HIP | HIP International

HIP International
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DOI: 10.1177/1120700020957354
journals.sagepub.com/home/hpi
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Hip resurfacing arthroplasty in young patients: international high-volume centres' report on the outcome of 11,382 metal-on-metal hip resurfacing arthroplasties in patients ⩽50 years at surgery

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Abstract

Background: Total hip arthroplasty (THA) in patients younger than 50 years poses significant challenges including postoperative limitations of activity and higher failure rates. Sub-par outcomes of hip resurfacing arthroplasty (HRA) in registries remain controversial due to multiple confounders. Favourable HRA results in some studies are often regarded as irreproducible. The aim of this study is to analyse HRA outcomes in a large international cohort.

Patients and methods: We compiled a database of 11,382 HRA patients ⩽50 years from an international group of 27 experienced HRA centres from 13 countries. 18 different metal-on-metal (MoM) HRA designs were included with a mean follow-up of 7.6 years. Outcomes were implant survivorship, revision rates, causes for revision, clinical scores and metal ion levels. Outcomes were compared between genders, sizes, implant types and pre-operative diagnoses.

Results: Overall cumulative Kaplan-Meier survivorship was 88.9% at 22 years (95% CI: 88.3–89.5%). 2 HRA designs (DePuy Articular Surface Replacement (ASR), and Corin Cormet Hip Resurfacing System (CORMET)) led to inferior results while all others yielded similar survivorships. Excluding ASR and CORMET, implant survivorship in 11,063 cases was 95% at 10 years and 90% at 22 years. In men, implant survivorship was excellent: 99% at 10 years and 92.5% at 21 years. In females, implant survivorship was 90% at 10 years and 81.3% at 22 years. The overall revision rate was 3.6% with most common reasons for revision being implant loosening and adverse local tissue reactions. The best survivorship was found in patients with osteoarthritis (95% CI, 92.1–93.3% at 22 years), the poorest was among dysplastic hips (78.3%; 95% CI, 76.5–80.1% at 20 years, $p < 0.001$).

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Conclusions: Comparable revision rates demonstrated here may mitigate some concerns for safety and longevity of MoM HRA implants. Higher demands for activity and functionality in younger patients make HRA a potential alternative to THA.

Keywords
Hip arthroplasty, hip resurfacing, metal-on-metal, survivorship, young patients

Date received: 3 May 2020; accepted: 29 June 2020

Introduction

Outcomes of total hip arthroplasty (THA) in patients 50 years and younger at the time of surgery are significantly worse compared to those of older patient populations.[1] The 2016 Annual Report of the Swedish Hip Register recorded all THA surgeries in Sweden between 1992 and 2015 outlining the 24-year cumulative Kaplan-Meier (KM) survivorship in patients undergoing surgery at different age groups. It was found that the 24-year survivorship in ages ⩽50 years at the time of surgery was 52.2% and 57.4% for female and male patients respectively. On the other hand, the age group 51–59 years at the time of surgery demonstrated a 69.7% and 62.8% survivorship; 60–75 years had an 83.7% and 77.6% survivorship; and >75 years had a 90.3% and 94.3% survivorship in females and males, respectively.[1]

Modern metal-on-metal (MoM) hip resurfacing (HRA) was developed in an attempt to delay THA in younger patients, as well as provide a more anatomical, bone preserving hip reconstruction.[2] Initial widespread use was followed by an increasing number of reported adverse local tissue reactions (ALTR) to metal wear debris and elevated systemic metal ion levels.[2–4] Reported high rates of adverse effects resulted in the worldwide withdrawal or recall of some implants.[5,6] This incident prompted further investigation into the incidence of adverse local tissue reaction (ALTR) associated with MoM. Trunnion corrosion at the junctions between modular THA components and surface wear,[7] as well as concomitant metal allergy, have all been implicated.[8,9] The significant overlap between failure modes coined the term "metal failure" to encompass all metal related complications leading to implant failure.[7] A multitude of factors predispose for metal failure, including: female gender, low body mass index (BMI), smaller implant sizes, poor component positioning, and most frequently too steep acetabular component placement or excessive anteversion with subsequent edge loading.[10]

Despite reports of poor outcomes, national hip registers have recently demonstrated good to excellent, medium to long-term survivorship results with certain HRA designs such as the Birmingham Hip Resurfacing system (BHR; Smith & Nephew, PLC, London, UK). In the Australian Joint Register (AOAJRR) 2018 report the cumulative survival at 10 and 15 years of the BHR (both genders, all sizes, all diagnoses) was 93.3% (95% confidence interval [CI]: 92.8–93.7%) and 90.0% (95% CI: 89.3–90.7%), respectively.[11] Additionally, the National Joint Registry (UK NJR) Annual Report 2018 reported a 92.05% (95% CI: 91.63–92.44%) cumulative survival of the BHR at 10 years and 88.98% (95% CI: 88.32–89.60%) at 14 years (all cases).[12] National registries have also demonstrated better outcomes reported by high-volume compared to low-volume centres.[13,14] Moreover, some studies indicate better functional and activity outcomes,[15] closer to normal gait patterns,[16] and lower mortality rates associated with HRA compared to THA.[17–19] Therefore, the potential for superior functional outcomes in the younger populations combined with reports of acceptable survivorship and low adverse effects of some implant types indicate a need for further evaluation of HRA outcomes.[1,11,12]

In June 2016, an international HRA registry database was created by high volume HRA surgeons from 13 countries, starting with the retrospective collection of all consecutive HRA in patients ⩽50 years of age at surgery with >3 years follow-up. The primary aim was to investigate the overall cumulative survivorship of HRA in patients ⩽50 years from high-volume HRA centres, evaluate complications, reasons for revision, and perform comparative subgroup analyses by gender, diagnosis, implant size and HRA implant type. In addition, clinical outcomes including patient-reported outcome measures (PROMs) and metal ion levels were investigated when available for analysis.

Patients and methods

From July 2016 to August 2019, blinded data from all consecutive HRA in patients ⩽50 years of age at surgery and with a minimum follow-up of 3 years, were collected in a single large database. High-volume hip resurfacing centres (>50 HRA per year) participated in this study and provided data that was either collected prospectively or retrospectively through arthroplasty databases such as OrthoWave (ARIA SARL, Houdin, France) or Socrates Ortho (Ortholink Pty Ltd, Pyrmont, Australia) (supported by institutional ethics approval/review board and informed consent according to the respective local legislation), in addition to national arthroplasty registries. Data included demographics of gender, age, diagnosis, side of the HRA, BMI; implant and surgery data (implant design, size, surgery date, unilateral or bilateral HRA, cemented or non-cemented); follow-up (FU) data (last FU date), status (*in situ*, revised, deceased with date of death, lost to FU (with last FU date); revision data (date, reason and revision procedure); complications and clinical data when available (Harris Hip Scores (HHS) and/or patient-reported outcome measures (PROMs) (Oxford Hip Scores (OHS), University of California-Los Angeles (UCLA) activity scores) and blood metal ion (cobalt [Co] and chromium [Cr]) measurements. The last FU date or contact was used to compute life tables and cumulative Kaplan-Meier survivorship. Last FU date was defined as the last visit to the clinic. Confirmation that the prosthesis was still in place was also obtained from national registries' individual surgeon's reports or telephone contact by the specific centre with the patient.

Statistical analysis

Statistical analysis was performed in SPSS version 25 (IBM-SPSS, Armonk, NY, USA); survival graphs including 95% confidence intervals were obtained with JMP 13 software (SAS, Cary, NC, USA). Kaplan-Meier survivorship analysis was used to estimate implant survivorship. Patients were censored based on the date of revision surgery or the last follow-up visit indicating implant survival. Subgroup survivorship comparisons were performed using the log-rank (Mantel-Cox) test. PROMs and metal-ion results were analysed using non-parametric statistical tests. Statistical significance was set at $p < 0.05$.

Results

Data from 11,382 HRA in patients ⩽50 years at surgery with >3 years FU were collected from 27 high volume HRA centres in 13 countries (USA, Canada, UK, Belgium, France, Germany, Italy, Spain, Portugal, the Netherlands, Australia, Japan, Brazil). Demographics of the population and HRA designs are summarised in Table 1. There were significantly more HRA in males (74.3%) compared to females (25.7%) ($p < 0.001$). Females were slightly younger (mean age 42.2 years vs. 42.9 years for men) ($p < 0.001$), more frequently diagnosed with developmental dysplasia of the hip (DDH) (26.3%) ($p < 0.001$) and had a significantly smaller femoral head size (a median size of 46 mm vs. 50 mm in men) ($p < 0.001$) (Figure 1).

Mean FU time was 7.6 years (range 0.01 (revision) to 22 years). HRA status included 9768 HRA confirmed *in situ* (85.8%), 407 were revised (3.6%), 92 in patients who were deceased (0.8%) and 1115 lost to FU (9.8%). Numbers of HRA and status per year of surgery are displayed in Figure 2. Of the 407 revisions (3.6%), 202 occurred in males (49.6%) and 205 in females (50.4%). The most common reason for revision was component loosening ($n = 111$; 27.3% of reported revisions) followed by ALTR ($n = 42$: 10.3% of reported revisions), infection ($n = 33$; 8.1% of reported revisions), femoral neck fracture ($n = 32$; 7.9% of reported revisions), pain ($n = 18$; 4.4% of reported revisions); the reason for revision was not specified in $n = 78$; 19.2% of reported revisions (all reasons for revision see Table 2). There was a statistically significant difference ($p < 0.001$) in demographics between the *in situ* group and the revised group with significantly more females, more preoperative diagnosis of DDH and osteonecrosis of the femoral head, smaller femoral head sizes and more DePuy Articular Surface Replacement (ASR), and Corin Cormet Hip Resurfacing System (CORMET) type HRA in the revised group. The demographics of the revised group were also significantly different from the deceased and the lost groups ($p < 0.001$), while the lost group did not differ from the *in situ* group in gender, diagnosis, head size or implant design ($p > 0.1$).

Overall cumulative Kaplan-Meier survivorship was 88.9% at 22 years (95% CI: 88.3–89.5%) (Figure 3) (Lifetables in addendum). Cumulative survival was significantly superior in males: 92.5% at 21 years (95% CI: 92.0–93.2%) versus females: 81.3% at 22 years (95% CI: 80.0–82.6%) (Figure 4(A)). HRA in osteoarthritis (OA) performed significantly better ($p < 0.001$) with 92.7% survival at 22 years (95% CI: 92.1–93.3%) compared to osteonecrosis: 85.2% (95% CI: 83.1–87.3%) and DDH: 78.3% (95% CI: 76.5–80.1%) (Figure 4(B)). Survivorship of HRA in male patients with OA was 95.1% (95% CI: 94.5–95.7%) versus 85.3% (95%CI: 83.6–87.0%) in females with OA ($p < 0.001$). For osteonecrosis there was no significant difference in cumulative survivorship, while HRA in females with DDH had worse survival rates ($p < 0.001$). Patients with DDH were significantly younger, 70% of female gender and had a smaller mean head size (all $p < 0.001$). Head sizes <48 mm had a significantly worse survival at 22 years: 81.1% (95% CI: 79.9–82.3%) compared to head sizes ⩾48 mm: 93.8% (95% CI: 93.2–94.4%) ($p < 0.001$). In both genders, survival of head sizes ⩾48 mm was significantly better than <48 mm: 94.3% (95% CI: 93.7–94.9%) versus 82.5% (95% CI: 80.4–84.6%) in males ($p < 0.001$); 85.6% (95% CI: 82.8–88.4%) versus 80.8% (95% CI: 79.4–82.2%) in females ($p = 0.005$) (Figure 4(C)). For <48 mm HRA sizes, the difference between genders was not significant ($p = 0.140$) but borderline significant for sizes ⩾48 mm ($p = 0.047$). It should be noted that there were 673 HRA sizes below 48 mm in males (8%) versus 2176 in females (74%).

Implant design was a significant factor for overall survivorship ($p < 0.001$) (Figure 5(A)). ASR and CORMET type HRA performed significantly worse (Figure 5(B)). There was a borderline statistically significant difference in survivorship between cemented (89.8% at 20.1years (95% CI: 87.2–90.3%) and non-cemented HRA (85.0% at 22.0 years (95% CI: 83.0–87.0%) ($p = 0.047$).

Table 1. Demographics and hip implant data.

Hip resurfacing arthroplasties (HRA)	Total *n*: 11,382 HRA	%
Gender:		
Male	8455	74.3
Female	2925	25.7
Not specified	2	
Mean age at surgery (range)	42.7 years (11–50 years)	
Median age at surgery	Median: 44.5 years	
Diagnosis:		
primary OA	8238	72.4
Osteonecrosis	759	6.7
DDH	1095	9.6
Other (Post-traumatic OA, inflammatory, SCFE, LCP)	562	Each <3%
Mean femoral head size (range - median)	49.7 mm (36–64 years) Median 50 mm	
Hip resurfacing brand/type		
ACCIS	13	0.1
ADEPT	528	4.6
ASR	41	0.4
BHR	5489	48.2
BHR dysplasia cup	136	1.2
BMHR	1	0.01
CONSERVE PLUS A-CLASS	49	0.4
CONSERVE PLUS	3162	27
CONSERVE quadrafix cup	1	0.01
CORMET	276	2.4
CORMET dysplasia cup	2	0.02
DUROM	257	2.3
DUROM MMC	9	0.09
ICON	8	0.08
MITCH	88	0.8
RECAP	1265	11.1
ROMAX	1	0.01
TARA	56	0.5
Mean follow-up (years)–median (range)	7.6 years–Median: 7.1 years (0.1 (revision)–22 years)	
Status at last follow-up: of all 11382 cases:		
In situ	9768	85.8
Revised	407	3.6
Deceased	92	0.8
Lost	1115	9.8

OA, osteoarthritis; DDH, developmental dysplasia of the hip; SCFE, slipped capital femoral epiphysis; LCP, Legg-Calvé-Perthes disease.

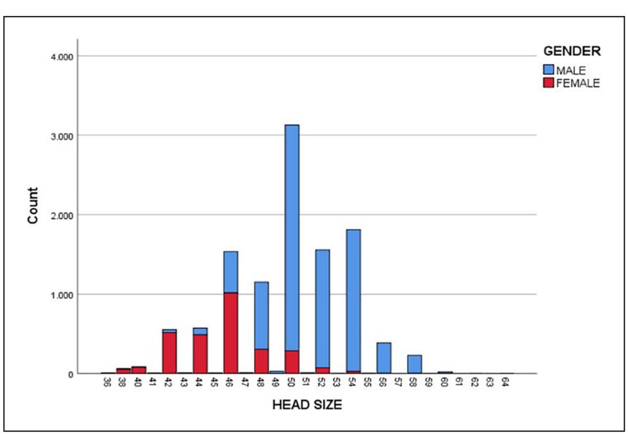

Figure 1. Femoral head sizes in male and female patients.

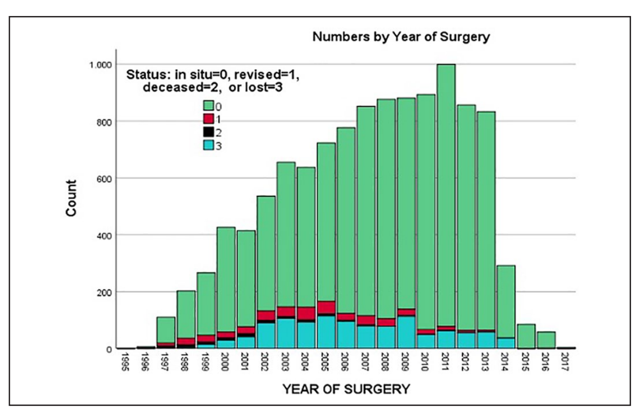

Figure 2. Numbers and status of hip resurfacings by year of surgery.

Table 2. Reasons for revision surgery.

Main reason for revision	*n*	% of revisions	% of cases ($n=10267$)
Infection	33	8.1	0.32
Femoral neck fracture	32	7.9	0.31
Implant component loosening	111	27.3	1.08
Malpositioning - high wear	14	3.4	0.14
Instability - dislocation	12	2.9	0.12
Osteonecrosis of the femoral head	14	3.4	0,14
Adverse local tissue reactions	42	10.3	0.41
High blood metal ions	10	2.5	0.10
Unexplained pain	18	4.4	0.17
Periprosthetic fracture	12	2.9	0.12
Periprosthetic osteolysis	6	1.5	0.06
Impingement	7	1.7	0.07
Component mismatch	2	0.5	0.02
Other less frequent	16	3.9	0.16
Not specified	78	19.2	0.76
			Total revisions = 3.96% (out of $n=10,267$)

Failures $n=407$, Total $n=11382$; Lost to follow-up: $n=1115$; Total cases with known follow-up until review: $n=(11,382–1115)$ 10,267.

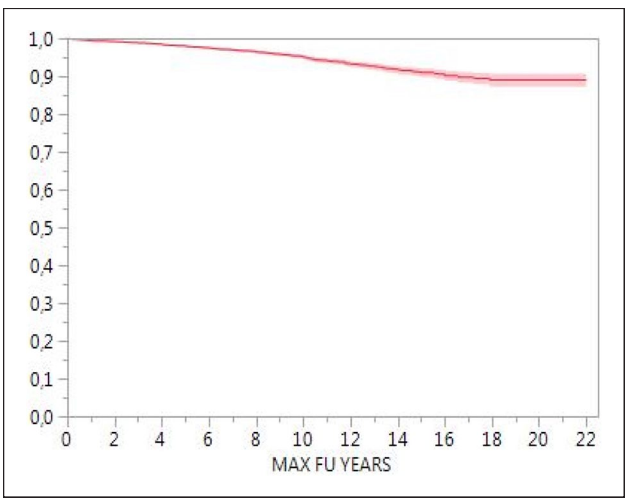

Figure 3. Overall Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve: all designs – all genders – all diagnoses – all sizes ($n=11,386$): 89.1% at 22 years (95% confidence interval, 88.5–89.7%).

Additionally, we performed a Cox proportional hazards regression analysis to assess simultaneously the effect of several risk factors on implant survival time. The Cox regression analysis showed that diagnosis, size and implant type (ASR/CORMET) were the most significant factors ($p<0.001$). Gender was significant ($p=0.022$) when only diagnoses of OA, osteonecrosis and DDH were considered, not when all diagnoses were considered ($p=0.079$).

Clinical scores and/or metal ion data were available in 9302 HRA (85%) at last follow-up. Mean HHS was 94.6 (median 98.4; max = 100; standard deviation [SD] 8.97) ($n=5295$); mean OHS was 45.8 (median 47; max = 48; SD 3.70) ($n=2579$); Mean UCLA activity score was 7.4 (median 8; max = 10; SD 1.98) ($n=4334$). There was no statistically significant difference in scores between males and females except for UCLA activity score with average score 7.7 in males versus 6.7 in females ($p<0.001$). Blood metal ion measurements were collected in 2813 patients at last FU. Median Co level was 1.3 µg/L (0–146). Cr levels were only collected in 969 HRA, median Cr level was 2.1 µg/L (0–89.5). Metal ion levels were used as prognostic or diagnostic information and high levels led to revision (see Table 2). Cumulative overall KM mortality rates were 1.2% at 10 years and 9.9% (95% CI, 7.9–8.9%) at 20 years with no statistically significant difference between genders ($p=0.162$) (Tables in addendum).

Discussion

This international registry containing 11,382 HRA in patients ⩽50 years at surgery with >3 years FU is the result of a collaborative effort of 27 high-volume HRA centres from 13 countries. To our knowledge, the sample size of this study draws close to that of large databases: the Swedish hip register 2000–2017 which included 13,257 hip replacements (of which only 1000 HRA) in patients <50 years,[1] the 2018 AOAJRR report included 8714 HRA in patients <55 years,[11] and the 2018 National Joint Registry report (UK) 13,637 HRA in patients <55 years.[12]

In this international multicentre study with 18 different HRA implants, the overall mid-term implant survivorship in patients ⩽50 years was found to be 94% at 10 years (Lifetables in addendum); 96% in males versus 90% in females. This compares favourably with the 89% 10-year implant survivorship in males and 87% in females for THA in patients ⩽50 (all genders, all diagnoses, cemented and uncemented implants) reported by the

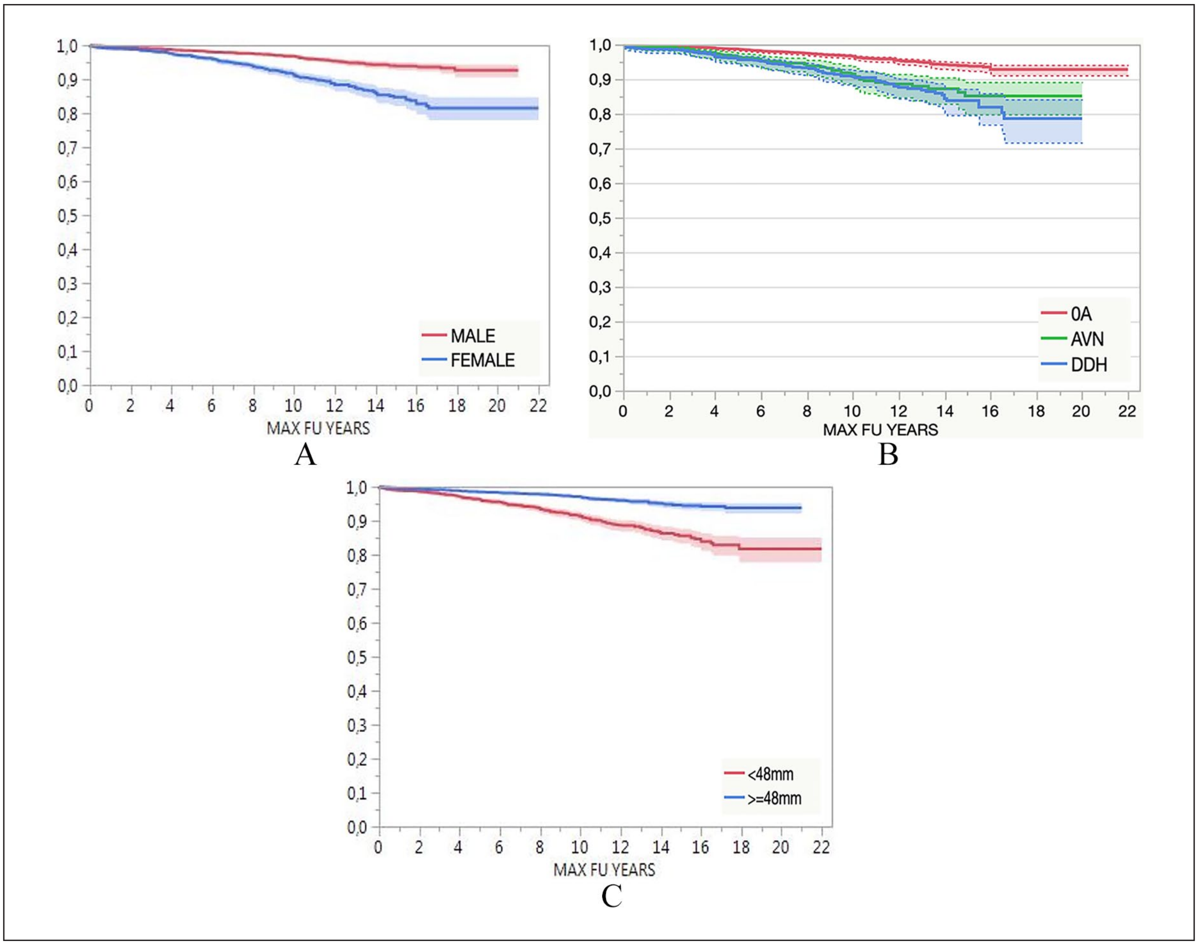

Figure 4. Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve according to gender (B) Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve according to diagnosis (osteoarthritis (OA); osteonecrosis (AVN); developmental dysplasia of the hip (DDH)) (C) Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve according to femoral head size.

Swedish registry,[1] where overall long-term HRA implant survivorship was found to be 88.9% at 22 years; 92.5% in males and 81.3% in females. These survivorship rates are considered acceptable when compared to THA standards.[1] Rames et al.[20] found a revision-free survivorship of 97.8% at 15 years follow-up when analysing highly cross-linked polyethylene in young THA patients (mean age of 38.8 years); however, this study had low numbers, only 80.9% follow-up and reported 16.9% mortality (11 patients).[20] Given the acceptable implant survival rates, HRA could provide a viable alternative to THA in younger patients, particularly males with OA. This is furthered by the HRA's improved function and higher activity levels described in some studies compared to THA.[15,16,21] Other potential advantages of HRA include easier femoral-side revision, low rates of instability (only 0.9/1000 dislocations in this study),[22] better bone preservation and lower 10-year all-cause mortality.[17,18,23,24]

In a 5-year implant failure comparison from the UK registry, Smith et al.[25] concluded that THA was superior to HRA. However, analysis of data in the appendix revealed that surgeons contributing HRA cases to the registry had performed a mean of 4.6 cases/year. This demonstrates that surgeons inexperienced in HRA cannot equal THA implant survivorship levels and that complicated modern technologies should be mastered by a few before being gradually disseminated via appropriate training. Our data gathered only from HRA specialists suggest that surgeons with sufficient experience in HRA can achieve similar if not better results than are currently reported for THA in young patients.

Adverse local tissue reactions (ALTR) to wear debris-related failure in this study of MoM resurfacing components (reported in 42 cases, 18 male and 24 female, accounting for 10.3% of reported revisions; 0.4% of 10267 actively reviewed cases to date) trended towards the lower of the 5–68% range reported by various studies that reported on the MoM THA counterpart.[26–31] This finding could be explained in part by the absence of modular junctions between implant components, which

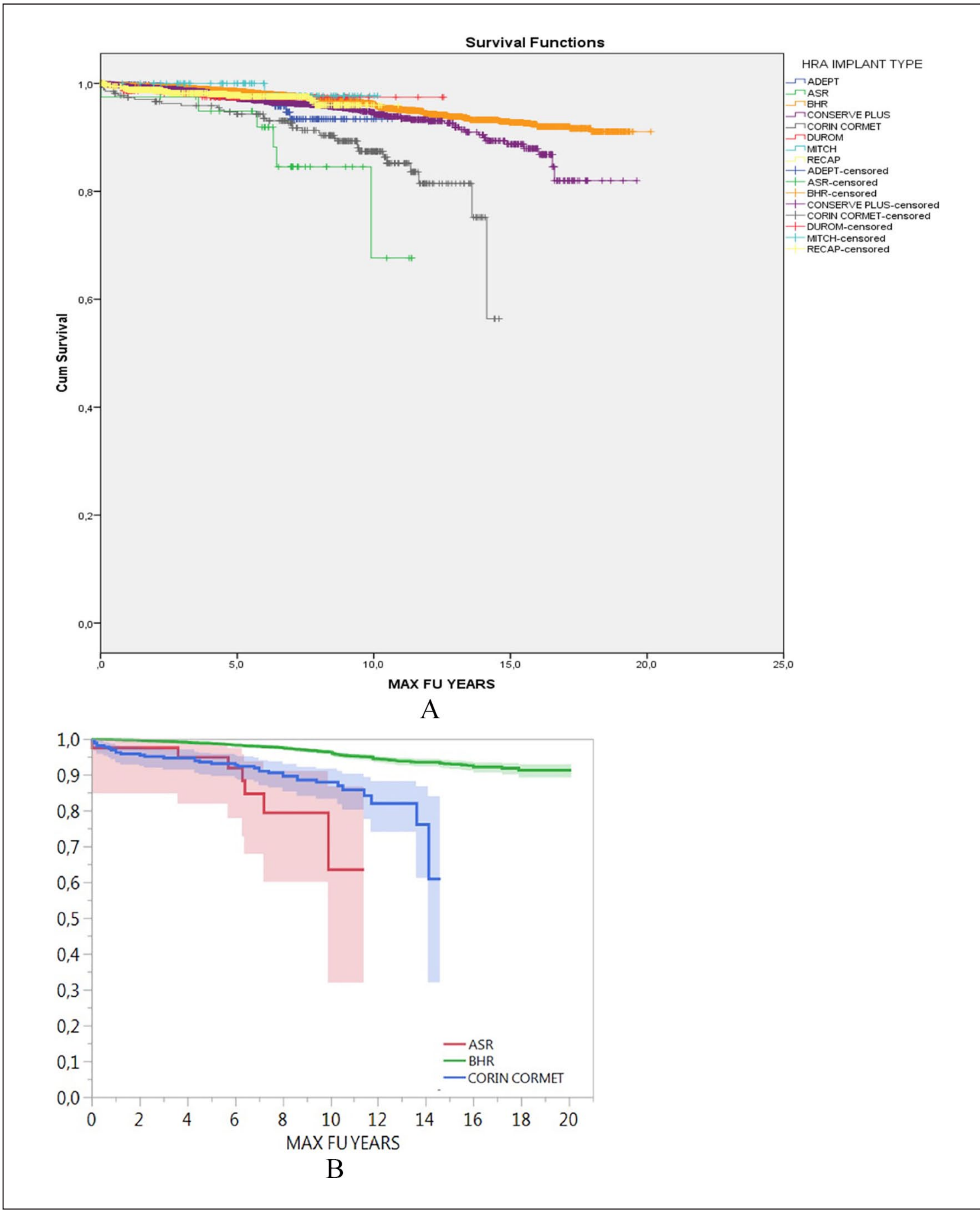

Figure 5. (A) Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve according to implant design (all designs) (B) Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve with confidence intervals: comparison between Smith & Nephew Birmingham Hip Resurfacing (BHR), DePuy Articular Surface Replacement (ASR), and Corin Cormet Hip Resurfacing System.

appear to be an important cause of ALTR in MoM THA.[2,4,5,8,9] Furthermore, proper component positioning and the use of implants with adequate coverage angles (which varies between manufacturers) can diminish edge loading and metal debris generation even further.[2,4,5] With the knowledge and experience gained regarding implant design and correct positioning, this failure mode can be mitigated.[32] Over a mean 4.8-year follow-up, Matharu et al.[33] found that the most common cause for MoM HRA revision was ALTR (7.8% of a total revision rate of 12.6%). Conversely, our study demonstrated lower overall revision rates (3.6%) within a

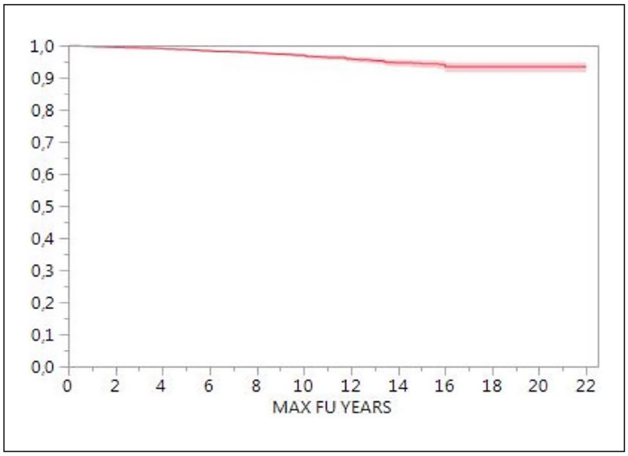

Figure 6. Overall Kaplan-Meier cumulative hip resurfacing arthroplasty survivorship curve: all genders – all diagnoses – all sizes – all designs except DePuy Articular Surface Replacement (ASR) and Corin Cormet Hip Resurfacing System: (n = 11,063): survival 95% at 10 years and 90% at 22 years.
MAX, maximum; FU, follow-up.

longer follow-up period (mean of 7.6 years). Furthermore, our study showed that ALTR represented the second most common mode of failure (10.3% of 407 revisions) after implant loosening (33.6%). Notably, the study sample utilised by Matharu et al.[33] encompassed a wider age range (mean 53.8 years [16.5–85.5 years]), had smaller femoral head sizes (mean 48.4 mm (38–58 mm)). On the other hand, in their prospective multicentric study, Su et al.[34] demonstrated a 97.6% (95% CI, 0.96–0.994) survival from revision surgery at 5 years and an overall revision rate of 2.4%. However, their short follow-up period (mean 3.6 years) as well as the exclusion of patients with osteoporosis or history of metal allergy might contribute to these superior outcomes.[34] Oak et al.[35] were able to report a 6.2 year mean follow-up with 5-year survivorship reported at 97.2% for females and 99.5% for males.[35]

Our subgroup analyses corroborated findings from the registers demonstrating poorer HRA outcomes in specific patient populations: females, DDH and small head sizes (<48 mm).[1,11,12] The aforementioned risk factors exhibited a degree of interrelation: female gender was associated with a significantly higher percentage of DDH as a primary diagnosis and smaller mean femoral head sizes. We also found that some implant designs such as the ASR and the CORMET HRA performed well below the reported average.[5,6,11,12] After exclusion of both designs (ASR and CORMET), there was a notable improvement in the overall survivorship reaching 96.9% and 93.4% for 10- and 20-year survivorship in OA respectively (all genders, all sizes, all other implants) (Figure 6). Improved survivorship was demonstrated in gender based analysis as well; 98% 10-year and 95% 20-year survival in males with OA (n=6434) and 93% 10-year and 87% 20-year HRA survival in females with OA (n=1596) (Life tables in addendum). When considering femoral head sizes ⩾48 mm, long-term cumulative survivorship in OA was 96.2% at 20 years with 98% in males (n=5923) and 92% at 19 years in females (n=421).

The durability of THA has consistently improved since its introduction. This resulted in the introduction of raised NICE (National Institute for health and Care Excellence) guidelines in the UK with a 95% 10-year implant survivorship as a mark of excellence.[2,3,5] However, results of THA implants in young patients frequently fall short of achieving these standards of quality,[1,11,12,36] a challenge that often remains unrecognised.[37] Recent reports have shown that all-cause mortality at 10 years is significantly lower in patients with HRA. Using the English hospital episode statistics (HES) database linked to the mortality records from the Office for National Statistics of the UK, Kendal et al.[17] found that all-cause mortality at 10 years was 3.6% in HRA compared to 6.1% in cemented THA in matched groups using propensity score matching (adjusting for all confounding factors) and 3.0% in HRA compared to 4.1% in uncemented THA after propensity score matching. Brooks et al.[18] confirmed these findings in a study in the USA. These findings agree with our study in which we demonstrated exceptionally low 10-year mortality rates (1.2%) in young patients with HRA (1.2% in men and 1.4% in women [p=0.162]).

Multiple considerations in the younger population make MoM-HRA an appealing alternative to THA provided equivalent safety. The anticipated implant wear in the highly active young population can be significantly diminished using MoM-HRA.[38,39] Furthermore, the similar wear rates evident in ceramic on ceramic implants are offset by their brittle nature, with consequent failure rates of up to 13% in young patients.[38] The large femoral head sizes provided by MoM-HRA is another advantage that offers heightened stability, which allows for more vigorous activity levels in the younger population. Finally, the retained bone-stock compared to THA diminishes the technical difficulty of future conversion to THA if needed.[38]

Our study is not without limitations. There is an absence of a control group; however, the aim of this study was to report on outcomes of a large cohort while assessing safety and efficacy compared to reported outcomes from similar large cohort studies and registries. Our mean follow-up period of 7.6 years does not cover the entire expected implant survivorship. However, it is considerably longer than most similar studies which report follow-up periods ranging from 3.4 to 7.1 years.[33] Loss to FU (9.8%) was another inevitable draw-back. High-volume centres often attract patients living far away or abroad which complicates FU and makes regular clinic visits difficult to impossible. Furthermore, despite the thorough data collection protocol, the international multicentric nature of the study poses an inherent risk of missed endpoints. We demonstrated that the demographics of the lost group were equivalent to the *in situ* group and significantly favourably different from the revised group. Matharu et al.[24] found improvement in long-term implant survival with the sequential capture of young and active patients undergoing HRA who were initially considered lost, showing that lost-to-FU patients were usually performing better than the remainder of the cohort and that adding them improved survivorship results. Bayliss et al.[37] similarly demonstrated that patients who were lost to FU due after moving elsewhere were more likely to be medically well. Another limitation is the deficiency of metal ion measurements and follow-up MRI. The use of these modalities is not customary practice in all centres especially in asymptomatic patients. This is due to their prohibitive cost, the need for dedicated clinical laboratories and the variation of interpretation. Standard radiographs were performed in all patients as part of daily orthopaedic practice and assessed critically by the surgeons at last follow-up.

Although this report only includes dedicated HRA centres, it also includes the initial learning curve of the surgeons involved. Finally, this study encompassed 18 different types of implants for comparison. Although this provides a comprehensive outcome stratification depending on implant type, some implants were poorly represented in the study group. However, since this study was meant to be a registry of all implants used in patients $\leqslant$50 years at surgery at the participating centres, we chose to keep them in the evaluation, especially when considering the overall results of HRA in this young patients population.

In this study, we demonstrated that HRA can be a safe and effective alternative for the young hip arthroplasty patient, where preserved functionality and activity associated with HRA can provide an advantage over the more traditional THA. Our study included multiple international high-flow centres, indicating that the yielded favourable outcomes compared to national registries are contingent upon the presence of sufficient surgeon experience. Therefore, appropriate training programs, and maintenance of experience by minimum yearly volumes will remain mandatory requirements to achieve good outcomes. In this regard, we should consider restricting HRA procedures to specialised centres whilst precluding hospitals where surgeons are not able to reach and maintain sufficient numbers from performing HRA.

Acknowledgements

The authors wish to thank Geert Byttebier, professional statistician, for his advice and review of the statistical analysis.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The International Hip Resurfacing Group consists of high volume hip resurfacing surgeons, whose consecutive surgeries in patients 50 years or younger at surgery and their clinical outcomes are included in this paper. The surgeons were not involved in data analysis, reporting or interpretation of results. The lead author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship and/or publication of this article.

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