2340–2345.
35. Restrepo C, Post ZD, Kai B, Hozack WJ. The effect of stem design on the prevalence of squeaking following ceramic-on-ceramic bearing total hip arthroplasty. *J Bone Joint Surg Am.* 2010;92:550–557.
36. Schmalzried TP, Huk OL. Patient factors and wear in total hip arthroplasty. *Clin Orthop Relat Res.* 2004;418:94–97.
37. Sedel L. Evolution of alumina-on-alumina implants. *Clin Orthop Relat Res.* 2000;379:48–54.
38. Walter WL, O'Toole GC, Walter WK, Ellis A, Zicat BA. Squeaking in ceramic-on-ceramic hips: the importance of acetabular component orientation. *J Arthroplasty.* 2007;22:496–503.