Clin Orthop Relat Res (2014) 472:630–636
DOI 10.1007/s11999-013-3187-0

Clinical Orthopaedics and Related Research®
A Publication of The Association of Bone and Joint Surgeons®

SYMPOSIUM: 2013 HIP SOCIETY PROCEEDINGS

Durable Fixation Achieved With Medialized, High Hip Center Cementless THAs for Crowe II and III Dysplasia

Danyal H. Nawabi MD, Morteza Meftah MD, Denis Nam MD, Amar S. Ranawat MD, Chitranjan S. Ranawat MD

Published online: 25 July 2013

Abstract

Background A high hip center total hip arthroplasty (THA) for dysplasia allows more complete socket coverage by native bone at the expense of abnormal hip biomechanics. Despite poor results with cemented components, intermediate-term results with cementless cups at a high hip center have been promising, but there are few reports at long-term followup without bone graft.

Questions/purposes The purpose of this study was to examine (1) survivorship; 2) radiographic results; and 3) hip scores at a minimum of 10 years for patients treated with high hip center cementless THA for Crowe II and III dysplasia without bone graft.

Methods We reviewed charts and radiographs of 32 patients with Crowe II or III dysplasia who were treated with high hip center cementless THA; at a mean followup of 12 years (range, 10–21 years), 23 patients (27 hips) were available for review. We sought to medialize cups to the inner table to achieve bony coverage of $> 75\%$. At final followup, the WOMAC and Harris hip scores were recorded. Radiographic analysis including computerized wear evaluation was performed. Radiographic parameters were compared with a control group of 23 patients with Crowe I dysplasia who had cementless cups placed at an anatomic hip center; among the high hip center reconstructions, we also compared wear between those in the superolateral and superomedial quadrants.

Results Kaplan-Meier survivorship for all-cause revisions was 97% (95% confidence interval, 79%–99%) in the high hip center group; this was no different from the anatomic hip center group. There were no revisions for acetabular loosening. Wear rates did not differ significantly between the high hip center and the control group, but lateralized high hip centers were associated with higher ($p = 0.002$) wear. Hip scores were excellent in both groups.

Conclusions In Crowe II and III dysplasia, a high hip center cementless cup obviates the need for bone graft and provides durable fixation beyond 10 years. Medialization of these reconstructions seems important to decrease wear.

Level of Evidence Level III, therapeutic study. See Instructions for Authors for a complete description of levels of evidence.

One of the authors certifies that he (ASR) or she, or a member of his or her immediate family, has or may receive payments or benefits, during the study period, an amount of less than USD 10,000 from DePuy (Warsaw, IN, USA), less than USD 100,000 from Conformis (Bedford, MA, USA), less than USD 10,000 from Convatec (Skillman, NJ, USA), and less than USD 100,000 from MAKO (Fort Lauderdale, FL, USA) and has ownership interest in Conformis. One of the authors certifies that he (CSR) or she, or a member of his or her immediate family, has or may receive payments or benefits, during the study period, an amount of less than USD 1,000,000 from DePuy and less than USD 1,000,000 from Stryker (Mahwah, NJ, USA). 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. *Clinical Orthopaedics and Related Research* neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. 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.

D. H. Nawabi (✉), D. Nam, A. S. Ranawat, C. S. Ranawat
Adult Reconstruction and Joint Replacement, Department of Orthopaedic Surgery, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, USA
e-mail: nawabid@hss.edu

M. Meftah
Ranawat Orthopaedic Center, Research Division, Hospital for Special Surgery, New York, NY, USA

Introduction

Acetabular reconstruction in adult patients with severe hip dysplasia continues to present technical challenges, predominantly as a result of anterolateral acetabular bone deficiency and increased socket anteversion. The literature has historically favored cup placement at an anatomic hip center, using bulk bone grafting when required [7, 8, 11, 20, 23]. Using this approach, failures in the first 5 years were rare [8, 11], but revision rates became unacceptably high with increasing followup, reported in two series to be 20% and 60% at 12 and 16 years followup, respectively [16, 23]. One feature common to all of the aforementioned studies was the use of cement for acetabular fixation.

In the mid-1980s, uncemented acetabular fixation was used in difficult dysplastic cases. The results were excellent with one study reporting no revisions at a minimum of 5 years followup [1]. The same cohort of 24 patients showed a 92% survival rate of the cup at a mean of 16.3 years with nine cups implanted at a high hip center resulting from poor bone quality at the anatomic location [9].

The high hip center has been used in THA for cases of severe hip dysplasia as a result of the presence of better bone stock than an anatomic location [21]. Early results with cemented fixation showed acetabular loosening rates ranging from 16% to 42% as a result of superior placement of the cup [4, 18, 21]. Recently, however, studies of cementless cups placed at a high hip center have shown greater than 80% survivorship beyond 15 years in revision THA [12] and no acetabular failures at a minimum of 10 years in THA for Crowe I to III hip dysplasia [14]. Both of these studies used bone graft in selected cases.

There still remains some controversy as to whether a high hip center, particularly without bone graft, is the best option for patients with severe hip dysplasia. To our knowledge, there is only one study in the literature that has compared the outcomes of a high hip center with anatomic cup placement [17]. This study was performed in a Japanese population with the majority of cases being Crowe I hip dysplasia.

We sought to examine 1) survivorship; 2) radiographic results (including wear rates); and 3) hip scores at a minimum of 10 years for patients treated with high hip center cementless THA for Crowe II and III dysplasia without bone graft. We compared a group of patients meeting those indications with a cohort of patients who had Crowe I dysplasia in whom cementless cups were implanted at the anatomic hip center at a minimum of 10 years followup.

Materials and Methods

From our departmental database, we identified all 51 patients (56 hips) who were treated with cementless THA for Crowe I, II, or III dysplasia before February 2002. All surgery was performed between January 1992 and January 2002 by the senior author (CSR). The general indication during the period in question for the high hip center cementless reconstruction was Crowe II or III dysplasia causing painful arthritis. Contraindications to this technique included cases of Crowe IV dysplasia or cases of Crowe III dysplasia in which $> 75\%$ bony coverage of the acetabular component could not be achieved. This was a retrospective study with a historical control group (Crowe II and III dysplastic hips treated with high hip center reconstructions were compared with Crowe I dysplastic hips treated with anatomic hip center reconstructions).

After obtaining institutional review board approval we attempted to contact all 51 identified patients to arrange a followup visit. Three patients (three hips) had died before a minimum of 10 years followup from causes unrelated to the procedure and two patients (two hips) were not able to be contacted by telephone or certified mail. These five patients all had osseointegrated acetabular components at a high hip center with no episodes of revision surgery at their last visits (5–12 years postoperatively). Therefore, 46 patients (51 hips) were available for this study. The mean age of the patients at the time of index arthroplasty was 49 years (range, 28–77 years). Thirty-four of the 51 patients were female. The minimum followup was 10 years (mean, 12 years; range, 10–21 years).

The patients were divided into two groups based on the severity of acetabular dysplasia on their preoperative radiographs according to the classification system of Crowe et al. [5]. The high hip center group consisted of 23 patients (27 hips) who had either Crowe II or III dysplasia. The anatomic center group consisted of 23 patients (24 hips) who had Crowe I dysplasia (Table 1).

Surgical Technique

All operations were performed using a posterolateral approach without trochanteric osteotomy by a single surgeon (CSR). A cementless THA was performed in all cases using a porous titanium acetabular component (with or without screws) and an SROM femoral component (DePuy Orthopaedics, Warsaw, IN, USA), except in two cases in which a Ranawat/Burstein cemented femoral component (Biomet, Warsaw, IN, USA) was used. The two patients who received a cemented femoral component were both in the high hip center group. Before September 2000, the Ranawat/Burstein acetabular component was used (Ringloc Acetabular Series; Biomet) in 25 hips. After this date, the remaining 26 hips received an Osteonics Securfit HA PSL acetabular component (Stryker Orthopaedics, Mahwah, NJ, USA). The median outer diameter of the

Table 1. Patient demographics and relevant preoperative data

Variable	HHC	AC	p value
Number of patients	23	23	
Number of hips	27	24	
Age (years)*	48 (30–70)	51 (28–77)	0.47
Body mass index (kg/m^2)*	24 (18–30)	25 (18–30)	0.25
Male:female	4:19	7:17	0.75
Period of surgery	January 1992 to January 2002	April 1997 to January 2002	
Mean followup (years)*	13 (10–21)	12 (10–16)	0.65
Crowe classification (number)†			
I	0 (0)	24 (100)	
II	13 (48)	0 (0)	
III	14 (52)	0 (0)	

* Values are expressed as mean with range in parentheses; †values are expressed as number with percentage in parentheses; HHC = high hip center; AC = anatomic center.

acetabular components was 52 mm (range, 48–58 mm) in the high hip center group and 52 mm (range, 46–60 mm) in the anatomic center group. A 28-mm cobalt-chromium femoral head and conventional ultrahigh-molecular-weight polyethylene liner were used in all cases. A plus head option was required in 18 hips (67%) in the high hip center group and seven hips (29%) in the anatomic center group. In cases of Crowe II and III dysplasia, the acetabular component was placed at a high hip center. This was planned by preoperative templating on an AP radiograph of the pelvis by placing the largest possible cup template that could be accommodated by the remaining acetabular bone. During templating and intraoperatively, the aim was to position the cup between 40° and 45° abduction with at least 75% of the porous-coated surface of the implant in contact with host bone. Screw fixation was used to provide additional stability in 21 hips (78%) in the high hip center group and 10 hips (42%) in the anatomic center group.

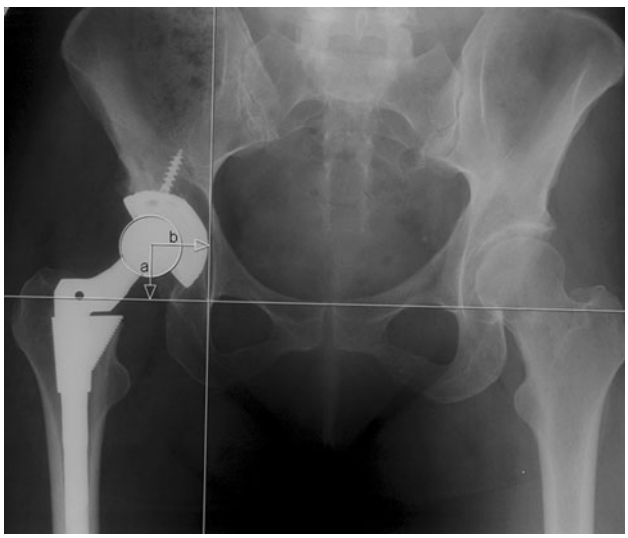

Fig. 1 AP radiograph showing (a) vertical distance and (b) horizontal distance of center of rotation from the acetabular teardrop.

Radiographic Evaluation

An AP radiograph of the pelvis centered on the pubic symphysis and including the iliac wings was obtained for all patients included in the study at last followup. The position of the cup was defined by the vertical and horizontal distances of the center of rotation in relation to the acetabular teardrop as described by Russotti and Harris [21] (Fig. 1). The vertical measurement is defined as the vertical distance along a line perpendicular to the interteardrop line to the center of the femoral head. The horizontal measurement is defined as the horizontal distance along the interteardrop line from a perpendicular dropped from the center of the femoral head to the inferior point of the teardrop. All measurements were made in millimeters on a digital Picture Archiving and Communication System workstation after performing a calibration step using either a 25-mm radioopaque marker or the known size of the artificial femoral head. In addition, we used the four-zone system described originally by Ranawat et al. [20] and then by Pagnano et al. [18] to assign each hip center to one of four zones: Zone 1, inferior and medial; Zone 2, superior and medial; Zone 3, superior and lateral; and Zone 4, inferior and lateral.

The mean vertical distance of the hip center was 28 mm (range, 21–39 mm) in the high hip center group and 17 mm (range, 14–20 mm) in the anatomic center group ($p < 0.001$). The mean horizontal distance of the hip center was 29 mm

(range, 22–35 mm) in the high hip center group and 28 mm (range, 15–38 mm) in the anatomic center group ($p = 0.89$).

The contralateral hip center was analyzed in terms of its vertical and horizontal position in those cases in which it was unaffected by osteoarthritis or dysplasia (lateral center-edge angle $> 25°$) and/or had not undergone arthroplasty. We identified 21 such hips and used the measurements for comparison to our study groups.

Acetabular inclination and anteversion were measured using Einzel-Bild-Roentgen-Analysis software (University of Innsbruck, Innsbruck, Austria). Radiolucent lines with a width of > 1 mm at the component-bone interface were recorded in the three zones defined by DeLee and Charnley [6]. The acetabular component was considered to be loose if there was more than 3 mm of migration or a change of at least 4° in the angle of abduction [15]. Osteolytic lesions were defined as circular or oval areas of distinct bone loss. Heterotopic ossification was classified according to the system of Brooker et al. [3]. Linear polyethylene wear was calculated digitally using roentgen monographic analysis (Roman V1.70 software; Robert Jones & Agnes Hunt Orthopaedic Hospital, Oswestry, UK) [19]. This is a two-dimensional, computer-assisted edge-detection method.

Clinical Assessment

The Harris hip score [10] and WOMAC [2] were calculated for each patient preoperatively and at last followup.

Statistical Analysis

Patient demographics, radiographic measurements and observations, and clinical scores were compared between the high hip center and anatomic center groups. The Shapiro-Wilk test was used to test normality of data. Continuous variables were evaluated using the Wilcoxon rank-sum test and categorical data were analyzed using Fisher's exact test. Vertical and horizontal distances for center of rotation and linear wear rate were compared between multiple groups using the Kruskal-Wallis test. Post hoc analysis of any significant differences was performed using an analysis of variance model on the rank-transformed data. The end point for survival was defined as either revision (removal or exchange of one component or the whole implant) for any reason, including exchange of the liner, or as revision because of aseptic acetabular loosening. Kaplan-Meier analysis was performed to determine the probability of survivorship in both groups at a mean of 12 years. Significance was set at $p < 0.05$. All analyses were performed using SAS Version 9.3 software (SAS Institute, Cary, NC, USA).

Results

Survivorship Analysis

Kaplan-Meier survivorship for all-cause revisions was 97% (95% confidence interval [CI], 79%–99%) in the high hip center group and 96% (95% CI, 74%–99%) in the anatomic hip center group (Fig. 2). The survivorship of the acetabular component was 100% in both groups with revision for aseptic loosening as the end point (Fig. 3A–B). There were no dislocations or revisions for acetabular loosening, polyethylene wear, or liner dissociation in either group. One SROM femoral component was revised at 1 year in the high hip center group for a periprosthetic fracture and another one at 2 years in the anatomic center group for failure of bony ingrowth resulting from undersizing.

Radiographic Results

The mean linear wear rate was 0.1 mm/year (range, 0.03–0.22 mm/year) in the high hip center group and 0.09 mm/year (range, 0.05–0.14 mm/year) in the anatomic center group ($p = 0.84$), and there were no differences among Crowe I, II, and III in terms of wear rates with the numbers available (Table 2). Of the 27 hips in the high hip center group, six hips had a center of rotation in Zone 3 (superior lateral) and the remaining 21 hips were in Zone 2 (superior medial). Perhaps importantly, lateralized acetabular reconstructions demonstrated more acetabular wear than medialized ones in the high hip center position (0.18 mm/year linear compared with 0.07 mm/year linear, $p < 0.001$; Table 3).

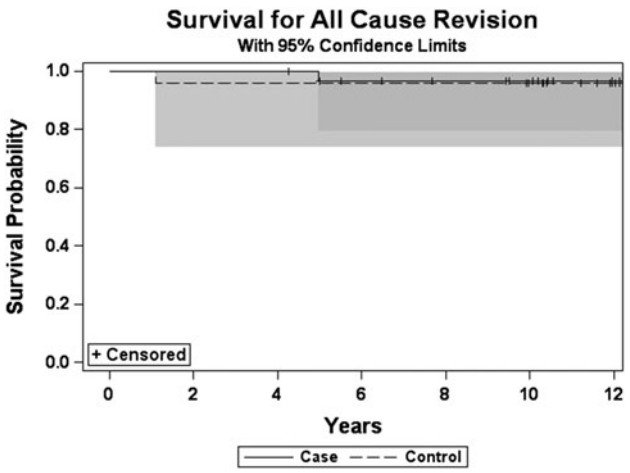

Fig. 2 Kaplan-Meier survivorship curve for cases (high hip center group) and controls (anatomic center group) for all-cause revisions. The shaded area represents the 95% CI.

One cup in the high hip center group was noted to have two regions of periacetabular osteolysis (Zone 2 and Zone 3) measuring 200 mm^2 and 300 mm^2, respectively. This cup had a wear rate of 0.22 mm/year but was not radiographically loose.

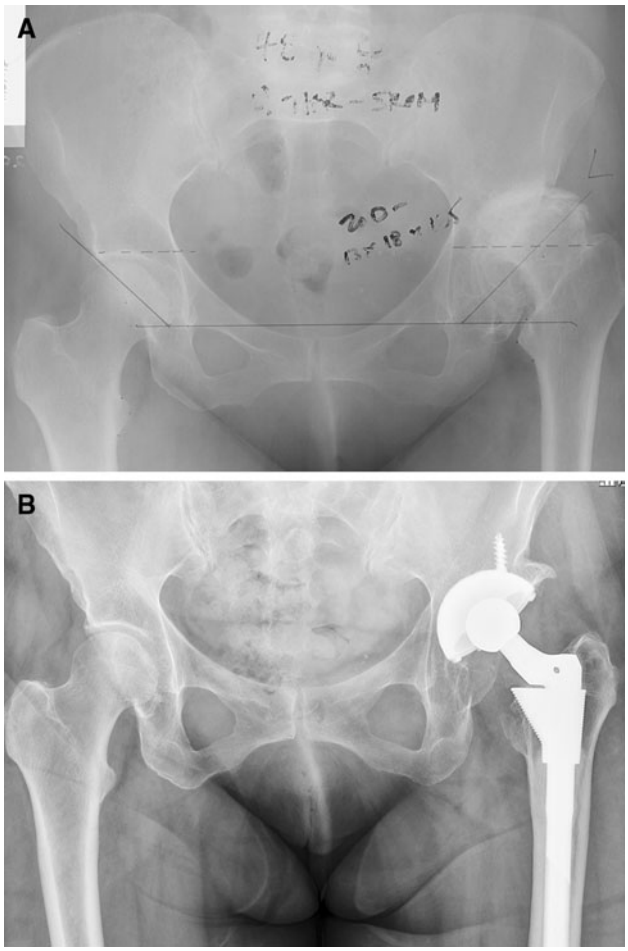

Fig. 3A–B (**A**) AP preoperative radiograph of a 49-year-old woman with Crowe II hip dysplasia. (**B**) Postoperative radiograph 16 years later showing an uncemented THA at a high hip center with osseointegration of the cup and no evidence of wear or osteolysis.

Clinical Assessment

The mean Harris hip score improved from 36 points preoperatively to 86 points at final followup ($p < 0.001$). The mean WOMAC score improved from 34 points preoperatively to 84 points at final followup ($p < 0.001$). There were no significant differences between the high hip center and anatomic center groups for the postoperative Harris hip score ($p = 0.22$) and the postoperative WOMAC score ($p = 0.26$).

Discussion

The anatomic location for acetabular component placement in severe dysplasia has been proposed by multiple authors as the optimal location for cup positioning after having demonstrated higher rates of acetabular loosening with nonanatomic placement [4, 18, 20]. Conversely, others have reported good to excellent results with a high hip center, citing the advantages of better acetabular bone stock [14, 17, 21]. To our knowledge, the proponents of the high hip center have yet to demonstrate long-term data proving the durability of acetabular fixation and low incidence of wear and dislocation in the setting of THA for severe dysplasia. In an attempt to address this gap in the literature, we analyzed the long-term outcomes of a high hip center in Crowe II and III dysplasia and compared these with a cohort of Crowe I cases treated with anatomic cup placement.

Our study has several limitations. First this study includes only a relatively small number of patients. However, the followup was in excess of 10 years, including thorough clinical and radiographic analyses, and the consistency associated with a study setting limited to a single surgeon's practice. Second, this was a retrospective study, raising the possibility of selection bias. However, it was the senior author's standard of care to perform a cementless high hip center reconstruction for all patients with Crowe II and III dysplasia over the study period unless acetabular

Table 2. Hip center position, cup orientation, and wear analysis according to preoperative Crowe classification

Variable	Number	Vertical distance (mm)*	Horizontal distance (mm)*	Inclination (°)*	Anteversion (°)*	Wear (mm/year)*
Crowe I	24	17.3 (13.6–20.1)	28.1 (15.1–38.1)	43.7 (32.1–62.2)	15.5 (5.2–30.3)	0.09 (0.05–0.14)
Crowe II	13	25.6 (21.1–29.9)	27.7 (23.4–34.2)	41.8 (30.6–53.5)	14.6 (3.1–28.2)	0.09 (0.05–0.22)
Crowe III	14	30.3 (21.5–38.7)	29.5 (21.6–35.4)			0.10 (0.03–0.22)
Normal hips	21	13.5 (10.5–16.1)	30.1 (24.1–36.4)			N/A
p value†		< 0.001‡	0.27	0.44	0.70	0.97

* Values are expressed as mean, with range in parentheses; †derived from performing comparison using Kruskal-Wallis test; ‡pairwise comparisons using an analysis of variance model were all statistically significant ($p < 0.05$), ie, normal versus Crowe I and Crowe II versus Crowe III; N/A = not applicable.

Table 3. Wear analysis according to zonal location of hip center

Variable	Number	Wear (mm/year)*
Zone 1 (inferior medial)	16	0.09 (0.1–0.14)
Zone 2 (superior medial)	19	0.07 (0–0.13)
Zone 3 (superior lateral)	6	0.18 (0.1–0.22)
Zone 4 (inferior lateral)	1	0.09 (0.09–0.09)
p value†		< 0.001‡

* Values are expressed as mean, with range in parentheses; †derived from performing comparison using Kruskal-Wallis test; ‡pairwise comparisons using an analysis of variance model were $p < 0.001$ (between Zone 2 and 3) and $p = 0.005$ (between Zone 1 and 3).

bone stock was severely deficient. Third, because of a change in the senior surgeon's practice, two different designs of uncemented cup were used in this study. To our knowledge, there are no significant reported survivorship differences between these components. Fourth, the lack of a comparison group of Crowe II and III hips treated with anatomic cup placement makes it difficult to draw an unbiased conclusion as to whether a high hip center is actually the best option for a severely dysplastic hip. However, a control group of mildly dysplastic patients with an anatomic center is a strength of this study and has given us a standard against which we can gauge our results. Fifth, we did not collect accurate data on leg length discrepancy in our patients, which is a common finding in patients treated with a high hip center [17]. Given the excellent clinical outcomes we have seen, it is unlikely that leg length discrepancy played a major role in our cohort.

We found that cementless acetabular components placed at a high hip center had an excellent survivorship with no cup failures resulting from acetabular loosening. Early reports of cementless cups at a high hip center from Schutzer and Harris [22] showed only a 6% rate of acetabular loosening at 5 years. They defined a high hip center as 35 mm from the interteardrop line. Their series consisted predominantly of revision surgeries. In our series, the mean vertical distance from the interteardrop line in Crowe II and Crowe III cases was 25.6 mm and 30.3 mm, respectively. These values are lower than those reported by Russotti and Harris [21] and Schutzer and Harris [22] and may be one of the reasons why we had no failures for acetabular loosening as a result of the improved biomechanics of a less elevated high hip center [13]. Recently, two studies investigating the use of a high hip center in Japanese patients [14, 17] have shown excellent results with near 100% survivorship of the acetabular component when placed at high hip center. Although these studies consisted of patients with predominantly Crowe I and II dysplasia, the findings are in concordance with our results in terms of the high survivorship, low polyethylene wear, near absent acetabular loosening, and a low incidence of dislocation. Furthermore, the vertical distance of the hip center in these two studies was also similar to our findings with values of 24.5 mm [14] and 26.8 mm [17].

Our computerized wear measurements did not show any differences in wear rates between high hip center and anatomic center cases. Kaneuji and colleagues [14] reported a mean linear wear rate of 0.06 mm/year in Crowe II and III hips at long-term followup. Our mean linear wear rates were comparable at 0.1 mm/year in the high hip center group. More importantly, we found that lateralized acetabular reconstructions demonstrated more acetabular wear than medialized ones in the high hip center position by a factor of over twofold. Pagnano et al. [18] in a study of 145 hips with Crowe II dysplasia found that at a mean duration of 14 years followup, the rate of acetabular loosening was as high as 30% for superiorly placed cemented cups regardless of lateralization. These findings are in contrast to Russotti and Harris [21] who showed only a 16% rate of acetabular loosening at 11 years in a cohort of patients with superiorly placed cemented cups without lateralization. The effect of lateralization of a cementless high hip center at long-term followup has not been studied. Although we have seen more polyethylene wear at the superior lateral position at 10-year followup, it remains to be seen whether our lateralized patients will have higher rates of acetabular failure.

We demonstrated significant improvements in the Harris hip and WOMAC scores at final followup, which were equivalent between our two groups. The improvements we have seen have also been reported by other authors who have investigated the high hip center in Crowe II and III dysplasia [14, 17].

At a minimum of 10 years of followup, we found that cementless acetabular fixation without structural bone graft at a high hip center in Crowe II and III dysplasia showed high survivorship and excellent hip scores. However, in contrast to previous studies of moderate to severe dysplasia, the high hip center we propose is only approximately 1 cm higher than the anatomic position. Medialization of these high hip center reconstructions is important, because the acetabular polyethylene wear rates were higher in those hips that were left in a lateralized position.

Acknowledgments We thank Huong T. Do MA, for her assistance with the statistical analysis and Matin Lendhey BS, and Dhanasekara Raja MD, for assisting us with the data collection. Danyal H. Nawabi thanks the British Hip Society Charnley Latta Fund for supporting his fellowship training.

References

1. Anderson MJ, Harris WH. Total hip arthroplasty with insertion of the acetabular component without cement in hips with total congenital dislocation or marked congenital dysplasia. *J Bone Joint Surg Am*. 1999;81:347–354.
2. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *J Rheumatol*. 1988;15:1833–1840.
3. Brooker AF, Bowerman JW, Robinson RA, Riley LH Jr. Ectopic ossification following total hip replacement. Incidence and a method of classification. *J Bone Joint Surg Am*. 1973;55: 1629–1632.
4. Callaghan JJ, Salvati EA, Pellicci PM, Wilson PD Jr, Ranawat CS. Results of revision for mechanical failure after cemented total hip replacement, 1979 to 1982. A two to five-year follow-up. *J Bone Joint Surg Am*. 1985;67:1074–1085.
5. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. *J Bone Joint Surg Am*. 1979;61:15–23.
6. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res*. 1976; 121:20–32.
7. Garvin KL, Bowen MK, Salvati EA, Ranawat CS. Long-term results of total hip arthroplasty in congenital dislocation and dysplasia of the hip. A follow-up note. *J Bone Joint Surg Am*. 1991;73:1348–1354.
8. Gerber SD, Harris WH. Femoral head autografting to augment acetabular deficiency in patients requiring total hip replacement. A minimum five-year and an average seven-year follow-up study. *J Bone Joint Surg Am*. 1986;68:1241–1248.
9. Hampton BJ, Harris WH. Primary cementless acetabular components in hips with severe developmental dysplasia or total dislocation. A concise follow-up, at an average of sixteen years, of a previous report. *J Bone Joint Surg Am*. 2006;88:1549–1552.
10. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am*. 1969;51:737.
11. Harris WH, Crothers O, Oh I. Total hip replacement and femoral-head bone-grafting for severe acetabular deficiency in adults. *J Bone Joint Surg Am*. 1977;59:752–759.
12. Hendricks KJ, Harris WH. High placement of noncemented acetabular components in revision total hip arthroplasty. A concise follow-up, at a minimum of fifteen years, of a previous report. *J Bone Joint Surg Am*. 2006;88:2231–2236.
13. Johnston RC, Brand RA, Crowninshield RD. Reconstruction of the hip: a mathematical approach to determine optimum geometric relationships. *J Bone Joint Surg Am*. 1979;61:639–652.
14. Kaneuji A, Sugimori T, Ichiseki T, Yamada K, Fukui K, Matsumoto T. Minimum ten-year results of a porous acetabular component for Crowe I to III hip dysplasia using an elevated hip center. *J Arthroplasty*. 2009;24:187–194.
15. Maloney WJ, Galante JO, Anderson M, Goldberg V, Harris WH, Jacobs J, Kraay M, Lachiewicz P, Rubash HE, Schutzer S, Woolson ST. Fixation, polyethylene wear, and pelvic osteolysis in primary total hip replacement. *Clin Orthop Relat Res*. 1999;369:157.
16. Mulroy RD Jr, Harris WH. Failure of acetabular autogenous grafts in total hip arthroplasty. Increasing incidence: a follow-up note. *J Bone Joint Surg Am*. 1990;72:1536–1540.
17. Murayama T, Ohnishi H, Okabe S, Tsurukami H, Mori T, Nakura N, Uchida S, Sakai A, Nakamura T. 15-year comparison of cementless total hip arthroplasty with anatomical or high cup placement for Crowe I to III hip dysplasia. *Orthopedics*. 2012;35:313–318.
18. Pagnano MW, Hanssen AD, Lewallen DG, Shaughnessy WJ. The effect of superior placement of the acetabular component on the rate of loosening after total hip arthroplasty. *J Bone Joint Surg Am*. 1996;78:1004–1014.
19. 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. *J Arthroplasty*. 2012;27:354–357.
20. Ranawat CS, Dorr LD, Inglis AE. Total hip arthroplasty in protrusio acetabuli of rheumatoid arthritis. *J Bone Joint Surg Am*. 1980;62:1059–1065.
21. Russotti GM, Harris WH. Proximal placement of the acetabular component in total hip arthroplasty. A long-term follow-up study. *J Bone Joint Surg Am*. 1991;73:587–592.
22. Schutzer SF, Harris WH. High placement of porous-coated acetabular components in complex total hip arthroplasty. *J Arthroplasty*. 1994;9:359–367.
23. Shinar AA, Harris WH. Bulk structural autogenous grafts and allografts for reconstruction of the acetabulum in total hip arthroplasty. Sixteen-year-average follow-up. *J Bone Joint Surg Am*. 1997;79:159–168.