Should We Worry About Periacetabular Interference Gaps in Hip Resurfacing?

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Abstract

Background Press-fit acetabular component seating in hip resurfacing can be challenging as a strong interference fit is required. It has not been established whether reducing the acetabular underream minimizes incomplete component seating or leads to increased acetabular loosening.

Questions/purposes We examined (1) the incidence and natural history of postoperative interference gaps in hip resurfacing and (2) whether reduction of the acetabular underream from 2 mm to 1 mm reduces the incidence of periacetabular interference gaps.

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Methods Of 327 Birmingham Hip™ Resurfacings (Smith & Nephew Inc, Memphis, TN, USA) performed by a single surgeon from 2005 to 2010, we evaluated 306 hips with a minimum 1-year radiographic followup. Postoperative periacetabular interference gaps were monitored for radiographic gap resolution at latest followup. The frequency of incomplete component seating was compared between acetabula prepared with 1- and 2-mm underream techniques. Minimum followup was 1 year (mean, 2.7 years; range, 1–6 years).

Results Fifty-one percent of the postoperative radiographs demonstrated the presence of a periacetabular interference gap. At latest followup, 96% of these gaps were no longer visible. We observed a reduction in the number of interference gaps identified when acetabular preparation changed from a 2-mm underream (63%) to a 1-mm underream (39%). There were no revisions due to acetabular failure.

Conclusions Periacetabular interference gaps were common in this series but not associated with acetabular component failure. The use of a 1-mm underream is sufficient for adequate short-term press-fit fixation of the acetabular component in Birmingham Hip™ Resurfacing arthroplasty.

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

Introduction

Hip resurfacing is a bone-sparing alternative to THA that is typically offered to young and active patients. Most current hip resurfacing designs employ a metal-on-metal articulation with an uncemented acetabular component. Unlike

most uncemented THA shells, the monoblock press-fit design of a hip resurfacing precludes the use of adjunctive screw fixation and thus a strong interference fit is sought for adequate fixation.

The use of a press-fit acetabulum in THA is associated with a survivorship of 92% to 99% at a mean followup of 6 to 10 years [5, 25, 26]. Likewise, porous-coated press-fit acetabula have demonstrated similar survivorship at a mean followup of 5 to 10 years with their use in hip resurfacing arthroplasty [2, 7, 9, 19, 23]. However, underreaming the acetabulum for fixation of an oversized press-fit component has been associated with acetabular fractures [3, 10] and incomplete component seating [2, 6, 12]. Concerns exist about incomplete seating leading to reduced bony ingrowth and acetabular failure [12]. Recommendations for the size of underream in acetabular press-fit fixation range from 1 to 3 mm [1, 3, 15, 16, 24]. A 2-mm underream has been recommended for use in Birmingham Hip™ Resurfacing (BHR™; Smith & Nephew Inc, Memphis, TN, USA) [21]. While a 2-mm underream reportedly increases the torque-out force required in implanted press-fit acetabular cups [8], several authors have suggested an undersized reamed cavity of less than 2 mm may provide adequate press-fit fixation, while reducing the risk of acetabular fracture during impaction [1, 16, 24]. Currently, the ideal underream for uncemented, press-fit acetabular fixation is uncertain and little is known about the effect of underream size and the incidence of incomplete acetabular component seating in hip resurfacing.

We therefore (1) assessed the incidence and natural history of postoperative interference gaps in hip resurfacing and (2) determined whether reduction of the acetabular underream from 2 mm to 1 mm reduced the incidence of periacetabular interference gaps.

Patients and Methods

Between February 2005 and April 2010, we performed 327 hip resurfacings in 296 patients. During that time, we performed 324 conventional THAs. General indications for patients receiving hip resurfacing were men younger than 65 years and women younger than 55 years, with adequate hip anatomy to accept the prostheses. Women of childbearing age or considering pregnancy were contraindicated. We excluded patients who did not have at least 1 year of radiographic followup available for assessment. This left 274 patients (221 men [247 hips], 53 women [59 hips]) with 306 hip resurfacings. The mean patient age was 51.6 years (range, 20.2–82.7 years) and the mean BMI was 29.5 kg/m² (range, 19.1–51.9 kg/m²). Diagnoses included primary osteoarthritis in 287 hips, osteoarthritis secondary to Legg-Calvé-Perthes disease in three hips, osteoarthritis

secondary to developmental hip dysplasia in three hips, and osteonecrosis in 13 hips. Minimum followup was 1 year (mean, 2.7 years; range, 1–6 years). No patients were lost to followup. No patients were recalled specifically for this study; all data were obtained from medical records and radiographs. The study was approved by our institutional ethics board.

A BHR™ was implanted in all cases. The acetabular component of the BHR™ is manufactured as an as-cast cobalt-chromium hemispherical shell (Fig. 1). Acetabular components are offered in 2-mm incremental sizes with diameters ranging from 44 to 66 mm. The porous backside of the shell consists of 0.4- to 0.5-mm-diameter cast-in beads, making the beads integral with the substrate metal. The porous beaded surface is coated in hydroxyapatite. The overall upper tolerance on the outer diameter of the shell is approximately 0.3 to 0.4 mm beyond the nominal outside diameter of the component (written communication, A Smith, PhD, Smith & Nephew Inc, 2012).

All procedures were performed by a single surgeon (EHS) through a standard posterolateral approach with an anterior capsulotomy. Acetabular preparation was undertaken with hemispherical reamers of increasing size until an interference fit could be achieved. Initially, the standard technique of preparing the acetabulum for insertion of a press-fit acetabular component in our institution involved underreaming the acetabulum by 2 mm. Underreaming of the acetabulum was reduced to 1 mm in May 2008 because of concerns that a 2-mm underream was excessive, leading

Fig. 1 An image of the porous-coated, press-fit acetabular component of the BHR™ system is shown. The Porocast™ beaded surface of the acetabular cup is comprised of cast Co-Cr beads that are integral with the substrate cup material. Individual beads are approximately 400 to 500 μ m in diameter. The beaded surface is coated in hydroxyapatite of 80- to 100- μ m thickness. Photograph courtesy of and reprinted with permission of Smith & Nephew, Inc.

to a high incidence of postoperative interference gaps. Of the 306 hips included in the analysis, 145 hips were prepared using the 2-mm underream technique and 161 hips were prepared using the 1-mm underream technique.

Four observers (BG, MO, MD, AK) performed radiographic assessment of the frequency of postoperative periacetabular interference gaps and their natural history. Assessment involved examination of AP hip view radiographs using digital radiograph software (MagicView 300; Siemens Healthcare USA, Inc, Malvern, PA, USA). The standard imaging protocol used in the clinical series involved supine positioning of the patient, with the pelvis in a neutral position. Femoral rotation was controlled by referencing the patella, which was aligned to point anteriorly. The x-ray beam was aligned perpendicular to the table and the source-to-image distance was 100 cm, centered over the acetabulum. The resulting image displayed the lateral pelvis and proximal $\frac{1}{3}$ of the femur.

Images were prepared by a third party, ensuring the same radiographs were used by all observers. Assessment occurred in a blinded fashion. Three observers (BG, MO, MD) examined 3-day postoperative radiographs for the presence of periacetabular interference gaps. Results were tabulated by a separate party and differences of opinion were resolved by consensus of the three observers' results. The definitions outlined by Gruen et al. [6] for interference gaps and acetabular zones were used. An interference gap was defined as a continuous lucency around the perimeter of an acetabular component, which involved more than 50% of the arc of at least one of the three acetabular zones. The acetabulum was divided into three contiguous equal zones of approximately 60°, which is a slight modification of the zones defined by DeLee and Charnley [4]. Radiolucencies were quantified by one observer (BG) for maximum depth, and the zone where maximum depth occurred was recorded.

Three blinded observers (BG, MO, AK) monitored identified gaps for radiographic gap resolution at latest followup. Results were tabulated by a third party and differences of opinion were again resolved by consensus of the three observers' results. During the study design phase, a set of patient images was examined to determine the incidence of periacetabular interference gaps and gain an understanding of their natural history and features associated with their resolution. It was noted resolving gaps consistently demonstrated some of the features of osteointegration that have been previously outlined [14]. A superomedial buttress would form, followed closely by radial bony trabeculae traversing the gap and contacting the acetabular component. This process would continue until the gap was completely filled and remodeled. Complete radiographic gap resolution was defined as bone infiltration into more than 50% of the originally identified gap.

The radiographic progress of interference gaps was further categorized as follows: partial resolution (bone infiltration of less than 50%), static (no change from the original radiograph), and worse (enlargement of the originally identified gap). Between-observer reliability in interference gap identification and assessment of gap resolution was expressed as a free-marginal multirater kappa statistic. We used an online macro to compute the level of agreement for categorical data among multiple observers [20] and Cohen's kappa statistic to determine intrarater reliability in assessment of interference gap resolution. The free-marginal multirater kappa statistic in identifying periacetabular bone gaps was 0.66. Agreement between observers in identifying gap resolution was 0.95. Intraobserver agreement for the assessment of gap resolution by an individual observer ranged from 0.54 to 0.91.

For analysis of differences within and between observers, we used Excel® (Microsoft Corp, Redmond, WA, USA) and SPSS® Version 16 (SPSS Inc, Chicago, IL, USA). Univariate linear regression was used to evaluate the marginal predictive merit of demographic parameters. For comparison of the proportions of gaps identified between sexes and between the two methods of acetabulum preparation, a chi-square statistic was used. A Somers' D statistic was used to evaluate the association of acetabular cup size with radiolucency presence and maximum width, as well as the association of maximum radiolucency width with incomplete radiolucency resolution at latest followup. We used linear regression to determine whether age and BMI were correlated with gap width and linear regression with sex as a dichotomous variable to determine whether sex correlated with gap width.

Results

One hundred fifty-five of the 306 (51%) hips had a periacetabular interference gap on the 3-day postoperative radiograph. The maximal gap occurred in Zone II in 151 hips (97%) and Zone I in the remaining four hips (3%). There were no gaps greater than 4 mm, 119 of 155 (77%) gaps were less than 2 mm, and 62 of 155 (40%) were less than 1 mm (Table 1). At latest followup, 149 of 155 (96%) interference gaps had completely resolved radiographically (Fig. 2). Partial gap resolution was identified in the remaining six gaps (4%) (Fig. 3). Four of the six patients with partial gap resolution had followup of less than 2 years.

At latest followup of the cohort with postoperative interference gaps, no new periacetabular radiolucencies were identified. None of these hips demonstrated features of radiographic acetabular failure as would be indicated by complete radiolucencies around the circumference of an acetabular component or evidence of gross movement.

The 2-mm underream group had a higher ($p < 0.001$) incidence of interference gaps (63% versus 39%) and there were proportionally more ($p = 0.01$) interference gaps 2 mm or more in width (30% versus 13%) (Table 2). We observed no differences ($p = 0.186$) in the rate of complete gap resolution or acetabular revision between the 2- and 1-mm underream groups and no differences in age, sex, BMI, and acetabular component size between the two groups (Table 3). Acetabular component size was not associated with ($p = 0.712$) the presence of interference gaps of 2 mm or larger. Age ($r = -0.138$), sex ($r = -0.064$), and BMI ($r = -0.099$) were not correlated with gap width. Interference gap width was not associated with ($p = 0.152$) incomplete gap resolution at latest followup.

There were no intraoperative or postoperative fractures of the acetabulum. There were nine (2.9%) revisions in the series although none were for acetabular loosening. Three (1%) hips were revised for deep infection. Two (0.7%) hips were revised for femoral neck fracture. One of these

occurred around a tantalum rod that had been inserted to treat osteonecrosis and was left in situ at the time of hip resurfacing. Four (1.3%) revisions were performed for concerns regarding raised cobalt and chromium ion levels. Metal ions were only checked in symptomatic patients or in those with an increased cup inclination.

Discussion

Implantation of the standard acetabular component in BHRTM arthroplasty relies on strong interference fit as adjunctive screw fixation is not available. The absence of a central introducer hole reduces intraoperative feedback about component seating, potentially increasing the incidence of interference gaps. Concerns exist about incomplete component seating because it may lead to inadequate fixation, reduced bony ingrowth, and acetabular failure [12]. We therefore (1) assessed the incidence and natural history of postoperative interference gaps in hip resurfacing arthroplasty and (2) determined whether a reduction of the acetabular underream from 2 mm to 1 mm reduced the incidence of periacetabular interference gaps.

This study was limited by several factors. First, routine radiographic assessment relied on AP hip radiographs rather than AP pelvic radiographs. It could be argued this would lead to problems with controlling pelvic tilt and rotation, making assessment of gap resolution on serial radiographs unreliable. Despite only using AP hip radiographs, this source of error was minimized through the use of a standardized imaging protocol, which controlled pelvic tilt and rotation. The absence of AP pelvic radiographs also

Table 1. Distribution of interference gap sizes for 2- and 1-mm underream groups

Gap size (mm)	Underream	
	2 mm (145 hips)	1 mm (161 hips)
< 1	25	37
1	39	18
2	22	5
3	3	2
4	3	1
Total	92 (63%)	63 (39%)

Fig. 2A–B (A) An initial 3-day postoperative radiograph demonstrates the presence of a Zone II interference gap (arrows). (B) A radiograph taken 2.3 years postoperatively demonstrates complete radiographic resolution of the interference gap.

Fig. 3A–B (A) An initial 3-day postoperative radiograph demonstrates the presence of a Zone II interference gap (arrows). (B) A radiograph taken 1 year postoperatively demonstrates partial resolution of the interference gap (arrows).

Table 2. Comparison of hips prepared with a 2-mm underream and those prepared with a 1-mm underream

Variable	Underream		p value
	2 mm	1 mm	
Number of hips	145	161	
Age (years)*	51.7	51.5	0.811
Sex (number of hips)			0.570
Male	119	128	
Female	26	33	
BMI (kg/m ²)*	29.5	29.9	0.826
Cup size (mm) [†]	60	58	0.412
Interference gaps (number of hips)	92/145 (63%)	63/161 (39%)	< 0.001
Interference gaps ≥ 2 mm (number of hips)	28/92 (30%)	8/63 (13%)	0.01
Complete gap resolution (number of hips)	90/92 (98%)	59/63 (94%)	0.186
Revisions (number of hips)	5 (3.4%)	4 (2.5%)	0.618

* Values are expressed as means; [†] values are expressed as modes.

precluded the assessment of acetabular component inclination and migration. As a consequence, we could not seek correlations between the acetabular inclination and the incidence of interference gaps and their rates of subsequent resolution. The inability to assess component migration

Table 3. Comparison of hips identified with interference gaps and those without interference gaps

Variable	No gaps	Gaps	p value
Number of hips	151	155	
Age (years)*	51.9	51.3	0.569
Sex (number of hips)			0.747
Male	123	124	
Female	28	31	
BMI (kg/m ²)*	30.0	29.1	0.813
Cup size (mm) [†]	58	58	0.779
Revisions (number of hips)	5 (3.3%)	4 (2.6%)	0.705

* Values are expressed as means; [†] values are expressed as modes.

meant it was not possible to determine whether the resolution of interference gaps was contributed to by subtle movement or settling of the acetabular components. Second, the short followup period (mean, 2.7 years; range, 1–6 years) did not allow assessment of the acetabular component's medium- and long-term clinical performance and correlation of this with the presence of initial interference gaps and reaming technique. Third, cases were not randomized into the two different methods of acetabular preparation, but rather a clinical decision was made to change from the 2-mm underream technique to the 1-mm underream technique. Comparison between the outcomes of these two cohorts is not methodologically ideal, but they were at least similar

Table 4. Comparison of acetabular component types and incidence of interference, rates of gap resolution and rates of component related complications

Study	Number of hips	Followup (months)*	Component type	Underream (mm)	Screws	Gap definition	Number of cups with gaps	Number of Zone II gaps	Gap followup (months)	Number with gap resolution	Number of intraoperative fractures	Number of revisions (all)	Number of acetabular shell revisions	Number with aseptic acetabular loosening†
Dorr et al. [5] (1998)	115	72 (60–89)	Titanium alloy Titanium porous coat	1–3	No	Any gap	39/115 (33.9%)	36/39 (92.3%)	Latest followup films	26/39 (66.7%)	0/115 (0%)	11/115 (9.6%)	0/115 (0%)	0 (0%)
Gruen et al. [6] (2005)	574	34 (24–58)	Porous tantalum monoblock	Varied 9 surgeons	No	Any gap	80/414 (19.3%)	67/80 (83.8%)	Latest followup films	84/100 (84.0%)‡	2/574 (0.3%)	Unclear	11/574 (1.9%)	0 (0%)
Hulst et al. [7] (2011)	643	125 (85–168)	Hip resurfacing Cobalt-chromium cup	Not documented	No	Any gap	155/643 (24.1%)‡	118/155 (76.1%)	36	147/155 (94.8%)	Not documented	45/482 (9.3%)	Not documented	4/482 (0.8%)
Macheras et al. [11] (2006)	86	87 (84–90)	Sintered bead porous coat Porous tantalum monoblock	2	No	Any gap	25/86 (29.1%)	25/25 (100%)	6	25/25 (100%)	Not documented	0/86 (0%)	0/86 (0%)	0/86 (0%)
Mercan and Randle [13] (2006)	132	33 (16–52)	Titanium alloy Titanium mesh layers welded to surface	1.5	Yes (36%)	Any gap	80/96 (83.3%)	76/80 (95%)	Latest followup films	86/96 (89.6%)	0/132 (0%)	2/132 (1.5%)	0/132 (0%)	0/132 (0%)
Morscher et al. [15] (1997)	280	63 (54–97)	Polyethylene monoblock bonded to 4 titanium mesh layers	1.5	No	Any gap	70/280 (25.0%)	69/70 (98.6%)	12 60	46/69 (66.7%) [¶] 60/69 (87.0%) [¶]	0/280 (0%)	Unclear	Unclear	Unclear
Ng et al. [17] (2007)	95	41 (24–74)	Single peg Titanium alloy shell Sintered titanium porous coat	1–2	No	Any gap	22/60 (36.7%)‡	19/22 (86.4%)	Latest followup films	21/22 (95.5%)	Not documented	Not documented	Not documented	Not documented
Onsten et al. [18] (1996)	30	24	Plasma-sprayed HA Titanium alloy shell Plasma-sprayed HA coating	Not clearly documented	Yes (33.3%)	Any apical gap	16/30 (53.3%) [§]	NA	24	16/16 (100%)	Not documented	0/30 (0%)	0/30 (0%)	0/30 (0%)
Springer et al. [22] (2008)	596	110 (60–192)	Titanium alloy shell Sintered titanium porous coat	1–2	No	≥ 1 mm	201/343 (58.6%)‡	133/343 (38.8%)	Latest followup films	125/133 (94.0%)	0/343 (0%)	36/343 (10.5%)	16/343 (4.7%)	0/343 (0%)

Table 4. continued

Study	Number of hips	Followup (months)*	Component type	Underream (mm)	Screws	Gap definition	Number of cups with gaps	Number of Zone II gaps	Gap followup (months)	Number with gap resolution	Number of intraoperative fractures	Number of revisions (all)	Number of acetabular shell revisions	Number with aseptic acetabular loosening†
Udomkiat et al. [26] (2002)	132	122 (84–143)	Titanium alloy shell Sintered titanium porous coat	1–3	No	Any gap	37/110 (33.6%)	Not documented	Latest followup films	33/37 (89.2%)	0/132 (0%)	33/110 (30%)	5/110 (4.5%)	1/110 (0.9%)
Current study	327	32 (12–72)	Cobalt-chromium shell	2	No	Any gap	92/145 (63.4%)	151/155 (97.4%)	Latest followup films	149/155 (96.1%)	0/306 (0%)	9/306 (2.9%)	7/306 (2.3%)	0/306 (0%)
			Cast-in cobalt-chromium beads	1	No	Any gap	63/161 (39.1%)							
			HA coat											

* Values are expressed as mean, with range in parentheses; †clinical aseptic acetabular loosening, requiring revision; ‡number of gaps in each zone listed rather than number of components affected; §only apical gaps were recorded; ||the acetabulum was divided into five equal contiguous zones (A, B, C, D, E) and all gaps occurred in the apical regions of the acetabulum (Zones B, C, D); ¶resolution of apical (Zone II); HA = hydroxyapatite; NA = not applicable.

groups with no statistical differences in the number of hips, age, sex, BMI, and cup size implanted (Table 2).

Several authors have reported the incidence and outcomes of interference gaps in porous acetabular components implanted with press-fit techniques in THA (Table 4). These series describe an incidence of postoperative interference gaps of between 19% and 83%. The vast majority of these gaps were located in the apical region (Zone II) of the acetabular components. Hulst et al. [7] reported on interference gaps in hip resurfacing arthroplasty, with an incidence of 24%, and 76% located in Zone II. Our findings are comparable to these series, with 51% of acetabular components demonstrating postoperative interference gaps, 97% of which were apical in location.

The literature indicates periacetabular interference gaps associated with press-fit acetabular implantation in THA tend to resolve, with reported rates of between 67% and 100% (Table 4). It has been suggested apical gaps indicate a strong peripheral interference fit, which reduces micromotion and allows osteointegration to occur [16, 18]. In support of this view, apical interference gaps have been associated with less component migration and 100% gap healing [18]. Hulst et al. [7] reported a 95% rate of resolution for principally apical interference gaps. Our findings were consistent with previous reports: interference gaps were almost universally apical (97%) and the rate of resolution was high (96%). We identified no patients with aseptic loosening or radiographic acetabular failure and found no association between the presence of interference gaps and revision surgery.

Reduction in underream from 2 mm to 1 mm led to a reduction in interference gaps (63% versus 39%) and gaps of 2 mm or larger (30% versus 13%). Although the patients were not allocated to the two techniques randomly, the groups were similar in number and there were no differences in demographics or cup size implanted (Table 2). This reduction in interference gap incidence and size did not come at the cost of stability, with no acetabular components being revised for aseptic loosening in either group and no differences in revision rate between the two groups.

Our study demonstrates apical interference gaps are common when using the press-fit technique with a 2-mm underream in BHR™ arthroplasty. These gaps however have a very high rate of radiographic resolution and are not associated with any short-term acetabular failures. We believe reduction of the underream to 1 mm is an appropriate modification of technique as it diminishes the incidence and size of interference gaps and does not compromise short-term acetabular fixation.

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References

- Adler E, Stuchin SA, Kummer FJ. Stability of press-fit acetabular cups. *J Arthroplasty*. 1992;7:295–301.
- Amstutz HC, Takamura KM, Le Duff MJ. The effect of patient selection and surgical technique on the results of Conserve[®] Plus hip resurfacing—3.5- to 14-year follow-up. *Orthop Clin North Am*. 2011;42:133–142. vii.
- Curtis MJ, Jinnah RH, Wilson VD, Hungerford DS. The initial stability of uncemented acetabular components. *J Bone Joint Surg Br*. 1992;74:372–376.
- DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res*. 1976;121:20–32.
- Dorr LD, Wan Z, Cohen J. Hemispheric titanium porous coated acetabular component without screw fixation. *Clin Orthop Relat Res*. 1998;351:158–168.
- Gruen TA, Poggie RA, Lewallen DG, Hanssen AD, Lewis RJ, O'Keefe TJ, Stulberg SD, Sutherland CJ. Radiographic evaluation of a monoblock acetabular component: a multicenter study with 2- to 5-year results. *J Arthroplasty*. 2005;20:369–378.
- Hulst JB, Ball ST, Wu G, Le Duff MJ, Woon RP, Amstutz HC. Survivorship of Conserve[®] Plus monoblock metal-on-metal hip resurfacing sockets: radiographic midterm results of 580 patients. *Orthop Clin North Am*. 2011;42:153–159. vii.
- Kaneko K, Inoue Y, Yanagihara Y, Uta S, Mogami A, Iwase H. The initial fixation of the press-fit acetabular shell—clinical observation and experimental study. *Arch Orthop Trauma Surg*. 2000;120:323–325.
- Khan M, Kuiper JH, Edwards D, Robinson E, Richardson JB. Birmingham Hip Arthroplasty: five to eight years of prospective multicenter results. *J Arthroplasty*. 2009;24:1044–1050.
- Kim YS, Callaghan JJ, Ahn PB, Brown TD. Fracture of the acetabulum during insertion of an oversized hemispherical component. *J Bone Joint Surg Am*. 1995;77:111–117.
- Macheras GA, Papagelopoulos PJ, Kateros K, Kostakos AT, Baltas D, Karachalios TS. Radiological evaluation of the metal-bone interface of a porous tantalum monoblock acetabular component. *J Bone Joint Surg Br*. 2006;88:304–309.
- MacKenzie JR, Callaghan JJ, Pedersen DR, Brown TD. Areas of contact and extent of gaps with implantation of oversized acetabular components in total hip arthroplasty. *Clin Orthop Relat Res*. 1994;298:127–136.
- Merican AM, Randle R. Early clinical and radiographic analysis of the Fitmore cup. *J Arthroplasty*. 2006;21:846–851.
- Moore MS, McAuley JP, Young AM, Engh CA. Radiographic signs of osteointegration in porous-coated acetabular components. *Clin Orthop Relat Res*. 2006;444:176–183.
- Morscher E, Berli B, Jockers W, Schenk R. Rationale of a flexible press fit cup in total hip replacement: 5-year followup in 280 procedures. *Clin Orthop Relat Res*. 1997;341:42–50.
- Morscher E, Masar Z. Development and first experience with an uncemented press-fit cup. *Clin Orthop Relat Res*. 1988;232:96–103.
- Ng FY, Zhu Y, Chiu KY. Cementless acetabular component inserted without screws—the effect of immediate weight-bearing. *Int Orthop*. 2007;31:293–296.
- Onsten I, Carlsson AS, Sanzen L, Besjakov J. Migration and wear of hydroxyapatite-coated hip prosthesis: a controlled roentgen stereophotogrammetric study. *J Bone Joint Surg Br*. 1996;78:85–91.
- Rahman L, Muirhead-Allwood SK, Alkinj M. What is the mid-term survivorship and function after hip resurfacing? *Clin Orthop Relat Res*. 2010;468:3221–3227.
- Randolph JJ. Online kappa calculator. 2008. Available at: <http://justus.randolph.name/kappa>. Accessed March 31, 2012.
- Smith & Nephew Inc. Surgical technique: Birmingham Hip[™] Resurfacing system. Available at: http://global.smith-nephew.com/cps/rde/xbcr/smithnephew/BHR_ST_Low_Res.pdf. Accessed March 21, 2012.
- Springer BD, Griffin WL, Fehring TK, Suarez J, Odum S, Thompson C. Incomplete seating of press-fit porous-coated acetabular components: the fate of zone 2 lucencies. *J Arthroplasty*. 2008;23(6 suppl 1):121–126.
- Steffen RT, Pandit HP, Palan J, Beard DJ, Gundle R, McLardy-Smith P, Murray DW, Gill HS. The five-year results of the Birmingham Hip Resurfacing arthroplasty: an independent series. *J Bone Joint Surg Br*. 2008;90:436–441.
- Stiehl JB, MacMillan E, Skrade DA. Mechanical stability of porous-coated acetabular components in total hip arthroplasty. *J Arthroplasty*. 1991;6:295–300.
- Torga Spak R, Stuchin SA. Cementless porous coated sockets without holes implanted with pure press-fit technique: average 6 year follow-up. *J Arthroplasty*. 2005;20:4–10.
- Udomkiat P, Dorr LD, Wan Z. Cementless hemispheric porous-coated sockets implanted with press-fit technique without screws: average ten-year follow-up. *J Bone Joint Surg Am*. 2002;84:1195–1200.