Primary Arthroplasty

Comparison of Cemented and Bone Ingrowth Fixation Methods in Hip Resurfacing for Osteonecrosis

Ryan J. O'Leary, Melissa D. Gaillard, MS [*], Thomas P. Gross, MD

Midlands Orthopaedics, Columbia, South Carolina

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ABSTRACT

Background: The optimal surgical treatment for osteonecrosis of the femoral head has yet to be elucidated. To evaluate the role of femoral fixation techniques in hip resurfacing, we present a comparison of the results for 2 consecutive groups: group 1 (75 hips) received hybrid hip resurfacing implants with a cemented femoral component; group 2 (103 hips) received uncemented femoral components. Both groups received uncemented acetabular components.
Methods: We retrospectively analyzed our clinical database to compare failures, reoperations, complications, clinical results, metal ion test results, and X-ray measurements. Using consecutive groups caused time interval bias, so we required all group 2 patients to be at least 2 years out from surgery; we compared results from 2 years and final follow-up.
Results: Patient groups matched similarly in age, body mass index, and percent female. Despite similar demographics, the uncemented, group 2 cases showed a lower raw failure rate (0% vs 16%; $P < .0001$), a lower 2-year failure rate (0% vs 7%; $P = .04$), and a superior 8-year implant survivorship (100% vs 91%; log-rank $P = .0028$; Wilcoxon $P = .0026$). In cases that did not fail, patient clinical ($P = .05$), activity ($P = .02$), and pain scores ($P = .03$), as well as acetabular component position ($P < .0001$), all improved in group 2, suggesting advancements in surgical management. There were no cases of adverse wear-related failure in either group.
Conclusion: This study demonstrates a superior outcome for cases of osteonecrosis with uncemented hip resurfacings compared to cases employing hybrid devices.
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Following success in elderly, inactive patients in the 1950s, Sir John Charnley's stemmed total hip arthroplasty (THA) design received acclaim and wide consideration as the paradigm of hip replacement prostheses; yet, he cautioned against use of THA in younger, active patients [1]. As Charnley predicted, standard stemmed THA exhibits inferior durability in these patients [2]. Hip resurfacing arthroplasty (HRA) offers an alternative to THA in young patients, providing a more functional [3], bone-preserving method. HRA offers numerous theoretical advantages, including minimal bone resection [4], greater stability [5,6], less thigh pain [7,8],

avoidance of stress shielding [9,10], ease of revision [11], resumption of high range-of-motion activities [12,13], and more nearly-normal gait [14-16]. During its nascent stages, HRA provided discouraging results [17], and as a result, many surgeons abandoned the concept entirely. During unsuccessful, early HRA procedures, the poor performance of polytetrafluoroethylene and metal-on-polyethylene bearings revealed the need for a reliable bearing material if a successful HRA procedure was to be realized [18,19]. In 1991, McMinn played an instrumental role in reviving HRA with a new cobalt-chromium (Co-Cr) metal-on-metal (MOM) implant system [20].

Despite excellent results for hybrid Co-Cr resurfacing implants using femoral cement in young men with osteoarthritis (OA) [21], outcomes for patients with osteonecrosis (ON) proved less favorable [22,23]. Our previous study revealed that the most common failure mode in patients with ON was femoral cement loosening [24]. Subsequently, our study on HRA patients of all diagnoses found that loosening occurred in 3% of cemented femoral components by 10 years postoperatively [5]. To address femoral cement fixation as a potential weak link in the MOM hip-resurfacing construct, we collaborated with Biomet to develop the

Table 1
Demographic Information.

Variable	Group 1	Group 2	P Value
Number of cases	75	103	—
Date range	January 2001-August 2013		—
Demographics			
Age	46 ± 12	45 ± 10	.588
Body mass index	27 ± 4	28 ± 5	.141
Female cases (# hips, %)	19/75 (25)	19/103 (18)	.267
Harris hip score (preoperative)	49 ± 12	53 ± 14	.042*
Diagnosis			
AVN (I)	0/75 (0%)	1/103 (1%)	.390
AVN (II)	2/75 (3%)	6/103 (6%)	.317
AVN (III)	32/75 (43%)	35/103 (34%)	.238
AVN (IV)	30/75 (40%)	61/103 (59%)	.011*
Unrecorded Ficat grade	11/75 (15%)	0/103 (0%)	<.0001*

Asterisk (*) represents a statistical difference.
Avascular necrosis (AVN) grades are shown.

uncemented Biomet ReCap™ system, which includes the first uncemented, fully porous-coated femoral component for MOM HRA. Its intended design pairs it together with the uncemented Magnum™ acetabular component. We first employed this porous ingrowth device in March 2007 and have continued to use it exclusively in all total resurfacing patients since 2008 [4].

The relative merits of these and other implants employing porous ingrowth fixation vs those fixed with poly-methylmethacrylate cement continue to be debated by surgeons and scientists worldwide. Porous fixation was first introduced in the 1970s, and now, approximately 60% to 90% of the 300,000 THAs performed per year in the United States involve these uncemented components [25]. As THAs move toward eliminating cement entirely, many HRA systems still continue to use femoral cement [24,26]. Although the results of cemented HRA implants are satisfactory for cases of OA [16,27], femoral failure in HRA remains a problem in high-risk, ON patients. The exothermic reaction generated from cement curing may lead to damage of the femoral head [28] and could influence these failure modes. A benchtop study [29] determined that increased temperature develops in cystic defects filled with cement, confirming the suspected hypothesis that cement results in thermal damage of the femoral head. In another study, the same author reported a higher incidence of femoral failures when cysts are present [28]. In our own study of femoral complications with head cysts, we found no difference in failure rate when cysts were present or not, but our technique involved filling cysts with acetabular bone graft before cementing [30]. This discrepancy between publications also supports the hypothesis that thermal injury from cement may be a causative factor in femoral failures after resurfacing. Hybrid fixation for MOM hip resurfacing is the current standard, but they exhibit a higher failure rate when implanted into patients with ON. Critics of uncemented femoral resurfacings contend that osteonecrotic femoral heads lack adequate blood supply to allow bone ingrowth and stable fixation into a porous coating. In our experience, however, we encounter live, bleeding bone at the base of the femoral head in all resurfacing cases for ON. If the femoral head were truly dead, we suggest that all implants would migrate radiographically and be symptomatic by 2-year follow-up.

The primary goal of this study is to examine 3 hypotheses on the reduction of femoral failure in resurfacing of the necrotic hip: First, uncemented fixation with a fully porous-coated implant will eliminate cement-related failures caused by thermal bone necrosis, cement toxicity to bone, or cement fatigue failure. Next, porous femoral implants will achieve stable implant fixation as evidenced by lack of migration or stem radiolucency at 2 years postoperation. Lastly, using a completely uncemented resurfacing system will eliminate both early and late femoral failure modes.

Materials and Methods

Patients and Methods

From January 2001 to August 2013, a single surgeon performed 3262 HRA procedures. Of these, we identified 178 cases (5.5%) in 150 patients with a primary diagnosis of ON as our study group from the prospective database. Choosing August 2013 as a cutoff allowed at least 2 years of follow-up for each patient. We offered

Table 2
Metal Ion Results and Associated Reference Values.

Variables	Group 1 (Hybrid)		Group 2 (Uncemented)		P Values Between Groups 1 and 2	
	Unilateral (N = 18)	Bilateral (N = 17)	Unilateral (N = 37)	Bilateral (N = 24)	Unilateral	Bilateral
Co (µg/L)*	1.2 ± 0.62	4.6 ± 10.6	3.1 ± 12.9	1.4 ± 0.69	.5369	.1463
Cr (µg/L)*	0.9 ± 0.60	3.5 ± 3.33	1.3 ± 3.50	1.5 ± 0.91	.6337*	**.0077***
Test date (y postoperative)*	7.9 ± 2.07	8.6 ± 1.36	3.0 ± 1.47	2.7 ± 0.91	**<.0001***	**<.0001***
#, % Patients tested	35 (47%)		61 (59%)		.0969	
#, % Levels converted	4 (22%)	3 (17%)	6 (16%)	5 (21%)	.5892	.8026
Total normal (#, %)	15 (43%)		39 (64%)		**.0455***	
Normal (#, %)	12 (67%)	3 (17%)	31 (84%)	8 (33%)	.1499	.2627
Optimal (#, %)	18 (100%)	16 (89%)	35 (95%)	24 (100%)	.3173	.2301
Acceptable (#, %)	0 (0%)	1 (5.5%)	1 (2.7%)	0 (0%)	.4839	.2301
Problematic (#, %)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1.000	1.000
Potentially toxic (#, %)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1.000	1.000

	Normal[a]	Optimal[b]	Acceptable[c]	Problematic[c]	Potentially Toxic[b]
Unilateral					
Co (µg/L)	<1.5	<4.0	4-10	10-20	>20
Cr (µg/L)	<1.5	<4.6	4.6-10	10-20	>20
Bilateral					
Co (µg/L)	<1.5	<5.0	5-10	10-20	>20
Cr (µg/L)	<1.5	<7.4	7.4-10	10-20	>20

Statistically significant P values are bolded and denoted by an asterisk (*).
[a] Laboratory normal for patients without metal bearings.
[b] According to DeSmet/van der Straeten.
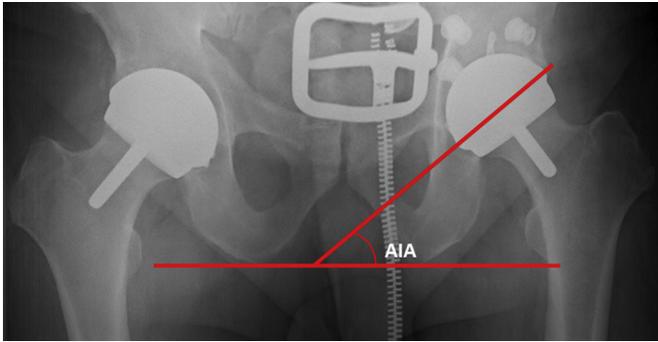[c] According to our previous analysis.

Fig. 1. Pelvic X-ray of a male patient with a cemented Corin device in their right hip from 2003 and an uncemented Biomet ReCap™ device in their left hip from 2009. AIA, acetabular inclination angle.

HRA to any patient younger than 65 years with ON and collapse as long as two-thirds of the femoral head was estimated to be viable. After the initial success of the uncemented component [24,31], we expanded the indication to include patients with only half of the head viable. All resurfacings employed an uncemented acetabular component. Between January 2001 and January 2008, 75 HRA procedures were performed in 64 patients using a cemented femoral component (group 1). The uncemented femoral ReCap™ component became available in March 2007 and was used in subsequent cases; this fully porous device was used exclusively beginning in January 2008. Between March 2007 and August 2013, 103 fully uncemented HRA procedures were performed in 86 patients (group 2). Magnum components, which are approved as a dual-mobility device, were used in an off-label fashion. Demographic information and grade of ON according to Ficat's classification [32] are listed in Table 1. Institutional review board

approval was obtained from Sisters of Charity Providence Hospitals, Columbia, South Carolina.

Implants

Two HRA devices were used in group 1; these include the hybrid Corin Cormet 2000 (Corin Group, Cirencester, Gloucestershire, United Kingdom) in the first 43 cases and the cemented ReCap™ with the uncemented Magnum™ (Biomet, Warsaw, IN) in the next 32 cases. Starting in March 2007, the fully porous-coated ReCap™-Magnum™ was used in all 103 uncemented cases.

The metallurgical composition of the Biomet system is high-carbon (0.2%) cast Co-Cr alloy without heat treatment. Each individual component was quality tested, with surface roughness less than 0.5 μm and a radial clearance of 75 μm. The ReCap™ femoral component has a hemisphere undersurface on top of a cylindrical section. The cylindrical stem is 8 mm in diameter. The apex of each component is 6-mm thick, tapering to 0 at the head-neck junction. The cemented femoral component has a grit blast Co-Cr under-surface with a machined radial gap of 0.5 mm for cement. The uncemented femoral component has a titanium plasma-spray plus hydroxyapatite coating for enhanced bone ingrowth. Similar femoral tools are used, but the uncemented femoral component has a 0.5-mm radial press fit over the machined bone surface. The femoral instrumentation was the first designed using a measured resection philosophy. This allows the surgeon to reproduce femoral length or to increase or decrease it by up to 6 mm to correct for mild deformity.

This was also the first system to offer 2-mm increment sizing to allow more accurate matching of the implants to the patient's particular anatomy, with femoral component sizes ranging from 38 to 60 mm. A matching Magnum™ acetabular component was originally available for each femoral size, and beginning in 2007, an
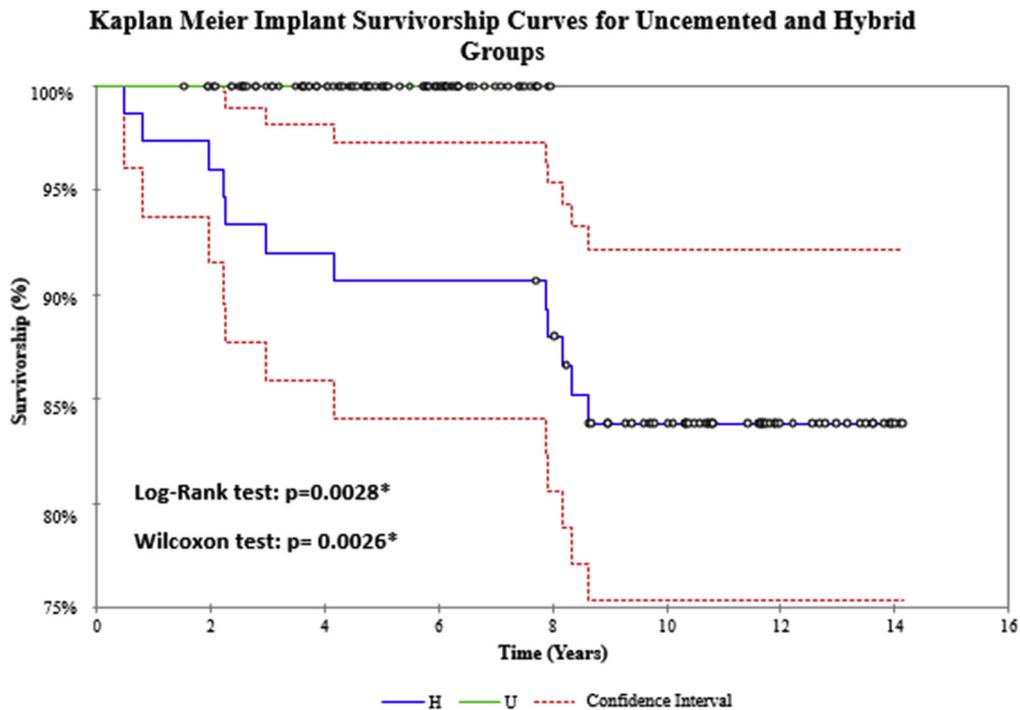

Fig. 2. Kaplan-Meier survivorship analysis using revision as an endpoint. Survivorship at 8 years was 88% for the hybrid group and 100% for the uncemented group. Results of the log-rank test (*P* value = .0028) and Wilcoxon test (*P* value = .0026) revealed femoral fixation method (cemented/uncemented) is a significant factor affecting survivorship. We postulate that cemented fixation of the femoral component is the most significant risk factor in HRA. "H" stands for hybrid and "U" stands for uncemented. White circles represent deaths unrelated to the patients' hip arthroplasties. An asterisk (*) represents a statistical difference. HRA, hip resurfacing arthroplasty.
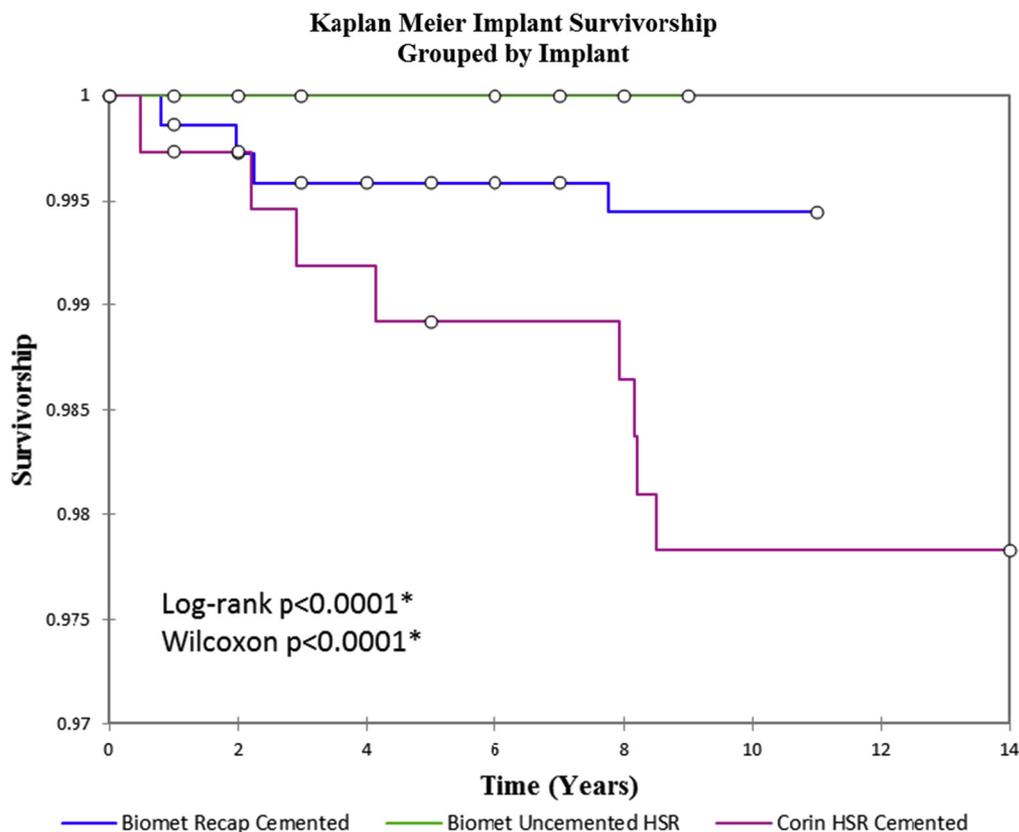
Fig. 3. Kaplan-Meier survivorship analysis grouped by implant type using revision as an endpoint. Results of the log-rank test (P value < .0001) and Wilcoxon test (P value < .0001) revealed difference in survivorship is significant between the least (uncemented ReCap™) and most (cemented Corin) frequently failed groups. White circles represent deaths unrelated to the patients' hip arthroplasties. An asterisk (*) represents a statistical difference.

additional Magnum™ Tri-Spike component also became available for each size.

The acetabular component is 3-mm thick at the equator and 6-mm thick at the pole, including the porous coating. Additional thickness at the apex increases stiffness of the components, decreasing deformation during impaction. The porous coating is titanium-plasma spray to allow for bone ingrowth. Four pairs of small fins are present to add rotational control. The acetabular bearing profile arc ranges from 154.6° in the smallest component to 163.6° in the largest component. These implants are slightly thinner than most others on the market.

The Corin device is no longer sold. It had similar metallurgy as the Biomet devices but was heat treated. The femoral implant was cemented employing a grit blast femoral component and instruments to cut a line-to-line fit. Three derotational longitudinal splines were present. The acetabular component had a 2-mm rim flare and 3 peripheral thick fins, and the coating was dual titanium-plasma spray with hydroxyapatite. Coverage arcs were similar to the Biomet device.

Procedure

All HRA cases were performed through the posterior approach as previously described [33]. Loose necrotic bone and cystic soft tissue were removed, and well-fixed necrotic bone was bored into with a 1/8-inch drill. Cement technique in group 1 included applying high-viscosity cement in thin layers to both implant and bone immediately after mixing, and the segmental bone defect was filled with cement. A cement trough was present on the inferior surface of the head for cement to escape. In group 2, defects were

filled with acetabular reamings before impacting the uncemented femoral component.

Postoperative Protocol

Weight bearing was advanced as tolerated by the patient. For most patients, crutches were used for 2 weeks and a cane for 2 weeks thereafter. There was no formal physical therapy required following hospital discharge. Unlimited activity was allowed at 6 months after surgery. The use of multimodal pain management and comprehensive blood management protocols eliminated the need for transfusion and accelerated recovery. Since 2012, resurfacing has been performed as an outpatient procedure on select patients.

Metal Ion Testing

We use our database to collect blood, serum, and plasma metal ion test results, which we routinely ask of our patients at 2 years postoperation. We initiated routine ion testing in 2007, and we also recommended ion testing at least once for all patients operated on before this time. As previous reports suggest, we use metal ion levels as indicators for potential failure due to excessive implant wear, a phenomenon we refer to as adverse wear-related failure (AWRF) [34]. We used whole blood ion levels for all comparisons, and in cases with only serum or plasma levels recorded, results were converted to whole blood ion levels by Smolders' method [35]. In our opinion, the most scientifically valid blood ion data and guidelines have been published by DeSmet and Van der Straeten [36]; therefore, we employed their methods to categorize ion levels as either "optimal" or
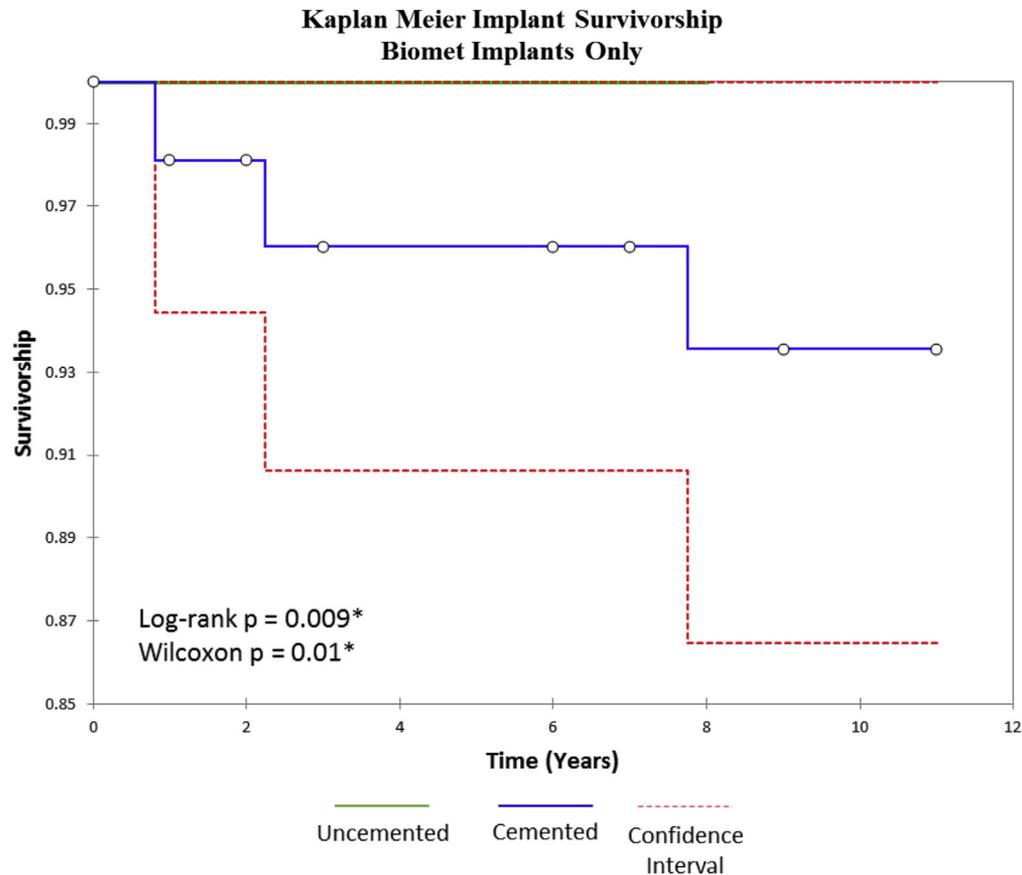
Fig. 4. Kaplan-Meier survivorship analysis for Biomet implants only using revision as an endpoint. Results of the log-rank test (*P* value = .009) and Wilcoxon test (*P* value = .01) show that the uncemented ReCap™ device has significantly greater survivorship than its uncemented counterpart. White circles represent deaths unrelated to the patients' hip arthroplasties. An asterisk (*) represents a statistical difference.

"potentially toxic." We expanded these classifications based on our own previous research and defined whole blood ion levels <10 μg/L as "acceptable" and those ≥10 μg/L as "problematic" [37-39]. In all, we established 5 different ion level categories: normal, optimal, acceptable, problematic, and potentially toxic (See Table 2 legend for metal ion reference values).

Clinical and Radiologic Analysis

Office or remote follow-up was requested of all patients at 6 weeks, 1 and 2 years, and every other year thereafter. A clinical questionnaire, radiograph analysis, and a physical examination testing range-of-motion and strength were performed at each visit; physical examinations were no longer completed routinely on remote follow-ups after 1 year. We used the OrthoTrack database (Midlands Orthopaedics, Columbia, SC) for collection and analysis of the demographic, clinical, metal ion, and radiographic data.

Patient questionnaires collected information to calculate the following scores for clinical evaluation: Harris hip score for functional assessment (HHS) [40], University of California, Los Angeles (UCLA) activity score [41], and visual analog scale (VAS) pain score for normal and worst days [42]. UCLA activity scores measure activity level after surgery on a scale from 1 to 10, for which 10 represent the highest level of activity; VAS pain scores rate the level of pain from 0 to 10, with 0 representing no pain and 10 representing maximum, debilitating pain.

Supine and standing anterior-posterior pelvis and lateral radiographs are taken and analyzed for component position, shifting, and radiolucencies. The acetabular inclination angle (AIA) is determined by taking the angle between a measurement line running across the face of the acetabular component and a reference line horizontal across the inferior pubic rami (Fig. 1). All measurements were taken using OrthoTrack (Midlands Orthopaedics) and InteleViewer (InteleRAD, Chicago, IL).

Statistical Analysis

Statistical analyses were performed using Microsoft® Excel (Microsoft, Redmond, WA) and JMP® (SAS, Cary, NC). Paired, 2-tailed Student *t*-tests were performed to find significant differences between numeric variables, and chi-square analyses were used to determine differences in categorical variables. Two-sample proportion Z-tests were used to compare ratios between the 2 groups. All tests were carried out at α = 0.05. Kaplan-Meier (KM) survivorship curves were generated using revision as an endpoint to estimate postoperative survival rates of implants. A log-rank test and a Wilcoxon test, at α = 0.05, were performed to test whether the implant survivorships were statistically different.

Results

KM implant survivorship (Fig. 2) at 8 years using revision as an endpoint was 100% for group 2, compared to 91% for group 1 (log-rank *P* = .0028; Wilcoxon *P* = .0026). Two-year KM implant survivorship using revision as an endpoint was 100% for uncemented group 2 and 93% for hybrid group 1 (*P* = .04). We present KM survivorship grouped by implant type for all failures (Fig. 3), for Biomet implants only (Fig. 4), for cemented femoral
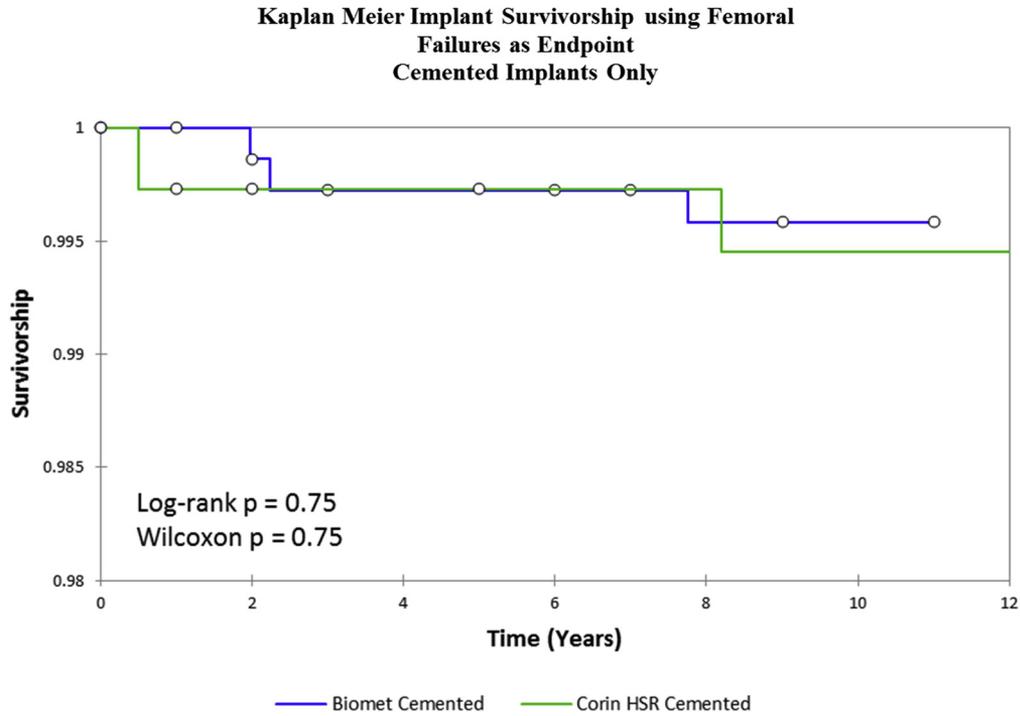
Fig. 5. Kaplan-Meier survivorship analysis for cemented implants only using femoral revision as an endpoint. Results of the log-rank test (*P* value = .75) and Wilcoxon test (*P* value = .75) show that there is no significant difference in overall femoral failures between cemented devices. This supports that the reduction of femoral failures over time is not a result of improved surgeon experience but rather the elimination of cemented fixation. White circles represent deaths unrelated to the patients' hip arthroplasties. An asterisk (*) represents a statistical difference.

Fig. 6. Kaplan-Meier survivorship analysis for uncemented vs grouped cemented implants using only femoral revision as an endpoint. Results of the log-rank test (*P* value = .05) and Wilcoxon test (*P* value = .05) show that uncemented fixation has significantly fewer femoral failures. White circles represent deaths unrelated to the patients' hip arthroplasties. An asterisk (*) represents a statistical difference.
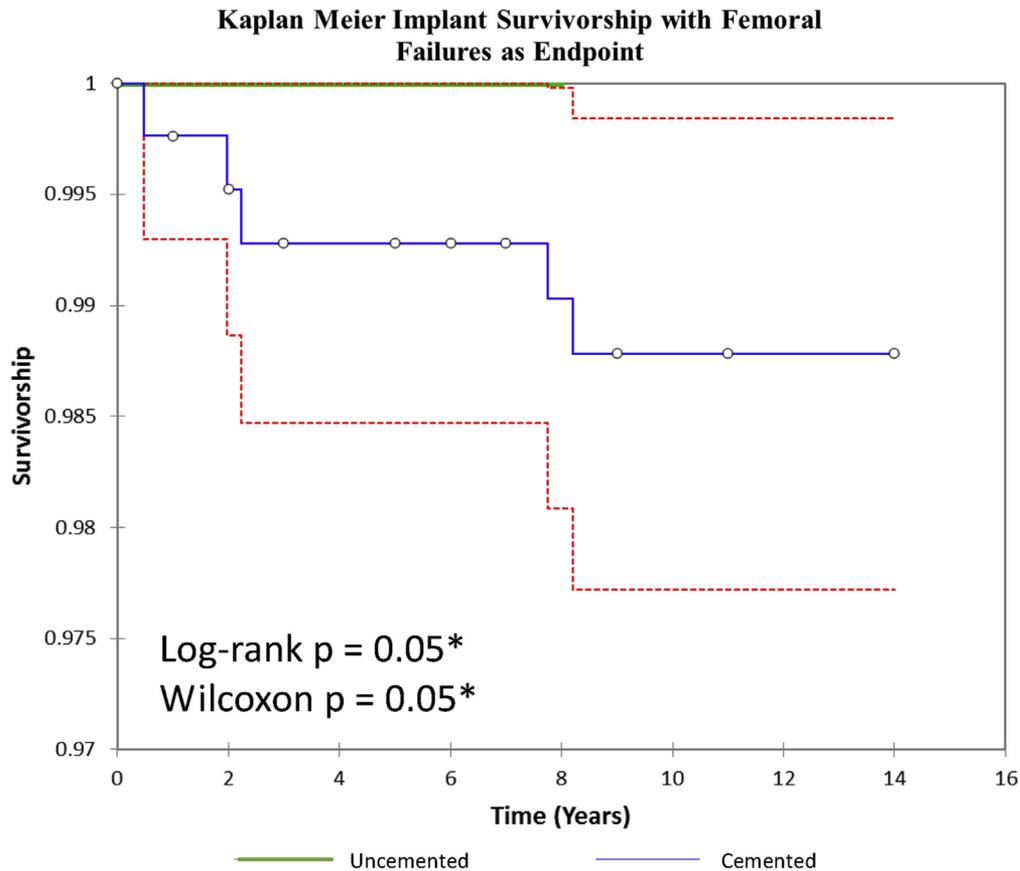
Table 3
Summary of All Failures.

Mode of Failure	Group 1	Group 2	P Value
Total failures	12/75; 16%	0/103; 0%	<.0001*
Femoral failure			
Femoral component loosening	5/75; 7%	0/103; 0%	.008*
Acetabular failure			
Acetabular component loosening	2/75; 3%	0/103; 0%	.095
Other failure			
Unexplained pain	1/75; 1%	0/103; 0%	.238
Deep infection (hematogenous, late)	2/75; 3%	0/103; 0%	.095
Psoas tendonitis	1/75; 1%	0/103; 0%	.238
Recurrent dislocation	1/75; 1%	0/103; 0%	.238

Cases that resulted in revision of the HRA replacement were considered failures.
An asterisk (*) represents a statistical difference.

failures only (Fig. 5), and for group 1 and 2 femoral failures (Fig. 6). Four ON patients, all from group 1, died of causes unrelated to their hip arthroplasties.

Failures requiring component revision are listed in Table 3. No cases in group 2 failed, whereas in group 1, 16% of hips (12/75) failed ($P < .0001$). The most common mode of failure was loosening of the femoral component (5/75; 6.7%), accounting for 42% of all failures. All 5 femoral failures were revised to THA. Two of the group 1 failures (2/75; 2.7%) were caused by loosening of the acetabular component: 1 failure occurred at 5 years and was revised to a THA; the other occurred at 8 years and was treated with an acetabular component revision. Five cases failed due to other causes and were all converted to THA. These included 2 cases of late, hematogenous infections (2/75; 2.7%), a recurrent dislocation revised by another surgeon (1/75; 1.3%), 1 case of unexplained pain (1/75; 1.3%), and 1 case of psoas tendonitis (1/75; 1.3%). The 39-year-old female with unexplained pain presented slightly elevated ion levels of Co = 11.9 µg/L and Cr = 7.6 µg/L; at revision surgery, components were found well fixed, and there were no signs of metallosis. Ion levels were resolved to optimal levels by 3 months postoperation. The 52-year-old patient with psoas tendonitis was revised 8 years after her original surgery, reported metal ion levels of Co = 2.1 µg/L and Cr = 2.0 µg/L, and her implant components were found to be well fixed during revision surgery.

Reoperations and other complications not requiring surgery are reported in Table 4. Group 1 hip-related complications occurred in 2.7% of cases (2/75); there was no significant difference in this frequency of complications compared with group 2. One hybrid-group patient suffered a late, nondisplaced, greater trochanteric fracture that healed with conservative treatment, and the other

patient suffered a femoral shaft fracture 14 years after resurfacing and was treated with open plating.

Group 2 hip-related complications occurred in 4% of cases (4/103). One patient developed a superficial infection and was cured surgically without implant removal. Another patient incurred wound necrosis, which was treated with plastic surgery without loss of the implant. In 2 cases, significant shifting of the acetabular component occurred within several days postoperatively but quickly stabilized, and both patients were asymptomatic with optimal metal ion levels.

Clinical and radiographic data from most recent follow-up visits are summarized in Table 5. Average postoperative HHS scores for both groups significantly improved from before surgery ($P < .0001$), and most of the patients (4/8 group 1, 30/60 group 2 follow-up patients; 50% for both groups) resumed active lifestyles (UCLA ≥ 7) by 2 years postsurgery. Average postoperative UCLA activity scores were 6.0 and 6.7 for the hybrid and uncemented groups, respectively ($P = .022$). Average HHS at 2 years significantly improved in both groups by approximately 45 points, but both preoperative ($P = .042$) and postoperative HHS ($P = .005$) were reported higher on average for group 2. These patients also reported lower average VAS pain scores than group 1 (1.1 vs 2.3 on worst days, $P = .003$, and 0.2 vs 0.5 on regular days, $P = .049$).

Although we lacked the quantitative data necessary for statistically valid proof on extent of fixation, a visual comparison of microradiographs (Fig. 7) between cemented and uncemented implants highlights the disparity between the 2 groups. Whereas the microradiograph from group 1 shows fair penetration of the cement into the bone, the microradiograph from group 2 shows extensive bone growth into the porous implant surface, creating a well-fixed, living, stable bone-implant interface. Routine radiographic analysis confirmed that there were no reported instances of osteolysis or radiolucency observed in either group, with the exception of cases ending in failure.

After our development of the Relative Acetabular Inclination Limit (RAIL) guidelines in 2009 [43], which aims to prevent metal ion wear through the optimal placement of acetabular components, 100% of group 2 implants (101/101 recorded values) were placed at an appropriate steepness, whereas group 1 implants met RAIL criteria in only 80% of cases (57/71 recorded values; $P < .0001$). X-ray analysis revealed that the average AIA was significantly less steep in group 2, with an average angle of 46° for the hybrid group and 36° for the uncemented group ($P < .0001$).

Concomitant metal ion data and reference values are presented in Table 2. A significantly higher percentage of patients in group 2 than in group 1 had normal ion levels (64% vs 34%; $P = .045$).

Table 4
Summary of Complications and Reoperations.

Reason for Complication/Reoperation	Group 1	Group 2	P Value
Total	2/75; 3%	4/103; 4%	.659
Complications			
Shift in acetabular component position (asymptomatic)	0/75; 3%	2/103; 2%	.226
IT fracture (late)	1/75; 1%	0/103; 0%	.238
Nerve palsy	0/75; 0%	0/103; 0%	1.000
DVT/PE	0/75; 0%	0/103; 0%	1.000
Reoperations			
Femoral fracture (late)	1/75; 1%	0/103; 0%	.238
Superficial infection (early)	0/75; 0%	1/103; 1%	.389
Deep infection (early)	0/75; 0%	0/103; 0%	1.000
Wound necrosis	0/75; 0%	1/103; 1%	.389

Complications were separated into 2 categories: complications that were observed and those requiring reoperation.
An asterisk (*) represents a statistical difference.
DVT, deep venous thrombosis; PE, pulmonary embolism; IT, intertrochanteric.

Table 5
Clinical and Radiographic Data.

Variable	Group 1	Group 2	P Value
Clinical data			
Harris hip score (Postoperative)	94 ± 11	98 ± 6	.005*
UCLA activity score	6.0 ± 2	6.7 ± 2	.022*
VAS pain—regular day	0.5 ± 1	0.2 ± 1	.049*
VAS pain—worst day	2.3 ± 3	1.1 ± 2	.003*
Radiographic data			
Acetabular inclination angle (°)	45 ± 6	35 ± 4	<.0001*
Cases meeting RAIL (#/%)	57/71; 80	101/101; 100	<.0001*
Radiolucency (#/%)	0/75; 0	0/103; 0	1.000
Osteolysis (#/%)	0/75; 0	0/103; 0	1.000

Cases of radiolucency and osteolysis noted in the table exclude cases ending in failure.
An asterisk (*) represents a statistical difference.
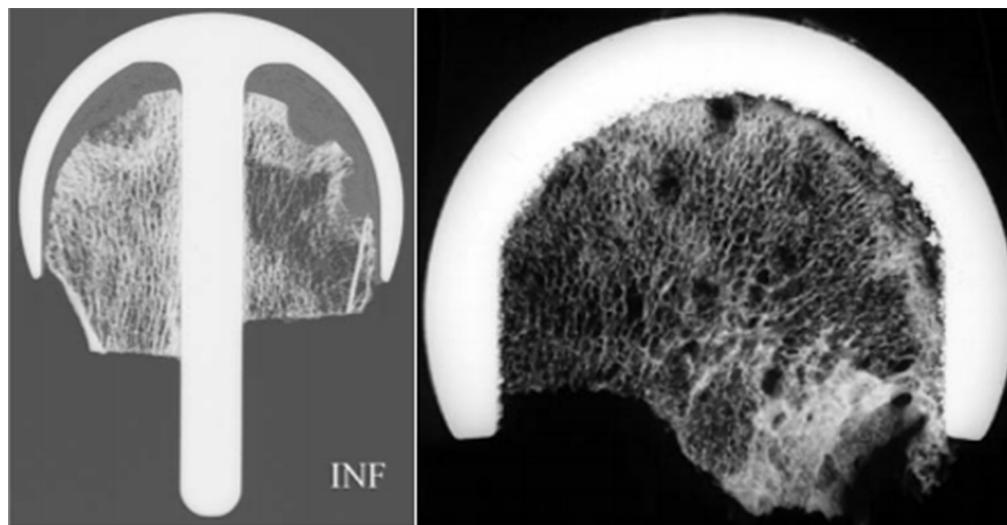RAIL, Relative Acetabular Inclination Limit [43].

Fig. 7. On the left is a microradiograph of a spliced section of a cemented femoral component. The thick layer of cement has penetrated into the bone of the femoral head. On the right is a microradiograph of a spliced section of a fully porous-coated, uncemented femoral component. The component is tightly wedged to the femoral head.

Additionally, Cr levels in bilateral group 2 patients were significantly lower than bilateral group 1 cases (1.5 vs 3.5 μg/L; $P = .0077$). There were no other significant differences in the data. There were no cases of AWRF in either group. After the 2007 implementation of routine ion level collection at our clinic, substantially more metal ion data were available (59% vs 24%, respectively; $P < .0001$), and the interval from surgery to the procurement of ion levels was less (3 vs 8 years; $P < .001$) for group 2 than group 1. Metal ion results were converted from serum or plasma levels to whole blood levels to facilitate analysis; this conversion occurred in 20% of cases from group 1 and 18% of cases from group 2 ($P = .81$). Rate of compliance with metal ion testing was less for these ON groups compared to the entire database (60% vs 74%; $P < .0001$).

Groups 1 and 2 were demographically similar (Table 1), although patients from the uncemented group tended to score higher preoperative HHS ($P = .042$). Although these data indicate more high-risk ON grades were present in group 2 ($P = .011$), there were significantly more unrecorded Ficat grades in group 1

($P < .0001$). The average follow-up duration for group 1 was 11 years (range, 8-14 years), and due to the uncemented femoral component not becoming available until March 2007, group 2 had a significantly shorter average follow-up duration ($P < .0001$) with a mean of 5.0 years (range, 2-8 years).

Discussion and Conclusions

These data support all 3 of our initial hypotheses: Our first hypothesis, that no more failures would occur from thermal necrosis or other cement-related complications, holds true as evinced by the complete elimination of femoral failures upon evolving to uncemented, porous devices in 2008. Furthermore, the present study verified our second hypothesis by validating an absence of radiolucencies and component migration in all group 2 cases. Finally, these data justified our third hypothesis because KM survivorship was significantly greater at both the 2-year and 8-year intervals. Simple visual inspection of the KM graphs (Figs. 2-5)

Table 6
Literature Comparison Between Survivorship of Various Surgical Procedures for ON Patients.

Study	Procedure	Prosthesis	Date Range	Diagnosis	Patient Cohort Hips	Patient Cohort Female	Average FU (y)	Survivorship FU	Survivorship Rate
Seyler et al [54]	Nonvascularized bone grafting	—	2002-2004	ON	39	41%	2	2	78.0%
Yoo et al [55]	Vascularized bone grafting	—	1979-1995	ON	124	15%	12	12	89.0%
Mont et al [56]	Multiple drilling	—	—	ON	45	—	2	2	71.0%
Song et al [57]	Multiple drilling	—	—	ON	163	—	7.2	7.2	88.0%
Mont et al [58]	Core decompression	—	—	ON	1206	—	—	—	63.5%
Min et al [59]	THA	—	—	ON	162	—	7.2	7.2	100%
Garino et al [60]	THA	—	—	ON	123	40%	4.6	5	98.0%
Kim et al [61]	THA	Cementless Spotorno	1993-1995	ON	114	32%	9	10	97.8%
Bose et al [62]	HRA	Birmingham	2000-2005	ON	96	16%	5.4	5.4	95.4%
Daniel et al [63]	HRA	Birmingham	1994-2003	ON	66	—	7.1	9.6	86.0%
Amstutz et al [64]	HRA	Conserve Plus	1996-2006	ON	85	19%	7.6	8	93.9%
Revell et al [65]	HRA	Birmingham	1994-2004	ON	73	29%	6.1	6.1	93.2%
Beaulé et al [66]	HRA	Conserve/Conserve Plus	1996-2002	ON	84	18%	4.9	4.9	96%
Aulakh et al [67]	HRA	—	1997-2002	ON	101	23%	7.5	7	97.7%
Mont et al [68]	HRA	Conserve Plus	2000-2003	ON	42	31%	3.2	3.2	94.5%
Present study, hybrid	HRA	Corin Cormet 2000/Biomet hybrid	2001-2008	ON	75	25%	11.3	8	88.0%
								14	84%
Present study, uncemented	HRA	Biomet fully porous-coated	2008-2013	ON	103	18%	5	8	100%

FU, follow-up; THA, total hip arthroplasty; HRA, hip resurfacing arthroplasty; ON, osteonecrosis.

should convince the reader of the dramatic difference between these 2 fixation study groups.

Despite unnecessary fears of AWRF arising from notorious complications with DePuy ASR systems [44] and poor results at 1 major academic center [45], we found success in avoiding this failure mode entirely in both groups of this study. We reported similar success in 2014 in the largest AWRF study of its kind. Similar to the findings of others [35], we found that steeper AIA correlated to higher ion levels [43,46]. In the present study, mean AIA was significantly lower and more cases met the RAIL guideline in group 2, likely due to our focus heavily shifting onto optimal implant alignment in 2007. Our previous study [43] discusses improvements in surgical techniques to achieve this new goal, and the present study's clinical outcomes reflect these advancements. However, as there are no cases of AWRF in either cohort, this intervention does not conflict with fixation method and its effect on overall change in failure rate.

We note these improvements in the failure rate as well as clinical scores given that all were statistically superior for uncemented cases. Group 2 average HHS and VAS scores were improved from group 1. Likewise, postoperative UCLA activity scores also improved for group 2, which shows consistency with data from others [47,48] and indicates, unlike stemmed THA [49], that high activity does not increase the chance of implant failure with HRA.

This study contains several limitations, including 1 notable shortcoming arising from the employment of nonconcurrent groups. We previously determined [5] that all causes of failure are reduced by greater surgeon experience with resurfacing using a single implant. Smith [50] demonstrated that surgeons who perform less than 5 HRA procedures per year achieve lower implant survivorship with HRA than with THA at 5 years. In the present study, group 1 cases were completed over the first 7 years of the senior author performing this operation, whereas group 2 were in the subsequent 6 years of surgeries. Therefore, we recognize the reasonable argument that these improved results potentially arose from enhanced knowledge and technical skills rather than advancements in fixation technique. However, the KM curve for cemented implants only (Fig. 4) shows that there is no difference in femoral survivorship based on improvement in surgical skill alone. Additionally, the present 2-year comparison is valid. This comparison, and the 100% implant survivorship at 8 years, certainly convinces us to employ exclusively uncemented devices, eliminating potential for a future randomized trial at our clinic. We encourage others who still doubt the superiority of porous ingrowth femoral fixation in HRA to undertake such a comparison. The second most notable limitation is the low rate of ion data obtained for ON group 2, which is significantly lower than in our overall database. The cost and inconvenience of going to a special laboratory seems to be too much for patients that show excellent clinical outcome. Additionally, ON patients seem to be less compliant with recommendations than our general patient population, which we suspect may be due to the high rate of alcoholism.

The present study presents an 8-year implant survivorship of 100% in 103 consecutive uncemented hip resurfacings, exceeding previously published results for osteotomy, bone grafting, stemmed THA, and hybrid resurfacing in ON (Table 6). The present study of 178 patients represents the largest report of HRA for patients with ON of the femoral head. Earlier studies of hybrid HRA in patients with ON present survivorship percentages ranging from 86% to 98% [16,24,26,28]. Our 100% success rate in the uncemented group, with an average follow-up of 5 years (range, 2-8 years), is the best reported midterm survival rate of HRA for ON, to our knowledge.

Although implant survivorship for HRA performed by expert surgeons [51] are superior to those of THA in young men with OA [52,53], resurfacings in certain high-risk subgroups, such as ON, have

continued to exhibit undesirable durability similar to THA systems. This study demonstrates that, with uncemented fixation, HRA can be dramatically improved for these challenging cases. Many resurfacing surgeons have limited or abandoned hybrid resurfacing in ON because of the less favorable results when compared to OA. Based on the notable results reported herein, we suggest that these surgeons consider uncemented resurfacing as an alternative.

1. HRA with porous ingrowth femoral components provides superior clinical results and better implant survivorship than cemented HRA in patients with ON.
2. 100% of uncemented resurfacings achieve stable fixation in ON by 2 years postoperation.
3. AWRF is rare in HRA for the treatment of ON of the femoral head, which primarily occurs in young men (80% of ON cases).
4. Reducing AIA improves wear of metal bearings as shown by the reduction of blood ion levels.
5. The results of uncemented HRA compare favorably with the results of THA and other nonarthroplasty options for advanced-stage ON.

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