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Interventions for Improving Hip Resurfacing Outcomes in Women: A High-Volume, Retrospective Study

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ABSTRACT

Background: Women seeking surgical intervention for their hip disorders will often find total hip arthroplasty (THA) presented as their only option. THA, when compared with hip resurfacing arthroplasty, removes substantially more bone-stock, limits range-of-motion, exhibits increased dislocation risk, and presents greater overall 10-year mortality rate. Despite these risks, most surgeons continue to select against women for hip resurfacing because registries notoriously report inferior survivorship when compared with men and THA.

Methods: We investigated the reasons for why resurfacing arthroplasty devices survive poorly in women to develop interventions which might improve hip resurfacing outcomes in women. Using these findings, we developed a series of surgical interventions to treat the underlying issues. Herein, we compare 2 study groups: women who received hip resurfacings before (group 1) and after (group 2) these interventions.

Results: Eight-year implant survivorship substantially improved from 89.6% for group 1 to 97.7% for group 2. Adverse wear-related failure, femoral component loosening, and acetabular component loosening were all significantly reduced in group 2, which we attribute to the implementation of our relative acetabular inclination limit guidelines, use of uncemented femoral fixation, and selection of the Tri-Spike acetabular component for supplemental fixation, respectively. Kaplan-Meier implant survivorship curves, grouped into 2-year time intervals, show that the disparity in failure rates between men and women is diminishing.

Conclusion: When experienced surgeons use refined and proper surgical technique, women show promise as excellent candidates for hip resurfacing as an alternative treatment for their debilitating hip conditions.

Although total hip arthroplasty (THA) has become an increasingly successful operation, hip resurfacing arthroplasty (HRA) presents higher function [1,2], better stability [1,2], greater bone preservation [1,3,4], decreased overall 10-year mortality rate [5,6], and improved durability [1,3,7]. For these reasons, women who desire to return to high-impact sports or extreme range of motion (ROM) activities find functional advantages in HRA over THA. However, reports suggest that women who have undergone HRA are more likely than men to experience femoral neck fracture [3,4], loosening of the acetabular component [2], metallosis [8–10], and persistent pain [2,11]. As such, many resurfacing surgeons select against patients by gender for the procedure, limiting the options available to women. We instead chose to identify the underlying issues that lead to high rates of failure in women and to develop strategies for improved implant survivorship and clinical outcome.

Recent studies have examined hip morphology in each sex to explain these distinct failure patterns [7,11]. In older women, femoral notching and poor bone quality have been cited as risk factors for femoral neck fracture [3], while higher incidence of hyperosteoidosis and excessive lymphocyte infiltration in women is associated with persistent pain [11]. Other studies have found that women require small femoral components (<48 mm) more often than men and that it is smaller components, and not gender, that increase risk of revision [1,12,13].

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We have developed guidelines for positioning each femoral component size with normalized-to-standing intraoperative radiographs (NSIOR), nullifying the risk associated with smaller average femur size in women [10,14]. Despite higher functional results than THA [15,16], overall use of hip resurfacing has declined because of the technical difficulty of the operation, the reports of adverse wear-related failure (AWRF), and the fear of cobalt toxicity [8,17–19]. We have shown previously [10] that our relative acetabular inclination limit (RAIL) positioning guidelines eliminated the occurrence of wear failure and abnormal metal ion levels in our general patient population, and we expect to retrospectively find that these guidelines have had a similar desired effect in women.

We suggest if each of the identified risks can be addressed individually with separate surgical interventions, survivorship in women would improve. Based on analysis of our single-surgeon database of more than 3700 resurfacings over 14 years, we explore the difference in results between women before (group 1) and after (group 2) establishing these interventions and elucidate the rate of improvement for both genders. By providing encouraging results, we hope that more surgeons gain the confidence to perform HRA in women, making this bone-preserving procedure more widely available.

Materials and Methods

Patient Cohort

From January 2001 to December 2014, a single surgeon performed 3777 consecutive metal-on-metal HRA procedures, of which, 27% were women. Choosing December 2014 as our date range cut-off point ensured a minimum of 2 years of follow-up results for both study groups. Group 1 consisted of 357 cases in 309 females performed before 2008, before the establishment of the newly developed surgical interventions. Group 2 comprises 654 resurfacings in 556 females. Table 1 lists demographic information for the 2 study groups. We chose surgical candidates who had significant deformity or narrowing of the hip and joint space; we did not select against patients based on age or sex.

Surgical Interventions

All surgical interventions were instituted gradually; we therefore chose 2008 as an approximate time in which all techniques had been implemented. These interventions and their intended effects include the following:

1. Additional acetabular fixation in selected, high-risk cases using the Tri-Spike component to reduce early acetabular failures.
2. RAIL guidelines [10] and NSIOR [20] for facilitating optimal acetabular component positioning to reduce wear failure.
3. Bone management program designed to increase bone turnover and reduce the risk of early femoral failure (EFF), femoral neck fracture, and femoral head collapse.
4. Employment of exclusively uncemented fixation [21] to reduce risk of late femoral loosening.

Implants

This study included 3 implant systems used in a consecutive fashion: the hybrid cemented Corin Cormet 2000 (119 hips), the hybrid cemented Biomet Magnum-ReCap (212 hips), and the uncemented Biomet Magnum-ReCap (690 hips). From 2001-2005, Corin Cormet 2000 implants were used as part of an Food and Drug Administration Investigational Device Exemption study. The senior author was involved in designing the Biomet system and switched to the hybrid cemented Biomet Magnum-ReCap implant, which was subsequently used from 2005-2007. Because of a strong surgeon bias for uncemented fixation, the surgeon switched to the uncemented Biomet Magnum-ReCap implant as soon as it became available in 2007. There was a transition period in 2007 because of implant availability; but after January 2008, all implants were exclusively uncemented.

In 2007, the Tri-Spike Magnum acetabular fixation component became available. This implant was identical to the standard Magnum component save for the addition of 3 small, smooth spikes. This implant was significantly more demanding to implant and correctly adjust position, but it did provide supplemental fixation for high-risk cases. It was recognized that patients with severe dysplasia, osteoarthritis with segmental wall defects, and osteoporotic patients would benefit from this supplemental fixation. It continues to be used on a selective basis in patients with any diagnosis in which the trial component is >30% uncovered, and in all patients who have had an acetabular complication on the opposite hip, or who have a DEXA scan T-score <−2.5 on the operative femoral neck. We hypothesized that this strategy would lead to a decrease in early acetabular failures.

Table 1
Demographics for 2 Female Cohorts.

Variable	Group 1, <2008	Group 2, >2008	*P* Value
Date range	January 2001-December 2007	January 2008-December 2014	—
# Cases	367	654	—
# Deceased[a]	6 (1.6%)	0 (0%)	**.0010**
Demographics	—		
Mean follow-up, y	11.7 ± 1.8	5.5 ± 2.0	**<.0001**
Age, y	50.3 ± 9.4	53.8 ± 8.0	**<.0001**
BMI, kg/m^2	25.9 ± 5.2	25.2 ± 4.8	**.0155**
T score	0.2 ± 1.6	−0.2 ± 1.2	**.0043**
Diagnoses	—		
Osteoarthritis	232 (63%)	363 (55.5%)	**.0164**
Dysplasia	84 (23%)	242 (37.0%)	**<.0001**
Rheumatoid arthritis	3 (0.8%)	2 (0.3%)	.2627
Post-trauma	3 (0.8%)	6 (0.9%)	.8729
Legg-Calve-Perthes disease	6 (1.6%)	9 (1.4%)	.7414
Slipped capital femoral epiphysis	3 (0.8%)	3 (0.5%)	.4715
Osteonecrosis	26 (7.1%)	21 (3.2%)	**.0047**
Other	10 (2.7%)	8 (1.2%)	.0801

Bold values indicate statistical significance of *P*-values.
BMI, body mass index.
[a] Deaths are unrelated to the patients' hip arthroplasties.

Surgical Procedure

The senior author performed all HRA operations through the posterior approach, as described previously [22]. Over time, the approach was modified to enhance the procedure as improvements were found [10,22,23]. Before 2009, acetabular components were positioned with an acetabular inclination angle of under 55°, based on research by De Smet et al [24]. The RAIL guidelines were developed and implemented in 2009; these guidelines provide an acetabular inclination angle limit based on femoral component size. We use 25° as our lower limit. The NSIOR x-ray technique was refined to ensure that acetabular components were implanted per the RAIL. This process, described previously [22], was implemented gradually and evolved over 2 years; it was in place in its entirety by January 2008. To prevent heterotopic ossification, we wrapped a wet towel around the femoral neck to collect dust, prescribed anti-inflammatories for 2 weeks after surgery, and in rare, high-risk cases occurring less than 1% of the time, the patient received x-ray therapy of 750 rads. Table 2 summarizes surgical information for the 2 study groups.

Postoperative Protocol

We allowed patients to progress to weight bearing as tolerated (WBAT). For most patients, crutches were used for 2 weeks and a cane for 2 weeks thereafter. We requested no formal physical therapy of the patients after hospital discharge. Patients could progress to unlimited activity at 6 months postoperatively. The use of multimodal pain management and comprehensive blood management protocols eliminated the need for transfusion and accelerated patient recovery, allowing selected patients to receive this HRA procedure in an outpatient setting since 2012.

Bone Management Program

Many early studies suggested that women and older patients had a higher risk of femoral neck fracture. Intraoperative notching is reported to increase the risk of fracture [25]. We have never notched and therefore could not evaluate this claim. Femoral head cysts have also been found as a risk factor [26], but we found this not to be true in our data [27]. We have learned that the only risk factors for EFF are low femoral neck bone density and body mass index (BMI) >30 kg/m^2. We have also demonstrated that a slowed weight-bearing protocol and alendronate can prevent EFF [28]. Over time, we evolved to develop a comprehensive protocol which establishes 3 groups based on proven risk factors: group A, femoral neck T-score >0 and BMI <30 kg/m^2; group B, femoral neck T-score between 0 and −1.5 and/or BMI >30 kg/m^2; and group C, femoral neck T-score <−1.5.

Group A patients progress to WBAT. They typically use crutches for 2 weeks, and a cane for another 2 weeks. Group B patients also progress to WBAT, but are prescribed alendronate for 6 months. Patients from group C and any patients who require a Tri-Spike cup are placed on a slowed weight-bearing protocol and prescribed alendronate for 1 year. We ask them to proceed at 10% weight bearing for 4 weeks, WBAT with crutches for 2 weeks, and then to use a cane for another 4 weeks. Isometric leg lifts, light aerobic activity, lower extremity weight lifting less than 50 pounds, and unrestricted walking is encouraged at 6 weeks for groups A and B and at 10 weeks for group C patients. All restrictions in all patients are lifted at 6 months, and they are encouraged to participate in full-impact sports. No formal physical therapy is recommended for the patient after hospital discharge.

Metal Ion Testing

Metal ion levels are an excellent indicator for potential wear failure [24,29,30]. Our clinical database facilitates collection of whole blood, serum, and plasma metal ion test levels, which we routinely requested from all patients at 2 years postoperatively since 2007; in addition, we contacted all patients operated on before this time for metal ion results. We chose 2 years as our ion-testing interval based on previous research showing that ion levels peak near this point [29,31,32]. We converted serum and plasma test results to whole blood ion values using Smolder method [29,33]. We subsequently used whole blood values for all comparisons. Based on previous research, we defined the following 5 categories of ion levels for both unilateral and bilateral patients [10,29,33,34]: normal, optimal, acceptable, problematic, and potentially toxic. These reference values are presented in the legend of Table 3.

Clinical and Radiographic Analysis

Patients are requested to return for an office visit or to complete a remote follow-up package at 6 weeks, 1 and 2 years, and every other year thereafter. Patients are briefed on these follow-ups before surgery and receive reminder phone calls at each of these intervals. Every follow-up consists of a clinical questionnaire, radiographic analysis, and a physical examination testing ROM and strength. We do not require physical examinations after the 1-year postoperative visit on patients completing remote follow-up. Since 2007, we have routinely asked patients to obtain a metal ion test for cobalt (Co) and chromium (Cr) at 2 years postoperative or on physician request. Our clinical database

Table 2
Surgical Data for 2 Female Cohorts.

Variable	Group 1, <2008 (367 Cases)	Group 2, >2008 (654 Cases)	*P* Value
Length of incision, in	4.7 ± 1.0	4.1 ± 0.4	**<.0001**
Operation time, min	110.2 ± 21.8	92.9 ± 18.7	**<.0001**
Estimated blood loss, mL	226.3 ± 106.2	147.2 ± 84.7	**<.0001**
Hospital stay, d	2.8 ± 1.0	1.6 ± 0.6	**<.0001**
# Transfusion received	0 (0.0%)	0 (0.0%)	1.000
# Cell savers (recirculated blood)	37 (10.1%)	69 (10.6%)	.5961
ASA score	1.8 ± 0.6	1.7 ± 0.6	**.0082**
Femoral component <48 mm	203 (55%)	474 (72%)	**<.0001**
Femoral component size, mm	46.3 ± 2.6	45.7 ± 2.2	**<.0001**
Implant brand	—		
Corin Cormet 2000	119 (32%)	0 (0.0%)	**<.0001**
Biomet Magnum-ReCap Hybrid	212 (58%)	0 (0.0%)	**<.0001**
Biomet Magnum-ReCap Uncemented	36 (10%)	654 (100%)	**<.0001**

Bold values indicate statistical significance of *P*-values.
ASA, American Society of Anesthesiologists.

Table 3
Metal Ion Results for 2 Female Cohorts.

Resurfacing in Women Case Study								
Variables	Group I (Pre-2008)			Group II (Post-2008)			*P* Values Between Groups I and II	
	Unilateral (N = 153)	Bilateral (N = 66)	*P* Value	Unilateral (N = 281)	Bilateral (N = 134)	*P* Value	Unilateral I vs II	Bilateral I vs II
Co[a], μg/L	1.8 ± 1.3	2.8 ± 1.5	**<.0001**	1.6 ± 1.1	2.1 ± 1.2	**<.0001**	.2540	**.0005**
Cr[a], μg/L	1.4 ± 1.3	1.7 ± 1.1	**.0725**	1.2 ± 1.2	1.5 ± 0.9	**.0072**	.1825	.1727
Follow-up date[a], y	6.9 ± 2.0	7.3 ± 2.5	.1774	2.6 ± 1.3	2.4 ± 1.4	.2529	**<.0001**	**<.0001**
#, % Patients tested	219/367 (60%)		—	415/654 (63%)		—	.2301	
#, % Levels converted	117 (76%)	54 (82%)	.3789	203 (72%)	112 (84%)	**.0114**	.3371	.7566
Normal (#, %)	87 (57%)	10 (15%)	**<.0001**	167 (59%)	46 (34%)	**<.0001**	.6031	**.0045**
Optimal (#, %)	141 (92%)	60 (91%)	.7566	264 (94%)	127 (95%)	.7279	.4777	.2983
Acceptable (#, %)	10 (7.0%)	6 (9.0%)	.5029	14 (5.0%)	6 (4.0%)	.8259	.4965	.1971
Problematic (#, %)	0 (0.0%)	0 (0.0%)	1.000	0 (0.0%)	0 (0.0%)	1.000	1.000	1.000
Potentially toxic (#, %)	0 (0.0%)	0 (0.0%)	1.000	0 (0.0%)	0 (0.0%)	1.000	1.000	1.000

Metal Ion Level Reference Table					
	Normal[b]	Optimal[c]	Acceptable[d]	Problematic[d]	Potentially Toxic[c]
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

Bold values and superscript "a" are statistically significant.
[b] Laboratory normal for patients without metal bearings; [c]According to De Smet/van der Straeten; and [d]According to our previous analysis.

supported the collection of demographic, clinical, and radiographic data for all patients.

The purpose of the clinical questionnaires is to collect information needed to calculate the following scores: Harris hip score (HHS) [35], University of California, Los Angeles (UCLA) activity score [36], and visual analog scale pain scores [37]. HHS is a quantitative measurement of overall clinical outcome on a scale of 0-100, for which 100 represents great function and ROM. UCLA activity scores measure patient activity level on a scale of 1-10, for which 10 represents regular participation in impact sports. Visual analog scale pain scores measure overall pain for normal and worst days based on a simple scale of 0, or no pain, to 10, or maximum, debilitating pain.

Radiographs are requested at each follow-up; these x-rays are analyzed for component position, shifting, and radiolucencies. We determine the acetabular inclination angle on a standing pelvis x-ray by measuring the angle formed between a horizontal reference line running across the base of the inferior pubic rami and a measurement line running across the face of the acetabular component. All measurements were performed using OrthoVault and InteleViewer (InteleRAD, Chicago, IL).

Statistical Analysis

We performed all statistical analyses using a 95% confidence interval. We used Student *t* tests to compare differences in numeric variables, and 2-sample proportion *Z* tests were performed to compare differences in ratios between the 2 study groups. We generated Kaplan-Meier (KM) survivorship curves using revision for any reason as the endpoint. XLSTAT (Addinsoft, New York, NY), Microsoft Excel (Microsoft, Redmond, WA), and SAS (SAS, Cary, NC) were used for all statistical analyses performed in this study.

Results

Survivorship

Group 2 cases were performed after we implemented all major improvements described herein. The 8-year KM implant survivorship was 97.7% in group 2 compared with 89.9% in group 1 ($P < .0001$; Fig. 1). By presenting a stacked KM curve broken down into 2-year intervals (Fig. 2), we show that cases beyond 2012 have achieved 99% 5-year implant survivorship. Overall, 15-year implant survivorship in unselected resurfacing patients has been 96% in 3773 cases, 91% in 1022 women, and 97% in 2751 men (Fig. 3). Before 2008, there was a 6.1% difference in 8-year survivorship between men and women (95.7% vs 89.6%; $P < .0001$); after 2008, this difference fell significantly to 1.6% (99.3% vs 97.7%; $P = .0009$).

Failures and Complications

All failures requiring revision in women before and after the surgical interventions, implemented in 2008, are shown in Table 4. Before 2008, there were 43 cases (11.7%) requiring revision, whereas there were 15 revised cases (2.3%) thereafter ($P < .0001$). Correspondingly, the occurrence of the following failure mechanisms significantly decreased after 2008: AWRF, acetabular

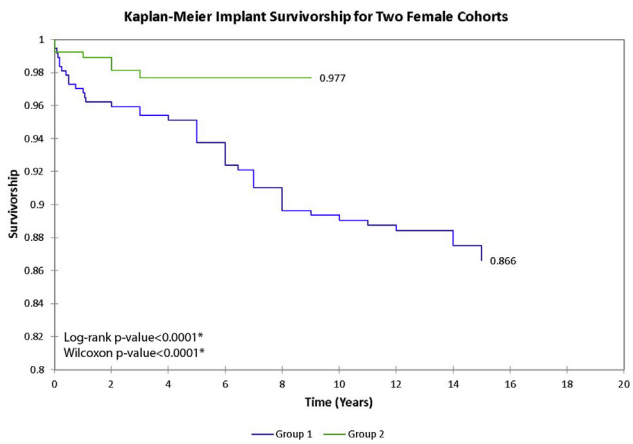

Fig. 1. Kaplan-Meier curve for 2 female cohorts. Kaplan-Meier survivorship analysis for the 2 female study groups using revision as an endpoint. Results of the log-rank test (*P* value <.0001) and Wilcoxon test (*P* value <.0001) show significant reduction in failures for cases performed after 2008 (group 2). Asterisks (*) represent significant statistical difference.

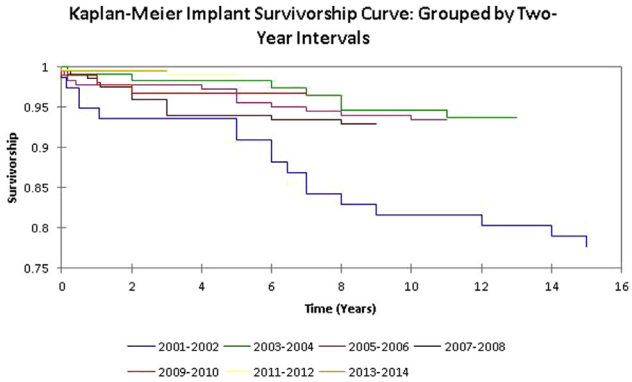

Fig. 2. Kaplan-Meier curve with stacked time intervals. Kaplan-Meier survivorship analysis for female cases grouped into 2-year intervals by date of surgery. Implant revision was used as the endpoint for all curves.

component loosening, femoral component loosening, and unexplained pain. In addition, there were no revisions beyond 3 years in group 2, whereas group 1 had 27 late failures.

We observed 25 complications in women, with 10 (2.5%) in group 1 and 15 (2.3%) in group 2 (Table 5). There was no statistically significant difference in any individual complication type or for overall complication rates. Likewise, there was no significant difference in the number of reoperations between the 2 female study groups (Table 6). However, 2 abductor tears from group 1 were categorized as complications and 2 others from group 1 as reoperations. Therefore, there were significantly more abductor tears in group 1 compared with group 2 ($P = .007$).

Metal Ion Results

We designed each surgical intervention to address a specific failure mode. Of these types of failures, AWRF was arguably the most significant. The occurrence of AWRF reduced from 2.0%-0.5% after 2008, with the last instance of wear occurring in a case from 2009. We request all patients obtain a metal ion test at 2 years postoperatively. Approximately, 60% of group 1 patients and 63% of group 2 patients complied with this request (Table 3). Of these patients, significantly more group 2 bilateral patients had metal ion levels categorized as "normal," which means they present ion levels similar to patients without any metal implants. Similarly, bilateral patients from group 2 presented significantly less average cobalt readings than group 1 bilateral patients. However, no other ion values for either unilateral or bilateral patients varied significantly between the 2 groups.

Clinical and Radiographic Results

Group 2 females reported higher mean HHS both preoperatively ($P < .0001$) and postoperatively ($P < .0001$) (Table 7). Women who received surgery after 2008 also reported a greater frequency of high-impact UCLA scores, which represents an activity score $\geq$9 on a scale out of 10. Furthermore, group 2 patients presented a lower average acetabular inclination angle; and correspondingly, more cases from this group met the RAIL guidelines. There were 4 reported instances of Brooker I heterotopic ossification in group 1 and none in group 2 ($P = .007$). There were no recorded radiolucencies for either group.

Demographic Results

The general consensus among arthroplasty professionals is that men represent a more favorable group for hip resurfacing [1,12,38,39]. Elucidating the difference in rate of clinical improvement between genders is a secondary aim of this study. As such, we briefly compare demographics between men and women. We note that men presented greater mean BMI and bone density ($P < .0001$). A substantially higher percentage of women diagnoses presented dysplasia (32% vs 5%, $P < .0001$), whereas diagnoses for men comprised a greater proportion with osteoarthritis (84% vs 59%, $P < .0001$) and post-traumatic arthritis (2.0% vs 0.9%, $P = .02$). All other diagnoses occurred in both groups at equal rates. Women required smaller implant sizes (<48 mm) in 67% of cases compared with 3% in men. Established risk factors for HRA include female gender, small bearing size, dysplasia diagnosis, low bone density, and high BMI [28,40,41]. In our database, women presented a higher percentage of all risk factors except for abnormal BMI.

Surgical Results

Surgical data are summarized in Table 2. All recorded surgical variables were superior for group 2. Length of incision, operation time, estimated blood loss, and hospital stay duration were all

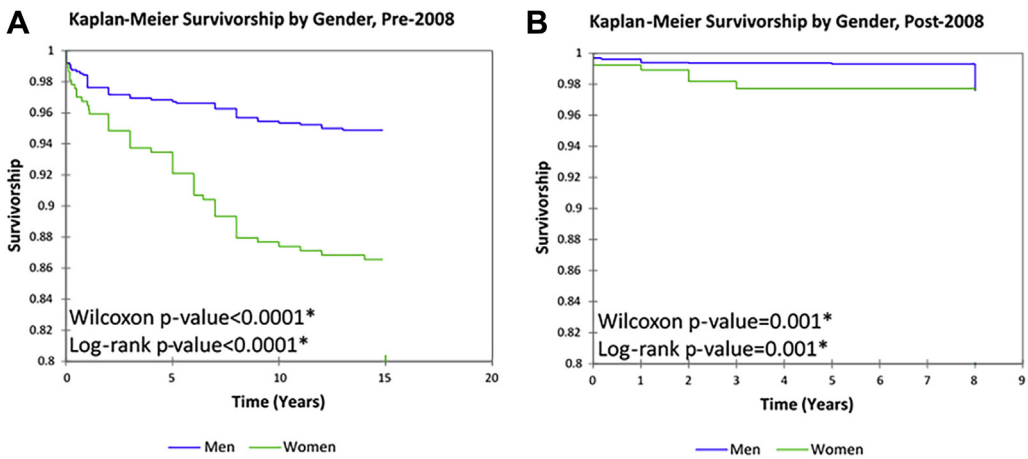

Fig. 3. Kaplan-Meier curve grouped by gender, before and after 2008. Kaplan-Meier survivorship analysis comparing survivorship between men and women before (A) and after (B) the establishment of surgical interventions in 2008. Log-rank and Wilcoxon tests show that the disparity in implant survivorship between genders was significantly reduced in cases after 2008 (Pre-2008 P value <.0001*; post-2008 P value = .001). Revision was used as the endpoint. Asterisks (*) represent significant statistical difference.

Table 4
Failures for 2 Female Cohorts.

Type	Group 1	Group 2	*P* Value
# Cases	367	654	—
Acetabular failures			
Adverse wear	7 (2.0%)	3 (0.5%)	**.0238**
Acetabular component loosening	7 (2.0%)	0 (0.0%)	**.0004**
Failure of acetabular ingrowth	6 (1.6%)	4 (0.6%)	.1118
Acetabular component shift	2 (0.5%)	1 (0.2%)	.2670
Femoral failures			
Femoral fracture/head collapse	8 (2.2%)	5 (0.8%)	.0524
Femoral component loosening	9 (2.5%)	1 (0.2%)	**.0003**
Other failures			
Unexplained pain	4 (1.1%)	0 (0.0%)	**.0074**
Recurrent instability	1 (0.3%)	0 (0.0%)	.1802
Total failures	44 (12.0%)	14 (2.1%)	**<.0001**

Bold values indicate statistical significance of *P*-values.

Table 6
Reoperations for 2 Female Cohorts.

Type	Group 1	Group 2	*P* Value
# Cases	367	654	—
Reoperations			
Abductor tear	2 (0.6%)	0 (0.0%)	.0588
Wound dehiscence	2 (0.6%)	0 (0.0%)	.0588
Dislocation	0 (0.0%)	1 (0.2%)	.4533
Early infection	1 (0.3%)	0 (0.0%)	.1802
Late infection	0 (0.0%)	1 (0.2%)	.4533
Early fracture	1 (0.3%)	0 (0.0%)	.1802
Late fracture	1 (0.3%)	1 (0.2%)	.6818
Psoas tendonitis	2 (0.6%)	0 (0.0%)	.0588
Unexplained pain	0 (0.0%)	0 (0.0%)	1.0000
Others	0 (0.0%)	2 (0.4%)	.2891
Total reoperations	9 (2.5%)	5 (0.8%)	.0257

significantly reduced ($P < .0001$). Neither group required any transfusions ($P = 1.0$).

Discussion

Survivorship

This study, which comprises a single-surgeon series of 3771 consecutive cases between 2 and 15 years of follow-up, elucidates the marked improvement of implant survivorship in women when adhering to proper, refined perioperative protocols. The implementation of our surgical interventions decreased raw failure rate in women by 19%. Although these interventions also reduced failure rate in men by 15%, the scope of this paper focuses on resurfacing outcomes in women; comparisons between genders are only used to highlight the greater rate of clinical improvement in women.

By comparing female cohorts before and after the set of perioperative protocols was established, we have demonstrated how surgeons' experience and refined technique significantly improved clinical outcomes. Raw failure rates dropped drastically, and 8-year implant survivorship improved from 89.9% in pre-2008 HRA cases to 97.7% in cases performed thereafter. Furthermore, there have been no failures to date occurring after 3 years postoperatively in group 2. According to the Orthopedic Data Evaluation Panel [42], these data indicate that HRA in our female cohort is on track to exceed the 2014 NICE guidelines [43], defined as 95% or greater 10-year implant survivorship.

Failures and Complications

By establishing these interventions, the following modes of failure have either been eliminated or significantly reduced in the group 2 female cohort: AWRF, acetabular component loosening, femoral component loosening, and unexplained pain.

Although each intervention was developed to address a specific issue, we cannot prove with certainty the exact cause of the reduction of each individual failure mode because these protocols were established concurrently. However, Figure 2 helps to clarify the effects of each intervention on survivorship. Survivorship rose in the first two 2-year intervals, which we suspect is most likely due to greater surgeons' experience alone, as no other interventions were in place at this point. In 2004, the surgeon began using cemented Biomet ReCap devices in replace of the Corin implants. The immediate, corresponding 2-year interval illustrates a drop in implant survivorship, likely due to a brief learning curve necessary for the new device. Similarly, survivorship dropped for the next 2-year interval after establishing all other surgical interventions in 2007 and 2008; again, this decrease is likely due to another learning curve because each consecutive 2-year interval thereafter shows a gradual increase in implant survivorship.

Of all our surgical interventions, intraoperative positioning of acetabular components using NSIOR and RAIL is, in our opinion, the most notable. A small number of outlier reports on AWRF have garnered much attention and aroused widespread fear of metal wear. As such, AWRF has disproportionately affected the willingness of surgeons to resurface women. At the time of these reports, AWRF was poorly understood and therefore difficult to diagnose and manage [18]. At present, we understand how to prevent AWRF, diagnose it early [10,24], and manage its treatment with a high degree of success [24,44,45]. Although we missed the RAIL in some

Table 5
Complications for 2 Female Cohorts.

Type	Group 1	Group 2	*P* Value
# Cases	367	654	—
Complications			
Acetabular complications			
Acetabular component shift	1 (0.3%)	4 (0.6%)	.4593
Other complications			
Deep vein thrombosis	1 (0.3%)	1 (0.2%)	.6818
Abductor tear	2 (0.6%)	0 (0.0%)	.0588
Hip dislocation	4 (1.1%)	3 (0.5%)	.2420
Nerve palsy	2 (0.6%)	0 (0.0%)	.0588
Early fracture	0 (0.0%)	1 (0.2%)	.4533
Pulmonary embolism	0 (0.0%)	2 (0.4%)	.2891
Hematoma	0 (0.0%)	2 (0.4%)	.2891
Urinary retention	0 (0.0%)	3 (0.5%)	.1936
Total complications	10 (2.5%)	15 (2.3%)	.6672

Table 7
Clinical and Radiographic Data for 2 Female Cohorts.

Variable	Group 1, Pre-2008	Group 2, Post-2008	*P* Value
Preoperative			
HHS score	51.4 ± 12.7	57.6 ± 14.5	**<.0001**
Postoperative			
HHS score	94.4 ± 9.6	97.6 ± 7.3	**<.0001**
UCLA score	6.5 ± 1.8	6.7 ± 1.8	.2671
High-impact UCLA (# cases, %)	21/137 (15%)	86/363 (24%)	**.0424**
VAS pain: regular	0.6 ± 1.4	0.2 ± 0.9	**.0002**
VAS pain: worse	1.9 ± 2.3	1.3 ± 2.1	**.0056**
Combined ROM[3]	285 ± 45	294 ± 37	.0837
Radiographic data			
Acetabular inclination angle	45.1 ± 9.3	34.9 ± 6.8	**<.0001**
Under RAIL (# hips, % of recorded)	36/116 (31%)	585/654 (89%)	**<.0001**
Radiolucency (# hips, %)	1 (0.3%)	0 (0.0%)	.1770
Osteolysis (# hips, %)	0 (0.0%)	0 (0.0%)	1.000

Bold values indicate statistical significance of *P*-values.
HHS, Harris hip score; RAIL, relative acetabular inclination limit; ROM, range of motion; UCLA, University of California, Los Angeles; VAS, visual analog scale.

Table 8
Literature Comparison of Female Cohorts.

Study	Procedure	Prosthesis	Date Range	Mean Age, y	Mean BMI, kg/m^2	Patient Cohort		Avg FU, y	Survivorship	
						Hips	Criteria		FU, y	Rate, %
NJR for England and Wales [46]	THA	Cemented metal-on-polyethylene	2003-2011	55	—	>400k total	22-mm	—	5	98.5
	HRA	-Varies-					42-mm head	—	5	91.7
		-Varies-					46-mm head	—	5	93.9
Amstutz et al [1]	HRA	Conserve Plus	11/1996-7/2007	49.5	24.6	280	None	6.8	8	87.1
Jameson et al [3]	HRA	DePuy ASR	4/2004-1/2007	48	28.6	45	<55	2.3	3.5	92.6
				60	26.4	55	>55	2.3	3	86.0
Present study, Pre-2008	HRA	Cormet + Cemented ReCap	2001-2007	50.3	25.9	367	None	11.7	**8**	**89.6**
									10	**89.1**
Present study, Post-2008	HRA	Uncemented ReCap	2008-2014	53.8	25.2	654	None	5.5	**8**	**97.7**

Bold values indicate statistical significance of *P*-values.
BMI, body mass index; HRA, hip resurfacing arthroplasty; THA, total hip arthroplasty; FU, follow-up.

initial 2008 cases, we have thereafter missed the RAIL only once; this case from 2009 resulted in AWRF. Since then, we have met the RAIL in 2030 consecutive cases and have had no reported instances of wear. After instituting the RAIL guidelines and NSIOR, we have only had a single case of AWRF. This demonstrates how a full understanding of edge-loading mechanisms [14,19,30–34] and proper intraoperative technique with NSIOR can eliminate AWRF.

Limitations

This study contains some notable shortcomings. First, group 1 patients presented lower preoperative function scores on average than group 2. Furthermore, group 1 patients were younger and presented greater average BMI; it could be argued that these differences contributed to superior postoperative results for group 2. However, we believe these disparities to be balanced by other high-risk factors found exclusively in group 2; these include lower average T score, smaller average femoral component size, and a greater occurrence of dysplasia. Overall, we believe the differences in these variables to be negligible on the dramatic improvement in outcomes.

Next, metal ion testing for group 1 was conducted at a significantly later interval. Previous research shows that metal ion levels peak between 1 and 2 years [29,31,32], and thus, maximum ion values were used for group 2 while later, and likely lower, ion values were analyzed for group 1. Despite this potential benefit to group 1 data, blood cobalt levels were significantly lower in bilateral cases of group 2.

We note potential bias toward the Biomet Magnum-ReCap system, as the primary surgeon contributed to the implant design process.

Another shortcoming of this study lies in the method by which these interventions were established. All protocols mentioned herein were implemented nearly concurrently, limiting our ability to identify the cause of each reduction in failure mode. Although each intervention was developed based on clinical data to address a specific issue, we are only able to speculate on the true effect of each. However, there is no doubt that the combination of these interventions drastically reduced all previously identified modes of failure.

Literature Comparison

Our current 97.7% 8-year HRA implant survivorship in an unselected cohort of 656 women is significantly greater than the 95.5% 3-year survivorship shown in the British registry and the 95.0% 5-year survivorship in the Australian registry [2,39,46]. The primary reason for this difference is surgeons' experience, as registries also contain data reported by less experienced resurfacing surgeons [39]. Table 8 lists other clinical series of HRA in which the results for women could be separated from those of men. From this comparison, it is clear these current data surpass registry results.

Our above-average implant survivorship in women is especially notable when considering the mean age of the cohort. The Scandinavian registry [47] reports substantially lower implant survivorship (83% at 10 years) for men and women under 50 years of age. Approximately, 40% of men and 36% of women in this study were under 50 years of age. The mean age of this cohort was 52 years, a decade younger than most reported cohorts of THA. Despite this potential limiting factor, implant survivorship for our cohorts greatly surpassed reported registry data.

Conclusions

We have shown that with a better understanding of perioperative protocols, young women can be resurfaced with an implant survivorship that meets or exceeds that of THA. In our experience, many patients who understand the implications of future revisions desire HRA for less bone resection, increased implant survivorship, and more nearly normal hip biomechanics [48]. Furthermore, impact sports do not increase failure in HRA, as opposed to many reports on THA [49]. Dislocation is less common than in THA [22,50], especially among high-risk dysplasia cases. Activity-related thigh pain does not occur, because there is no stem in the canal like in THA [51,52]. In the Australian registry, mortality at 10 years is 30% lower for HRA [6,53]. We therefore hope that the interventions presented herein will allow other resurfacing surgeons to rethink their selection against women and further inspire other orthopedic surgeons to become expert at resurfacing.

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