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Outcomes of metal-on-metal hip resurfacing arthroplasty: a single-surgeon series of 6114 cases with 2–19 year follow-up

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Abstract

Between December 2004 and April 2022, a single surgeon completed 6114 hip resurfacing cases using the Biomet Magnum-ReCap™ system; the first 739 cases were performed using hybrid fixation, and the latter 5375 cases, beginning in 2007, were fully uncemented. The primary purpose of this study was to evaluate the long-term clinical outcomes of a large single-surgeon series of metal-on-metal hip resurfacing, with a secondary aim of comparing these results with the current best outcomes among available literature and registry data for total hip replacement and hip resurfacing. For the entire cohort, 19-year Kaplan-Meier implant survivorship was 97.5%, while for the hybrid fixation subgroup, this was 94.6%. For the uncemented subgroup, 16-year Kaplan-Meier implant survivorship was 98.2%. Since 2012, no difference was seen regardless of sex; there's been no difference in implant survivorship based on diagnosis or implant size since 2007. At the time of publication, this study represents the largest single-surgeon series of metal-on-metal hip resurfacing with long-term data and the second-best long-term implant survivorship for any type of hip arthroplasty ever published.

Keywords Hip resurfacing, Hip arthroplasty, Metal-on-metal

Background

Support for metal-on-metal (MoM) hip resurfacing arthroplasty (HRA) remains lacking in the orthopedic community primarily due to concerns of metallosis and adverse wear-related failure (AWRF) [1, 2]. MoM bearing surfaces release cobalt and chromium through normal wear, but excessive wear, particularly from malpositioned cups, may lead to elevated systemic metal ion levels. High levels of cobalt (>20 µg/L) have been associated with

adverse reactions to metal debris, or even cardiomyopathy or neuropathy [3, 4]. In the United States, high-profile lawsuits against manufacturers of poor-performing MoM devices have affected the acceptance and use of well-designed MoM implants [5]. While available studies report an increased risk of wear and corrosion failures with MoM bearings in traditional stemmed total hip arthroplasty (THA), excellent outcomes have been reported for most MoM HRA groups among hip resurfacing specialists [4, 6–12]. MoM HRA outperform polyethylene HRA designs, MoM THA, and non-MoM THA in younger patients [12–14]. When performed by experienced HRA surgeons who have surpassed the notable HRA learning curve [15], benefits of this procedure compared to THA include higher function, improved stability, more normal gait, bone preservation, and lower 10-year all-cause mortality [16–20].

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Table 1 Demographics

Variable	Hybrid	UC	Combo
Date Range	12/2004-8/2008	3/2007-4/2022	12/2004-4/2022)
# of Cases	739	5375	6114
# Deceased ¹	19 (2.6%)	57 (1.1%)	76 (1.2%)
Demographics	--	--	
% Female	212 (28.8%)	1500 (27.9%)	1712 (28.0%)
Age (Years)	51.2±8.2	54.1±8.6	54.0±8.4
BMI	27.3±4.7	27.2±4.7	27.2±4.6
T-Score	-0.1±1.1	-0.1±1.2	-0.1±1.3
Diagnoses (#, %)	--	--	
Osteoarthritis	608 (82.3%)	4300 (80.0%)	4908 (80.3%)
Dysplasia	62 (8.4%)	655 (12.2%)	717 (11.7%)
Osteonecrosis	31 (4.2%)	243 (4.5%)	274 (4.5%)
Post-Trauma	17 (2.3%)	63 (1.2%)	80 (1.3%)
Legg-Calve Perthes Disease	12 (1.6%)	57 (1.1%)	69 (1.1%)
Slipped Capital Femoral Epiphysis	7 (0.9%)	20 (0.4%)	27 (0.4%)
Rheumatoid Arthritis	0 (0.0%)	10 (0.2%)	10 (0.2%)
Other	2 (0.3%)	27 (0.5%)	29 (0.5%)

1- Deaths unrelated to arthroplasty surgery

This study aims to expand the available clinical evidence for MoM HRA by reporting on up to 19-year postoperative outcomes of 6114 MoM HRA cases performed by a single surgeon.

Methods

We prospectively collected perioperative data in a clinical SQL database. For this study, we retrospectively queried the database for all cases of MoM HRA with the Biomet Magnum-ReCap™ system. A single surgeon (TPG) performed 739 hybrid resurfacing cases between December 2004 and December 2007 and 5375 uncemented (UC) resurfacings between March 2007 and April 2022. The cohort was closed at this time point to ensure all cases had at least 2 years of minimum follow-up. The only difference between these two implant systems was femoral fixation. However, perioperative techniques and management changed gradually over this 19-year span of time. This was due to a program of continuous process improvement (detailed in Supplemental Table 1).

The hybrid implant featured the ReCap™ femoral component with a grit-blast surface for cement fixation, while the UC version comprised the same design but with an added titanium-alloy plasma-spray coating of 1-mm thickness for bone ingrowth fixation. This means that the cemented femur had a 0.5-mm gap for a cement mantle, while the UC version had a 0.5-mm circumferential

Table 2 Surgical data

Variable	Hybrid	UC	Combo
Length of Incision (in)	4.2±0.6	4.2±0.5	4.2±0.5
Operation Time (min)	118.8±22.0	92.4±15.6	95.8±18.7
Estimated Blood Loss (mL)	229.3±113.2	166.9±95.3	174.6±99.9
# Transfusion Received	2 (0.6%)	1 (0.02%)	3 (0.05%)
ASA Score	1.6±0.6	1.8±0.6	1.8±0.6
Femoral Component Size (mm)	51.4±3.8	49.7±3.5	49.9±3.6
Hospital Stay (days)	2.7±1.2	1.0±1.0	1.2±1.2

(1-mm diametrical) press fit. All implants were made of high-carbon (>0.2%) cast cobalt-chrome alloy. Coverage arcs of the acetabular component varied from 156° in the 40-mm bearing to 164° in the 60-mm bearing. This design feature is the primary reason why smaller implants are more prone to edge loading failures. More exhaustive details on this implant design have been previously published [21]. Table 1 lists demographics of the current study group. Table 2 presents surgical data.

We requested routine follow-up at 6 weeks, 1 year, 2 years and then every other year. At the first two follow-up intervals, we collected clinical questionnaires, physical exams, and radiographs. After that, physical exams were only performed on in-person follow-ups. Due to the nature of our practice (which is national in scope), most follow-ups beyond 2-years postoperative were performed remotely.

When we initially queried the database for this study in June 2022, there were 6114 cases with 1336 (22%) delinquent in their 2-year follow-up intervals. We sent a brief follow-up questionnaire to these patients in the manner of Brooks [22] and received a completed response in 561 cases. Of these, 132 patients sent additional full follow-up data. This resulted in 5339 (87%) with up-to-date (UTD) follow-up to their latest 2-year interval. Of these, 413 (6.8%) were brief follow-ups. If they responded as satisfied, we assumed that their latest follow-up still applied. This method captured 2 additional revisions (both from a single bilateral patient). The satisfaction rate in this brief follow-up cohort was 99.4%, significantly better than the 96.7% satisfaction in the previous full follow-up cohort ($p < 0.0001$). The mean time from surgery was 10.5 years (range 2–19; excludes patient deaths and implant revisions). A total of 2172 cases (35.5%) has a minimum of 10-year follow-up, 891 cases (14.6%) had a minimum of 15-year follow-up, and 491 cases (8.0%) had > 16 year follow-up. The mean latest follow-up date was 7.2 years. We compared the risk factors of those remaining lost to UTD follow-up (853 cases) to the remaining cohort in Table 3. This excludes deceased patients, failures, and patients that requested no contact. Risk factors considered in this analysis were female sex, age over 60, diagnosis of dysplasia or osteonecrosis, and implant bearing size less than

Table 3 Analysis of cases lost to Follow-up

Risk factor	Follow-up UTD (n=4681)*	Lost to Follow-Up (n=853)*	p-value
Female	1323 (28.3%)	226 (26.5%)	0.289
Age ≥ 60	1063 (22.7%)	172 (20.2%)	0.101
Dysplasia	569 (12.2%)	85 (10.0%)	0.069
Osteonecrosis	166 (3.5%)	74 (8.7%)	<0.0001*
Size < 50 mm	1782 (38.1%)	304 (35.6%)	0.177

*These values exclude revised cases, deceased patients, and requested no-contact patients

Table 4 Clinical outcomes

Variable	Hybrid	UC	Combo
UTD Follow-up	70.4%	87.8%	85.6%
Min. 2-yr	99.8%	92.6%	93.5%
HHS Score	95.4 ± 9.6	95.0 ± 10.1	95.1 ± 10.1
UCLA Score	6.9 ± 2.2	7.1 ± 2.3	7.1 ± 2.3
VAS Pain: Regular day	0.5 ± 1.2	0.6 ± 1.3	0.5 ± 1.3
VAS Pain: Worst day	1.6 ± 2.4	1.7 ± 2.4	1.7 ± 2.4

Table 5 Failures

Type	Hybrid	UC	Combo
# Cases	739	5375	6114
1) Acetabular Failures			
Adverse Wear	6 (0.8%)	4 (0.07%)	10 (0.2%)
Acetabular Loosening (> 2 years)	3 (0.4%)	6 (0.1%)	9 (0.1%)
Failure of Acetabular Ingrowth (< 2 years)	8 (1.1%)	11 (0.2%)	19 (0.3%)
Acetabular Component Shift ¹	0 (0.0%)	2 (0.04%)	2 (0.03%)
2) Femoral Failures			
Early Femoral Head Collapse (< 6 months)	0 (0.0%)	3 (0.06%)	3 (0.05%)
Femoral Component Loosening	7 (0.9%)	2 (0.04%)	9 (0.1%)
Early Femoral Fracture (< 6 months)	6 (0.8%)	17 (0.3%)	23 (0.4%)
3) Other Failures			
Recurrent Instability	2 (0.3%)	2 (0.04%)	4 (0.07%)
Early Infection (< 1 year)	4 (0.5%)	0 (0.0%)	4 (0.07%)
Late Infection (> 1 year)	1 (0.1%)	2 (0.04%)	3 (0.05%)
Late Fracture	1 (0.1%)	6 (0.1%)	7 (0.1%)
Unexplained Pain	2 (0.3%)	2 (0.04%)	4 (0.07%)
Psoas Tendonitis	1 (0.1%)	1 (0.02%)	2 (0.03%)
Other	0 (0.0%)	3 (0.06%)	3 (0.05%)
TOTAL FAILURES	38 (5.1%)	61 (1.1%)	99 (1.6%)

1 - Did not begin capturing Acetabular Component Shifts until Dec 2007

50 mm. Patients with osteonecrosis were more likely to be lost to follow-up.

Table 4 summarizes most recent follow-up data for all patients without revision. Table 5 lists failures that resulted in component revision, Table 6 reported reoperations that did not require implant removal. Table 7 records other complications.

We recommended blood metal ion testing at 2 years postoperatively for all patients. Of this cohort, 66.1% of patients complied with testing. Table 8a lists ion data for

Table 6 Reoperations (no implants revised)

Type	Hybrid	UC	Combo
# Cases	739	5375	6114
Acetabular Component Shift*	0 (0.0%)	1 (<0.01%)	1 (0.02%)
Gluteal Tear	1 (0.1%)	1 (<0.01%)	2 (0.03%)
Dislocation	0 (0.0%)	1 (<0.01%)	1 (0.02%)
Early Fracture (< 6 months)	1 (0.1%)	2 (<0.01%)	3 (0.05%)
Early infection (< 3 months)	0 (0.0%)	4 (0.07%)	4 (0.07%)
Early infection (< 1 year)	2 (0.3%)	6 (0.1%)	8 (0.1%)
Late Infection (> 1 year)	1 (0.1%)	0 (0.0%)	1 (0.02%)
Fascia Failure	0 (0.0%)	3 (0.1%)	3 (0.05%)
Hematoma	0 (0.0%)	4 (0.1%)	4 (0.07%)
Late Fracture (> 6 months)	1 (0.1%)	11 (0.2%)	12 (0.2%)
Psoas Tendonitis	2 (0.3%)	1 (<0.1%)	3 (0.05%)
Unexplained swelling	0 (0.0%)	2 (<0.1%)	2 (0.03%)
Other	2 (0.3%)	3 (0.1%)	5 (0.08%)
TOTAL REOPERATIONS	11 (1.5%)	35 (0.7%)	46 (0.8%)

Table 7 Complications (no additional surgery required)

Type	Hybrid	UC	Combo
# Cases	739	5375	6114
Acetabular Component Shift*	0 (0.0%)	30 (0.6%)	30 (0.5%)
Dislocation	8 (1.1%)	20 (0.4%)	28 (0.5%)
Anxiety	0 (0.0%)	3 (0.1%)	30 (0.5%)
Early Fracture (< 6 months)	0 (0.0%)	5 (0.1%)	5 (0.08%)
Late Fracture (> 6 months)	0 (0.0%)	4 (0.1%)	4 (0.07%)
Early Infection (< 3 months)	0 (0.0%)	1 (<0.1%)	1 (0.02%)
Fascia Failure	1 (0.1%)	1 (<0.1%)	2 (0.03%)
Femoral Component Shift	0 (0.0%)	4 (0.1%)	4 (0.07%)
Hematoma	3 (0.4%)	5 (0.1%)	8 (0.1%)
PE/DVT	2 (0.3%)	16 (0.3%)	18 (0.3%)
Nerve Palsy	0 (0.0%)	7 (0.1%)	7 (0.1%)
Spinal Headache	0 (0.0%)	7 (0.1%)	7 (0.1%)
Severe constipation	0 (0.0%)	2 (<0.1%)	2 (0.03%)
Urinary Retention	0 (0.0%)	8 (0.1%)	8 (0.1%)
GI Bleed	0 (0.0%)	2 (<0.1%)	2 (0.03%)
Unexplained swelling/pain	0 (0.0%)	3 (<0.1%)	2 (0.03%)
Nausea/Vomiting	0 (0.0%)	2 (<0.1%)	2 (0.03%)
Other	2 (0.3%)	7 (0.2%)	27 (0.4%)
TOTAL COMPLICATIONS	17 (2.3%)	128 (2.4%)	145 (2.4%)

*The first case of a shift was recognized in 2009. Prior to this, the xr protocol was not accurate enough

all unrevised cases, and Table 8b defines ion categories. All patients with cobalt levels above ten are considered problematic and are advised to have a metal artifact reduction sequence magnetic resonance image (MRI). Convincing patients to obtain routine ion testing once at 2 years if they are not experiencing problems is somewhat difficult, asking them to get an MRI would be much harder. Our rate of metallosis is 0.2% overall; this rate is 0.0% in all cases after 2009. With such a low rate, we do not think routine MRIs are justified. It is not much different than requiring an MRI to rule out trunnionosis in routine THA follow-up.

Table 8a Metal ion test results (unrevised cases, most recent level)

Variables	Hybrid ReCap (n = 739)	Uncemented ReCap (n = 5375)	P-value	All ReCap, Unilateral (n = 2930)	All ReCap, Bilateral (n = 3169)
Co* (µg/L)	1.6 ± 1.4	1.5 ± 1.0	0.039*	1.2 ± 1.1	1.6 ± 1.1
Cr* (µg/L)	1.2 ± 1.1	1.1 ± 0.9	0.018*	0.9 ± 0.9	1.2 ± 1.0
#, % Patients Tested ¹	563 (76.1%)	3478 (64.7%)	< 0.0001*	1597 (54.5%)	2569 (81.0%)
Normal (#,%) ²	353 (62.7%)	2265 (65.1%)	0.263	1283 (80.3%)	1549 (60.3%)
Optimal (#, %)	529 (94.0%)	3335 (95.9%)	0.04*	1557 (97.5%)	2458 (95.7%)
Acceptable (#, %)	14 (2.5%)	55 (1.6%)	0.124	37 (2.3%)	53 (2.1%)
Problematic (#, %)	2 (0.4%)	5 (0.1%)	0.263	3 (0.2%)	4 (0.2%)
Potentially Toxic (#, %)	0 (0.0%)	0 (0.0%)	1.000	0 (0.0%)	0 (0.0%)

Unrevised cases are not included

Table 8b Metal Ion Reference Table

	Normal ¹	Optimal ²	Acceptable ³	Problematic ³	Potentially Toxic ²
Unilateral	< 1.5 µg/L	< 4.0 µg/L	4–10 µg/L	10–20 µg/L	> 20 µg/L
• Co	< 1.5 µg/L	< 4.6 µg/L	4.6–10 µg/L	10–20 µg/L	> 20 µg/L
• Cr					
Bilateral	< 1.5 µg/L	< 5.0 µg/L	5–10 µg/L	10–20 µg/L	> 20 µg/L
• Co	< 1.5 µg/L	< 7.4 µg/L	7.4–10 µg/L	10–20 µg/L	> 20 µg/L
• Cr					

1- common laboratory normal for patients without metal bearings

2 - according to DeSmet and Van der Straeten [51]

3 - according to our previous analysis [52]

For all statistical analyses, we used a significance level α of 0.05. A paired, 2-tailed T-test was used to calculate the significant difference between preoperative and postoperative numerical outcomes within and between study groups; the Student's T-test was used to compare the difference of numeric variables between groups. When comparing two population proportions, a two-sample Z-test was used. We generated a Kaplan-Meier (KM) implant survivorship curve for all 6114 Magnum-ReCap™ cases using implant revision for either component as the endpoint (Fig. 1). We display both femoral fixation subgroups. Log-rank and Wilcoxon tests were performed to calculate significant differences between survivorship curves. Curves and survivorship statistical tests were generated using XLSTAT (New York, NY).

Results

The combined 19-year implant survivorship with the Biomet Magnum-ReCap™ device in this consecutive single-surgeon series of 6114 cases with minimum 2-year follow-up is 97.5%. The 19-year survivorship for the hybrid implant is 94.6%, and the 16-year survivorship for the UC implant is 98.2%. Most failures occurred during the first two years (58.6% of all failures). If a case was successful at 2 years postoperative, the odds of failure in the next 17 years was 0.7%. Since 2012, there has been no difference in implant survivorship between sexes; there's been no difference in implant survivorship based on diagnosis or implant size since 2007 (Table 9).

The overall rate of failure among this cohort is 2.3%. Overall failure rate was 5.1% for the hybrid group and 1.1% for the UC group ($p < 0.0001$). The most common causes of revision were early femoral failure (femoral neck fracture or femoral head collapse before 1 year, 0.5% overall), failure of acetabular ingrowth (0.4% overall), AWRF (0.2% overall), and late femoral loosening (0.2% overall). The rate of these failure modes significantly decreased over time, manifesting in lower failure rates for the later UC group. This was due to continuous process improvements, with each designed to address a specific failure mode. The most common causes of revision were identified, solutions were implemented, and outcomes were monitored to determine if results improved. For example, early femoral failures, including collapse or loosening, were significantly more common with cemented femoral components (0.9% vs. <0.1% for UC). This may be due to thermal necrosis caused by exothermic polymerization of bone cement, which can compromise bone viability. Our transition to uncemented fixation in 2007 coincided with a marked reduction in femoral component loosening, and our bone management protocol further reduced early femoral failure rates to 0.3% after 2010.

Our most recent 10-years of follow-up data (minimum 2-years postoperative, 2010–2020, $n = 4162$) suggest we have minimized major failure modes. In addition to the reduction in early femoral failure rates, other notable changes in rates of failure modes include: the rate of

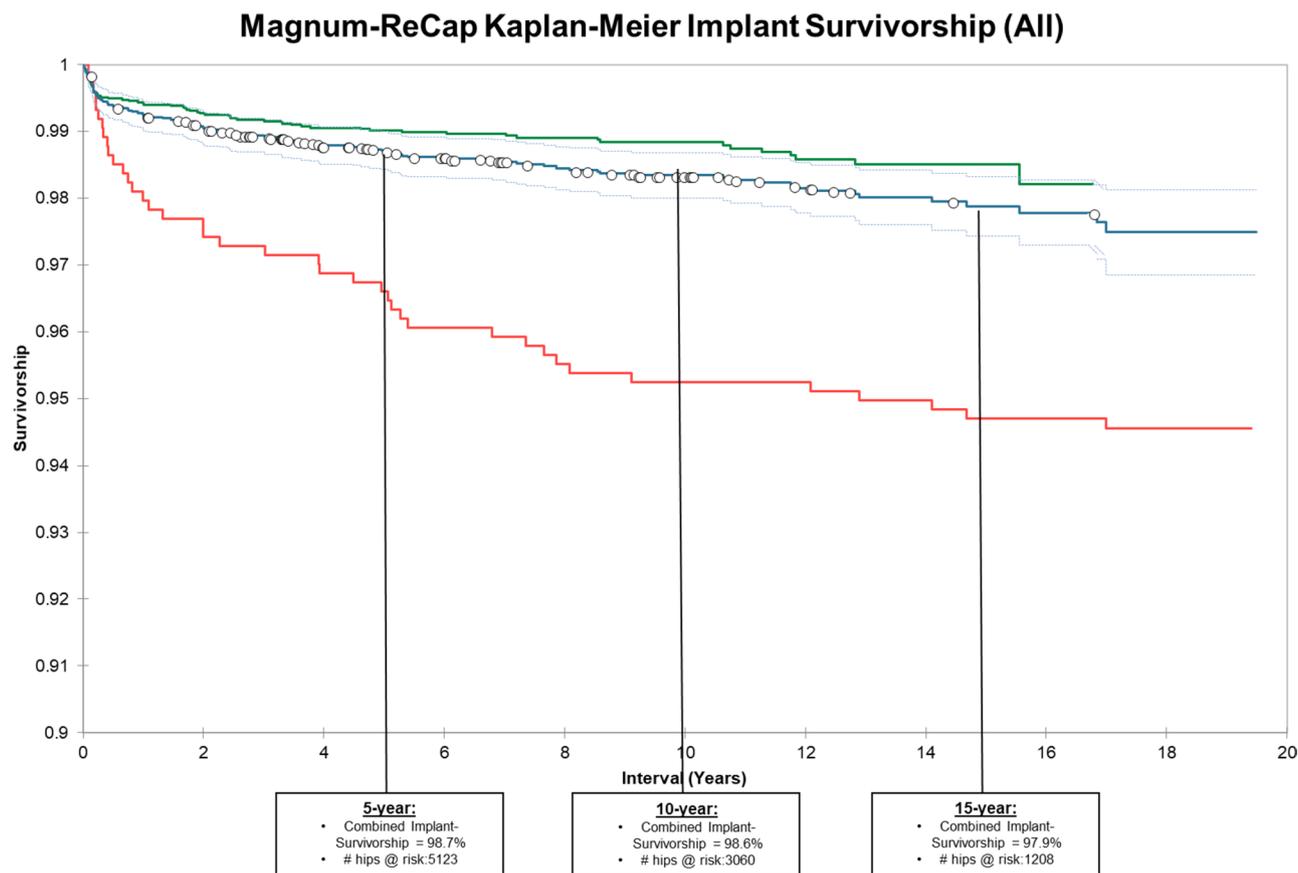


Fig. 1 Kaplan-Meier Implant Survivorship (All ReCap Cases). Circles represent deceased, 95% confidence intervals for entire group is displayed. KM implant survivorship for the UC implants @ 17 years is 98.2%, for entire group at 19 years is 97.5%, and for hybrid group at 19 years is 94.6%

adverse-wear related failure is down to 0.0%, the rate of early perioperative infections (<3 months) is down to 0.0%, the rate of 1-year perioperative infections is down to 0.02%, the rate of dislocations is down to 0.3%, and failure due to recurrent instability is down to 0.02%. Rather than practicing patient selection, we have expanded our indications as our understanding and skill with this technique grew. We have summarized the improvements in Supplemental Table 1.

The overall rate of reoperation not requiring revision was 0.8 – 1.5% for the hybrid group and 0.7% for the UC cases ($p < 0.0001$). The overall rate of postoperative complications not requiring any operation was 2.4% – 2.3% for the hybrid group and 2.4% for the UC group ($p = 0.9$).

Four notable complication types deserve further mention: instability, nerve palsy, infection, and unexplained pain. The overall rate of instability was 0.5%. The rate of recurrent instability resulting in reoperation or revision rate was only 0.05%. The rate of peroneal nerve palsy was 0.14%. Early (<3 months) postoperative infection rate was 0.1%, and the 1-year perioperative rate was 0.3%. After 2010 the rates were 0 and 0.02%. Four late infections (>1 year) were encountered (0.07%). There were a total of 19/5585 infections. Implants were saved in 6/15

early and 2/4 late infections. All infections were cured. Lastly, there were 3.7% of patients that had moderate or greater unexplained pain and 4 cases (0.1%) that were revised for unexplained pain.

Cobalt and chromium levels are listed in Table 8a, and ion categories are described in Table 8b. For the entire cohort, mean whole blood levels were 1.4 $\mu\text{g/L}$ for cobalt and 1.1 $\mu\text{g/L}$ for chromium. All cases with problematic or potentially toxic cobalt levels were investigated.

- Normal ion levels (< 1.5 $\mu\text{g/L}$) for patients without implants were found in 80.6% of cases.
- Optimal ion levels were seen in 97.3% of cases.
- Acceptable levels were recorded in 2.7% of cases.
- Problematic ion levels were observed in seven cases (0.1% of unrevised cohort) with cobalt ion levels between 10 and 20 $\mu\text{g/L}$. Four of these patients were asymptomatic, had whole blood chromium levels below 10 $\mu\text{g/L}$, and were not imaged. The remaining three unrevised cases with problematic ion levels had cobalt levels ranging from 10 to 20 $\mu\text{g/L}$. MRI revealed no fluid for one case. The bilateral patient with the remaining two cases of problematic ion levels showed some fluid collection on MRI, but they

Table 9 Implant survivorship comparison

Group	KM rate (study)	KM rate (control)	p-value
All ReCap	97.5% @ 19 yrs	--	--
All ReCap (> 2 year failures only)	98.4% @ 19 yrs	--	--
Hybrid ReCap	94.6% @ 19 yrs	--	--
UC ReCap (all)	98.2% @ 16 yrs	HYBRID: 94.7% @ 16 yrs	< 0.0001*
-Women	97.6% @ 16 yrs	MEN: 98.5% @ 16 yrs	0.006*
-Women > 2012	99.1% @ 11 yrs	MEN after 2012: 99.5% @ 11 yrs	0.278
-Over 65	98.6% @ 16 yrs	< 65: 98.2% @ 16 yrs	0.654
-Dysplasia	97.8% @ 16 yrs	OA: 98.6% @ 16 yrs	0.391
-AVN	98.9% @ 16 yrs	OA: 98.6% @ 16 yrs	0.633
-T-Score < -1.0	98.1% @ 16 yrs	T-score > -1.0: 98.2% @ 16 yrs	0.08
-Size < 50 mm	97.3% @ 16 yrs	> 50 mm: 98.7% @ 16 yrs	0.05

reported no pain, a 100 HHS, and a 7 UCLA activity score at latest follow-up.

- Potentially toxic ion levels ($\geq 20 \mu\text{g/L}$) were only observed in failed cases/revisions (13 cases, 0.2% of cohort). Of these 13 failed cases with high ion levels, 10 were confirmed cases of AWRF. These were found to have complex fluid collections and were revised with typical findings of AWRF - including viscous white sterile fluid surrounded by a thick-walled membrane stained grey with cobalt. None had significant surrounding muscle damage. All of these patient's cobalt and chromium blood values dropped to acceptable levels after revision surgery. The remaining 3 cases of potentially-toxic ion levels failed due to loosened cups that shifted to steep angles. They had no symptoms of cobalt toxicity, they had benign MRIs, and their levels subsequently dropped to acceptable levels within a year post-revision surgery. Of the 10 cases of AWRF, 6 had no self-reported symptoms before testing revealed high blood ion levels. Three patients reported increased pain levels, and one reported hearing difficulty and memory loss.

All AWRF occurred in cases performed before 2010 and all had an acetabular inclination angle (AIA) outside of the safe zone. Since then, every acetabular component has been placed in our published and validated safe zone, known as the relative acetabular inclination limit (RAIL) [23, 24], and there have been no further AWRF cases.

Discussion

In this cohort of 6114 MoM HRAs, combined KM implant survivorship with the Biomet Magnum-ReCap™ MoM hip resurfacing system is 97.5% at 19 years post-operative. This exceeds both UK's National Institute for Clinical Excellence (NICE) criteria and all registry benchmarks for THA [25–27]. The UC group has a 16-year survivorship of 98.2%, exceeding registry benchmarks even further. This study demonstrates how experience and constant process improvement can substantially improve the results of a new operative technique (Supplemental Table 1). In our first published series of HRA with 375 Corin™ hybrid implants, mean patient age was 50 years, and 10-year KM implant survivorship was 93% [28]. Our most recent 10-year implant survivorship results with the current UC Biomet™ device is 98.8%.

Comparison to registry data and expert-surgeon series in the literature is summarized in Table 10. The current study is now the largest published long-term, single-surgeon series of hip arthroplasty in younger patients. Long-term outcomes for the Biomet Magnum-ReCap™ (97.5% 19-year survivorship, 6114 cases) compares favorably to the two most used MoM HRA systems, the Birmingham hip resurfacing (94–96% 15-year survivorship, 1500 cases) and Conserve Plus™ (89% 15-year survivorship, 1300 cases). The results of 7 expert surgeon series [6, 22, 29–32] and those of an international multi-center study of over 11,000 HRA show that excellent HRA implant survivorship is generalizable across multiple implants and surgeons worldwide [12]. Overall, implant survivorship in the international study of higher-risk patients under 50 years old was 95% at 10 years and 90% at 20 years postoperative. For comparison, the Swedish registry found THA survivorship in patients under 50 years age was 83% at 10 years and only 50% at 20 years postoperative [33]. No datasets for patients under age 50 without diagnosis selection are available within the British or Australian registries [26, 34].

We think of registry data as average surgeon benchmark data, and the best clinical series as results experts can achieve. There are very few series of THA that have durability outcomes that can compare to MoM HRA in younger patients. In Table 10 we list details of numerous studies, including four THA series in younger patients with excellent outcomes. These include: 1) Lombardi et al. [35]. publish 643 UC ceramic-on-vitamin E cross-linked polyethylene cases with 97% 10-year implant survivorship. 2) Pallante et al. [36]. report 91 cases (mostly UC ceramic-on-ceramic) with 97% 10-year implant survivorship. 3) Clohisy et al. [37]. report 144 cases (varied implants) with 96% 15-year implant survivorship. 4) HS Kim et al. [38]. publish a series of 293 cases (UC ceramic-on-ceramic) with 96% 15-year implant survivorship. While these studies show similar durability outcomes as

Table 10 Literature review

Study	Procedure	Implant	Date Range	Patient Cohort			Survivorship (%)		# Surgeons
				Hips	Avg Age	Female	10 year	15 year	
Single Surgeon Expert Series									
Current Study (Hybrid)	HRA	MoM Biomet Hybrid	2004–2008	739	51.2	29%	97.9%	95.1%	1
Current Study (Uncemented)	HRA	MoM Biomet Uncemented	2007–2018	4301	53.7	27%	98.6%	97.9%	1
Amstutz [6]	HRA	MoM Hybrid Conserve	1996–2012	1321	51	27%	93.5%	89.4%	1
McMinn [32]	HRA	MoM Hybrid BHR	1997–2000	1000	53	34%	97.4%	95.8%	1
Treacy [29]	HRA	MoM Hybrid BHR	1997–2006	447	41	41%	96.3%	94.1%	1
Brooks et al. [22]	HRA	MoM Hybrid BHR	2006–2009	389	53	27%	96.9%	N/A	1
Shimmin. [30]	HRA	MoM Hybrid BHR	1999–2001	230	52	34%	95%	--	3
Beaule [31]	HRA	MOM 92% Conserve 53% Hybrid	2006–2015	555	49	14%	91.9%	-	1
Murray (Oxford) [32]	HRA	MoM hybrid Conserve and BHR	1999–2009	646	52	41%	87%	--	Many
Registry HRA									
British NJR [53]	HRA	All HRA	2003–2021	41,121	--	--	89.8%	86.5%	N/A
Australian Registry [26]	HRA	All HRA	1999–2020	17,729	--	--	90.6%	87.3%	N/A
Van der Straeten [12]	HRA	All HRA (10)	1998–2018	11,063	42.7	26%	95%	90% (20 yrs)	27
Registry THA									
Australian Registry [26]	THA	All THA	1999–2020	459,265	69	52%	93.6%	90.5%	N/A
British registry [25]	THA	Cemented THA	2003–2020	35,300	74	66%	97%	94%	N/A
British registry [25]	THA	Uncemented THA	2003–2020	410,296	65	55%	94%	90.7%	N/A
Swedish registry [54]	THA	various	1995–2007	14,6100	< 50	51%	83%	--	N/A
THA in Young Patients									
Sochart [55]	THA	PE-Metal Cemented Charnley	1966–1978	226	31.7	71%	91%	80%	2
Whitehouse [56]	THA	MoP Cemented Exeter	1988–1995	130	41.8	N/A	~95%	~86%	Many
Swarup (HSS) [57]	THA	various	1982–2011	548	26.6	59%	87%	~78%	Many
Solomon [58]	THA	Cemented Charnley	UNK	130	38	50%	88%	88%	4
Walter [59]	THA	CoC uncemented	1997–1999	110	45	53%	96.5%	--	2
McAuley (Engh) [60]	THA	MoP uncemented	1982–1997	561	40		89%	60%	1
Kim, YH [61]	THA	CoC uncemented	1995–2000	1131	53	27%	99.7%	99.7% (20 year)	1
Kim, HS [62]	THA	CoC uncemented	2003–2009	293	47.2	36%	-	96%	N/A
Sedel [63]	THA	CoC Hybrid	1990–1992	71	46	37%	93.7	--	N/A
Lombardi (JIS) [35]	THA	CoP uncemented	2007–2014	643	50	44%	97.3	-	3
Pallante (Mayo) [64]	THA	Various UC, most CoC	1998–2016	91	17	47%	97.2	-	N/A
Parilla (Clohisy) [37]	THA	UC XLPE ceramic or metal heads	2000–2010	144	23	63%	96%	96%	1
Halawi (Brooks) [65]	THA	Various	2006–2010	426	50	27%	91% (5 year)	-	1

Abbreviations used include: MoM (metal-on-metal), BHR (Birmingham hip resurfacing), HRA (hip resurfacing arthroplasty), THA (total hip arthroplasty), PE (polyethylene), MoP (metal-on-polyethylene), CoC (ceramic-on-ceramic), UC (uncemented), XLPE (cross-linked polyethylene)

MoM HRA in younger patients, the study cohorts are significantly smaller than the current study.

The series of 1131 UC ceramic-on-ceramic THA in young patients by YH Kim et al. [39]. has the best durability outcomes at 99.7% at 20 years. In this series, implant squeaking was seen in 0.4% of cases. In other

reports of ceramic-on-ceramic, squeaking is present in 10–20% of cases [40, 41]. Although abnormal stripe wear patterns are reported at the time of revision, no adverse tissue response is associated with squeaking. Squeaking is rare in MoM HRA; although we have experienced several cases, they always resolved after a few weeks to

months. We have never read or heard of a single revision for squeaking.

There is published evidence that AWRF in HRA is caused by edge-loading [42, 43]. Edge-loading is contributed to by low coverage arc of the cup, as well as the position this cup is placed by the surgeon [23, 44]. This has also historically contributed to females being selected against for HRA, as they have smaller average component sizes - which are associated with lower acetabular coverage angles and increased risk of edge loading and AWRF [45]. We have previously established and validated a safe zone for placing acetabular components to prevent AWRF [23]. In over 7000 HRA cases to date, we have not observed any cases of AWRF when an acetabular component is within the RAIL. In this series, we have observed no sex-based differences in implant survivorship since 2012, which we largely attribute to RAIL guidelines. Over the last 19 years, our rate of AWRF (0.2%) appears lower than what is estimated to be the rate of trunnionosis in THR [46]. Our mean levels of cobalt 1.2 µg/L for unilateral cases and 1.6 µg/L in bilateral cases are within the normal range for most labs. For comparison, Levine et al. [47] reported mean cobalt levels of 0.5 µg/L in a small series of hybrid metal-on-polyethylene THA. Luetzner et al. found a mean cobalt level of 3.28 µg/L in 41 cases of total knee replacement [48], and Lons et al. reported a mean cobalt level of 1.27 µg/L in 90 primary total knee arthroplasties [49]. None of the series of HRA and THR in our literature review (Table 10) have included routine ion testing. The literature and our data support the conclusion that MoM HRA releases more cobalt than metal-on-polyethylene THR but does not routinely result in more cobalt release than total knee replacements.

We present several limitations of this study. First, there are limitations inherent to retrospective studies, including loss of follow-up. However, we maintain an UTD follow-up on 87% of 6114 cases over 19 years. We present evidence that with a prospective database, most patients who have been lost to follow-up for several years have excellent outcomes, a lower failure rate, and a higher rate of satisfaction when compared with our UTD group. This corroborates the previous findings of Joshi et al. who found that higher average clinical outcomes and lower rates of failure in patients followed prospectively that were initially lost to follow-up [50]. Next, this is a series of cases performed by a single expert surgeon, and thus, these results may not be immediately reproducible. Comparison with registry benchmark data may also therefore not be accurate, as these include surgeons performing HRA at lower volumes and provide limited demographic and failure-mode information. As another limitation of single-surgeon series is that they may not be generalizable, we provide a selected literature review that shows

multiple other expert surgeons can achieve similar results with MoM HRA.

Conclusions

Implant survivorship with the Biomet Magnum-ReCap™ MoM HRA in this cohort of over 6114 cases (mean age 54) is 97.5% at 19 years. In 5375 UC cases, this is 98.2% at 16-years and 98.8% at 10 years. This compares favorably with the best published series on other HRA devices. This study cohort's implant survivorship surpasses NICE criteria and all registry benchmarks for THA at any age. Our data no longer supports that the following are risk-factors for failure after HRA surgery: female sex, smaller implant size, or diagnosis of osteonecrosis or dysplasia. These data also confirm that metallosis is preventable with proper acetabular cup positioning. If an implant meets the RAIL criteria, our data suggests minimal to no risk of AWRF (0/5786 cases); even when outside the RAIL, the chance of revision due to AWRF is 3% (10/328). With a large-volume of cases over 19 years, this study suggests MoM HRA can be performed safely and with desirable clinical outcomes that compare well with available best-published clinical results.

Abbreviations

MoM	Metal-on-metal
HRA	Hip resurfacing arthroplasty
AWRF	Adverse wear related failure
THA	Total hip arthroplasty
UC	Uncemented
UTD	Up-to-date
MRI	Magnetic resonance imaging
AIA	Acetabular inclination angle
RAIL	Relative acetabular inclination limit
KM	Kaplan-Meier
NICE	National Institute for Clinical Excellence

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13018-025-06076-5>.

Supplementary Material 1: Process Improvement*

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We have no acknowledgements to declare.

Author contributions

Author 1 designed the study and collected data, while Author 2 analyzed data, performed statistical analyses, and designed figures and tables. Author 1 drafted the original manuscript, while Author 2 was tasked with proofing and finalizing the manuscript. All authors reviewed the manuscript.

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Data availability

Data is provided within the manuscript. Limited raw data is provided within the Synapse repository at project ID syn66245575. Expanded raw data is available upon request to the corresponding author.

Declarations

Ethical approval

We present a retrospective analysis of prospectively collected data, with patient information withheld. This type of study is exempt from IRB review based on 45 CFR 46, "Collection or Study of Existing Data", considering the HIPPA Privacy Rule (45 CFR 160 and 164a).

Competing interests

The authors declare no competing interests.

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