■ HIP

The mean ten-year results of metal-on-metal hybrid hip resurfacing arthroplasty

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Aims

This study presents the long-term survivorship, risk factors for prosthesis survival, and an assessment of the long-term effects of changes in surgical technique in a large series of patients treated by metal-on-metal (MoM) hip resurfacing arthroplasty (HRA).

Patients and Methods

Between November 1996 and January 2012, 1074 patients (1321 hips) underwent HRA using the Conserve Plus Hip Resurfacing System. There were 787 men (73%) and 287 women (27%) with a mean age of 51 years (14 to 83). The underlying pathology was osteoarthritis (OA) in 1003 (75.9%), developmental dysplasia of the hip (DDH) in 136 (10.3%), avascular necrosis in 98 (7.4%), and other conditions, including inflammatory arthritis, in 84 (6.4%).

Results

The mean follow-up time was 10.5 years (1 to 20). Using revision for any reason as the endpoint, the overall survivorship at 15 years was 89.4% (95% confidence interval (CI) 86.8 to 91.4). There was a substantial increase between the first and second generation of surgical technique (86.6% *vs* 90.1%; p = 0.05). Men with idiopathic OA had a 15-year survivorship of 94.5% and women, 82.2% (p = 0.001); gender was not a risk factor after stratification by component size and aetiology. Using revision for excessive wear (ion levels > 7 µg/l associated with symptoms or adverse local tissue reactions) as the endpoint, the 15-year survivorship was 98.5%. Risk factors for revision for all modes of failure were an underlying pathology of hip dysplasia, a contact patch to rim (CPR) distance of 7 mm or less, an age at surgery of 55 years or less, and a femoral component size of 46 mm or less. Specific risk factors for aseptic failure of the femoral component were early surgical technique, a cementless metaphyseal stem, and a body mass index of 24 kg/m² or less.

Conclusion

HRA is a viable concept; metal-on-metal bearings are well suited for this procedure when a well-designed device is properly implanted. The best results were obtained in men with OA, but survivorship was better for other underlying pathologies and for women after changes were made to the technique of implantation. Lifetime durability is a possible outcome for many patients despite a high level of activity.

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In the late 1990s and the early part of this century, there was a resurgence in popularity of hip resurfacing arthroplasty (HRA) using metal-on-metal (MoM) bearings.[1] These were intended to eliminate polyethylene wear, debris-induced osteolysis, and aseptic loosening of the components.[2] After encouraging early results,[3-5] the finding of adverse local tissue reactions (ALTR) associated with metal wear debris[6] and the recall of one design, the articular surface replacement (ASR) (DePuy Synthes, Warsaw, Indiana), triggered a considerable reduction in the use of HRA worldwide.

Today, the causes of excessive wear of MoM bearings are largely understood.[7-9] A few specialized centres are currently continuing to implant them and have reported excellent ten-year survivorship results for selected patient populations[10-13] in which HRA rivals, or even exceeds, the results of THA.[14] However, there is little long-term data to show whether MoM HRA deserves a place in the surgical options for the patient with an osteoarthritic hip.

This study presents the long-term survivorship results, the specific risk factors for prosthesis

Table I. Patient demographic data

Characteristic	Whole cohort	1st generation	2nd generation	3rd generation
Mean age at surgery, yrs (range)	51.1 (14 to 83)	48.4 (15 to 71)	49.7 (14 to 78)	53.2 (14 to 83)
Mean weight, kg (range)	83.7 (42 to 179)	85.4 (45 to 164)	82.3 (42 to 135)	83.8 (45 to 179)
Mean height, m (range)	1.76 (1.40 to 2.03)	1.75 (1.52 to 1.98)	1.76 (1.40 to 1.98)	1.76 (1.47 to 2.03)
Mean body mass index, kg/m² (range)	27.0 (16.7 to 47.1)	27.8 (18.3 to 46.4)	26.4 (16.7 to 41.2)	27.0 (17.3 to 47.1)
Mean postoperative UCLA activity score (range)	7.3 (2 to 10)	7.0 (2 to 10)	7.4 (3 to 10)	7.3 (2 to 10)
Mean component abduction angle, ° (range)	44.3 (16 to 71)	43.1(22 to 62)	43.9 (16 to 71)	45.1 (24 to 65)
Mean component anteversion angle, ° (range)	17.0 (2 to 42)	15.7 (2 to 40)	18.6 (2 to 40)	16.8 (3 to 42)
Mean CPR distance, mm (range)	14.8 (3.2 to 24.6)	15.2 (6.4 to 23.8)	14.1 (3.2 to 24.6)	15.1 (3.6 to 23.9)
Gender, n (%)				
Male hips	972 (*73.6*)	226 (*75.3*)	279 (*75.2*)	467 (*71.8*)
Female hips	349 (*26.4*)	74 (*24.7*)	92 (*24.8*)	183 (*28.2*)
Aetiopathology, n (%)				
Osteoarthritis (OA), including post-traumatic OA	1003 (*75.9*)	208 (*69.3*)	264 (*71.2*)	531 (*81.7*)
Developmental dysplasia of the hip	136 (*10.3*)	32 (*10.7*)	44 (*11.9*)	60 (*9.2*)
Osteonecrosis (ON), including post-traumatic ON	98 (*7.4*)	35 (*11.7*)	32 (*8.6*)	31 (*4.8*)
Childhood disorders (LCP, SCFE, epiphyseal dysplasia)	43 (*3.3*)	13 (*4.3*)	19 (*5.1*)	11 (*1.7*)
Inflammatory (ankylosing spondylitis and inflammatory OA)	22 (*1.7*)	7 (*2.3*)	6 (*1.6*)	9 (*1.4*)
Rheumatoid (RA and JRA)	13 (*1.0*)	4 (*1.3*)	5 (*1.3*)	4 (*0.6*)
Other	6 (*0.4*)	1 (*0.3*)	1 (*0.3*)	4 (*0.6*)

UCLA, University of California, Los Angeles; CPR, contact patch to rim; LCP, Legg–Calvé–Perthes disease; SCFE, slipped capital femoral epiphysis; RA, rheumatoid arthritis; JRA, juvenile rheumatoid arthritis

survival, and an assessment of the long-term effects of changes in surgical technique in a large series of patients treated with MoM HRA.

Patients and Methods

Between November 1996 and January 2012, 1074 patients (1321 hips) underwent hybrid HRA by the senior author and designer surgeon (HCA). The prosthesis used in all hips was the Conserve Plus Hip Resurfacing System (Wright Medical Technology Inc., Arlington, Tennessee). Its implantation had been approved by the Food and Drug Administration for use in the United States. There were 787 men (73%) and 287 women (27%) in the series with a mean age of 51.1 years (14 to 83) at the time of surgery (Table I).

All candidates for hip arthroplasty were offered the option of HRA even if there were significant femoral defects or an eroded or dysplastic acetabulum. Follow-up visits were scheduled annually for the first five years, then every two to three years, then every five years after the ten-year mark.

The position of the acetabular component was assessed on postoperative anteroposterior (AP) radiographs using Ein Bild Roentgen Analyse (EBRA, University of Innsbruck, Innsbruck, Austria) to measure component abduction and anteversion angles. The contact patch to rim (CPR) distance, a 3D estimate of the hip's functional coverage, was then computed as previously described.[15,16] The variables included in the calculation of CPR distance were component abduction angle, component anteversion angle, component inside diameter, and component articular arc angle (CAAA).[17] The first 643 hips had the original 5 mm thick socket. In November 2003, a thinner 3.5 mm component was introduced and used for all but 18 of the 678 subsequent hips. However, CAAA and clearance remained unchanged between the two component designs. The geometry of the designs and comparative results have previously been published.[17,18]

The surgical technique used in this series has also previously been described.[19] There were three phases in the evolution of the technique for implantation of the femoral component. In the first generation (the first 300 hips), cystic material was only curetted out and few drill holes made in the dome of the acetabulum. In the second generation (the next 371 hips), a high-speed burr was used to clear cystic and necrotic material; drill holes were added in the dome and chamfer areas, and a suction tip inserted into the metaphyseal stem drilled hole. The third generation (current technique, after hip #671) had a second suction tip added to the lesser trochanter and a CO_2 blow dry (Carbojet, Kinamed, Camarillo, California) was used to complete drying of the bone before introduction of the cement.

In addition, 557 (42%) femoral components had the metaphyseal stem cemented to increase the bonding area between the bone and the component. The indications for cementing the stem evolved over time as described in previous publications,[20,21] but settled on hips with a small diameter of femoral head (≤ 46 mm) or large defects in the femoral head (≥ 1 cm).

There were minor differences in the demographics and underlying pathology of the three generation cohorts (Table I). Overall, serum cobalt (Co) and Chromium (Cr) ion studies were available for 401 patients (509 hips), performed either within the scope of a prospective study,[22] because the patient had at least one device with a CPR distance of 10 mm or lower,[16] or because the patient requested them.

Statistical analysis. Kaplan–Meier survival estimates were calculated for overall survivorship using revision surgery for any reason as the endpoint, and for specific modes of failures. A log-rank test with stratification by component size and underlying pathology was used to study the effect of gender on the

Table II. Comparative survivorship results of the three generations of femoral fixation technique, using revision for any reason as endpoint. No 15-year survival estimate was computed for the third generation because the follow-up was too short for this group

Generation	5-yr K–M survival estimate (95% CI)	10-yr K–M survival estimate (95% CI)	15-yr K–M survival estimate (95% CI)
First (first 300 hips)	*94.2* (90.8 to 96.4)	*89.7* (85.5 to 92.7)	*86.6* (82.0 to 90.0)
Second (hips 301 to 671)	*98.0* (95.9 to 99.1)	*94.2* (91.0 to 96.3)	*90.1* (85.7 to 93.1)
Third (hip 672 and beyond)	*98.2* (96.7 to 99.0)	*95.5* (93.0 to 97.1)	N/A

K–M, Kaplan–Meier; N/A, not available

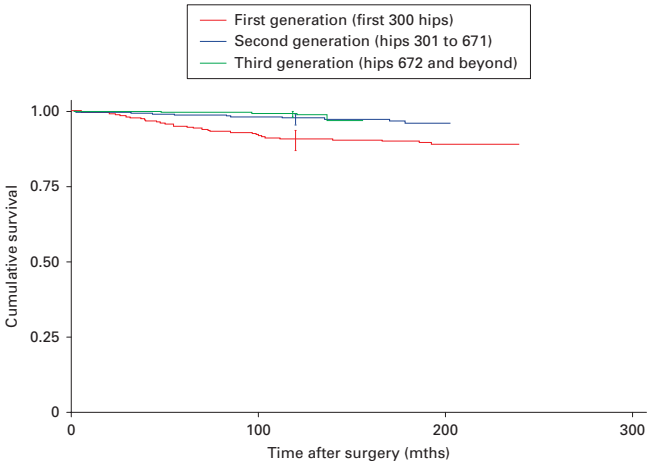

Fig. 1a

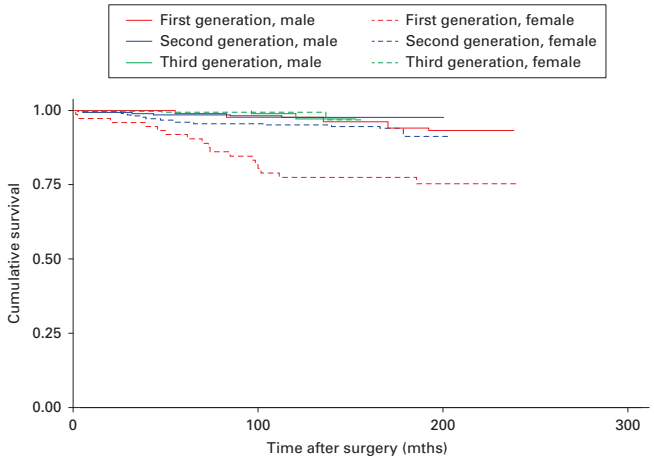

Fig. 1b

a) Kaplan–Meier survivorship curve of the femoral component by generation of femoral surgical technique. Revision surgery for aseptic femoral failure (femoral neck fracture or femoral component loosening) was used as the endpoint. b) Kaplan–Meier survivorship curve of the femoral component by gender and by generation of femoral surgical technique. Revision surgery for aseptic femoral failure (femoral neck fracture or femoral component loosening) was used as the endpoint. Note that women (who typically have smaller implants) improved the most with the evolution of the femoral preparation technique, particularly between the first generation and the second generation.

overall survivorship. The log-rank test was also used to study the differences in survivorship between subgroups of the cohort. The Cox proportional hazard ratio was used to determine the risk factors for HRA. The independent variables tested as possible risk factors were: age at surgery; a diagnosis of development dysplasia of the hip (DDH); weight; height; body mass index (BMI); University of California, Los Angeles (UCLA) activity score; femoral head size; cementation of the metaphyseal stem; femoral head preparation technique; femoral defect size; femoral stem-shaft angle; component abduction angle; component anteversion angle, and CPR distance. The variables showing significance in a bivariate analysis were included in a subsequent multivariate model. All statistical analyses were performed using Stata 6.0 (StataCorp, College Station, Texas).

Results

The mean elapsed time since surgery was 13.7 years (5 to 20). The mean follow-up time was 10.5 years (1 to 20). A total of 40 patients (47 hips) had died with well-functioning devices from causes unrelated to the surgery: six patients (seven hips) were lost to follow-up. A total of 719 patients (67%) returned to a high level of physical activity, including participation in sporting activities (UCLA activity scores of 7 and above), of whom 218 (20%) engaged in impact sports (UCLA activity scores of 9 and 10).

The median serum Co and Cr concentrations for the group of patients with unilateral devices were 1.3 µg/l (0.2 to 175.3) and 1.5 µg/l (0.1 to 88.7) and for those with bilateral devices 2.2 µg/l (0.4 to 139) and 2.9 µg/l (0.4 to 123).

Of the patients with unilateral devices, ten had serum Co levels ≥ 7 µg/l, seven of whom underwent revision surgery while the other three had serum Co levels ≤ 11.6 µg/l (two have CPR distances < 10 mm and the third has a Co level of 7.6 µg/l with hardware left *in situ* adjacent to the acetabular component). These three patients are asymptomatic.

Of the patients with bilateral devices, 19 had serum Co levels ≥ 7 µg/l, eight of whom underwent revision surgery, while the other 11 had serum Co levels ≤ 16.5 µg/l. This should be put into perspective as patients with well-functioning bilateral MoM devices typically show levels of metal ions which are twice as high as those of patients with unilateral devices.[22] The patients who underwent revision surgery for excessive wear had a median serum cobalt concentration of 64.3 µg/l (6 to 140) and a median serum chromium concentration of 47.8 µg/l (8.9 to 89.5). The mean CPR distance of their revised components was 7.5 mm (3.2 to 18.3).

At a mean of 88 months (1 to 199) after HRA, 87 patients (95 hips) underwent revision surgery. Indications for revision surgery included: femoral neck fracture (n = 11); femoral loosening (n = 36); acetabular loosening (n = 25); excessive wear defined as elevated ion levels (> 7 µg/l) associated with symptoms or ALTR, in absence of component loosening (n = 11); sepsis (n = 4); instability (n = 2); ALTR (subcutaneous fluid collection) without excessive wear (n = 1); osteolysis (n = 1);

Table III. Kaplan-Meier survivorship for the seven underlying pathology groups; the number of hips followed at that point in time are given in parentheses

Aetiology	5-yr K–M	10-yr K–M	15-yr K–M
Rheumatoid (RA, JRA), n = 13	*100* (13)	*100* (12)	*100* (9)
Osteoarthritis (OA), including post-traumatic OA, n = 1003	*97.9* (822)	*95.4* (515)	*92.1* (237)
Osteonecrosis (ON), including post-traumatic ON, n = 98	*96.8* (87)	*91.6* (61)	*88.8* (33)
Childhood disorders (LCP, SCFE, epiphyseal dysplasia), n = 43	*95.0* (40)	*95.0* (28)	*88.0* (13)
Developmental dysplasia of the hip, n=136	*95.2* (113)	*83.1* (82)	*74.1* (44)
Inflammatory (ankylosing spondylitis, inflammatory OA), n = 22	*80.7* (17)	*75.6* (16)	*75.6* (9)
Others (meloheostosis, PVNS, osteopetrosis, artrokatadysis), n = 6	*100* (6)	*100* (4)	*100* (2)

RA, rheumatoid arthritis; JRA, juvenile rheumatoid arthritis; LCP, Legg–Calvé–Perthes disease; SCFE, Slipped capital femoral epiphysis; PVNS, Pigmented villonodular synovitis

Table IV. Multivariate analysis showing the risk factors for revision for any reason

	Hazard ratio	p-value*	95% confidence interval
CPR ≤ 7 mm	4.02	0.001	2.11 to 7.69
Head size ≤ 46 mm	3.40	0.001	2.10 to 5.50
Diagnosis of DDH	1.86	0.01	1.16 to 2.96
Age ≤ 55 years	1.81	0.03	1.05 to 3.13

*Cox proportional hazard ratio

CPR, contact patch to rim; DDH, developmental dysplasia of the hip

unexplained pain (n = 1), and for unknown reasons where the revision surgery was performed outside our centre (n = 3). The described ALTR without excessive wear happened in a patient who had a cobalt level of 2.6 µg/l and a chromium level of 3.6 µg/l. The components were revised eight years after HRA at another hospital.

Using revision for any reason as the endpoint, the overall survivorship of the series was 97.2% (95% confidence interval (CI) 96.1 to 98.0) at five years, 93.5% (95% CI 91.8 to 94.8) at ten years, and 89.4% (95% CI 86.8 to 91.4) at 15 years, at which point 337 hips had been reviewed. Results improved as the femoral surgical technique was refined, as shown by the survivorship results (log-rank test; p = 0.05) of the three generations (Table II). Most of the improvement was as a result of the changes made between the first and second generations Figure 1.

We found a difference in survivorship rates between underlying pathologies (log-rank test, p = 0.0001) with substantially lower survivorships in the DDH and inflammatory groups, but not in the rheumatoid group (Table III).

The survivorship of men with osteoarthritis (OA) was 98.4% (95% CI 97.1 to 99.1) at five years, 97.4% (95% CI 95.8 to 98.4) at ten years, and 94.5% (95% CI 91.7 to 96.5) at 15 years. Men with OA who were 55 years and younger at the time of surgery had a survivorship of 97.9% (95% CI 95.9 to 98.9) at five years, 96.5% (95% CI 94.0 to 98.0) at ten years, and 92.6% (95% CI 88.0 to 95.5) at 15 years.

The survivorship of women with osteoarthritis was 96.2% (95% CI 92.3 to 98.2) at five years, 87.2% (95% CI 80.5 to 91.7) at ten years, and 82.2% (95% CI 73.7 to 88.1) at 15 years. This difference was significant (p = 0.0001).

After stratification by underlying pathology and femoral component size (components > 46 mm *vs* components ≤ 46 mm), there was no significant difference between the genders in overall survivorship (log-rank test; p = 0.2332). This result prompted our decision to exclude gender as a variable in our subsequent multivariate models and use the underlying pathology of DDH and component size instead.

Our multivariate model showed that four variables were associated with revision for any reason: a diagnosis of DDH, a CPR distance of 7 mm or less, age at surgery of 55 years or less, and a femoral head size of 46 mm or less (Table IV).

There were four main modes of failure in this series: femoral neck fracture, aseptic femoral component loosening, aseptic acetabular loosening, and excessive wear.

Using aseptic femoral failure (femoral neck fracture or femoral component loosening combined) as the endpoint, the ten-year survivorship was 90.7% (95% CI 86.7 to 93.5) for the first-generation technique, 97.6% (95% CI 95.3 to 98.8) for the second-generation technique, and 99.2% (95% CI 97.7 to 99.7) for the third-generation technique (Fig. 1a). These differences were significant (log-rank test; p = 0.0001). Women benefited the most from the improvements made in femoral preparation technique (Fig. 1b).

Our multivariate model showed that five variables were associated with revision secondary to aseptic femoral component loosening: an early femoral preparation technique, leaving the metaphyseal stem cementless, a femoral head size of 46 mm or less, age at surgery of 55 years or less, and a BMI of less than 24 kg/m^2 (Table V).

Using revision for aseptic acetabular component loosening as the endpoint, the survivorship of the acetabular component was 99.5% (95% CI 98.8 to 99.8) at five years, 98.3% (95% CI 97.3 to 99.0) at ten years, and 96.7% (95% CI 95.0 to 97.9) at 15 years. Our multivariate model showed that a diagnosis of DDH was associated with revision secondary to aseptic loosening of the acetabular component (Table VI).

Using revision for excessive component wear as the endpoint, the survivorship was 100% at five years, 99.5% (95% CI 98.7 to 99.8) at ten years, and 98.5% (95% CI 97.1 to 99.2) at 15

Table V. Risk factors associated with revision for aseptic femoral component loosening

	Hazard ratio	p-value*	95% confidence interval
Head size ≤ 46 mm	4.15	0.001	1.83 to 9.40
BMI < 24 kg/m^2	2.71	0.004	1.38 to 5.32
Uncemented stem	7.37	0.01	1.63 to 33.45
Age ≤ 55 yrs	12.21	0.01	1.67 to 89.21
Generation	2.08	0.02	1.14 to 3.79

*Cox proportional hazard ratio

BMI, body mass index

Table VI. Risk factors associated with revision for aseptic acetabular component loosening

	Hazard ratio	p-value*	95% confidence interval
Diagnosis of DDH	4.96	0.001	2.16 to 11.40
Head size ≤ 46 mm	2.65	0.06	0.96 to 7.33
CPR ≤ 10 mm	1.91	0.17	0.76 to 4.76

*Cox proportional hazard ratio

DDH, developmental dysplasia of the hip; CPR, contact patch to rim

Table VII. Risk factors associated with revision for excessive component wear

	Hazard ratio	p-value*	95% confidence interval
CPR ≤ 7 mm	74.52	0.001	17.19 to 322.9
Head size ≤ 46 mm	1.22	0.809	0.24 to 6.19

*Cox proportional hazard ratio

CPR, contact patch to rim

years. A CPR distance of 7 mm or less was very strongly associated with revision secondary to excessive wear (Table VII).

Discussion

When we started our series of MoM HRA, the long-term survivorship of the Charnley low friction arthroplasty in young patients with osteoarthritis was 51% at 20 years.[23] The rationale for the use of HRA was to implant a bone-conserving arthroplasty with the possibility of improved survivorship and to provide the best possible conditions for a conversion to THA if needed. Now, 20 years later, it is important to assess the survivorship results of this procedure to determine whether these initial goals were achieved. Our study aimed to provide long-term data, to determine the risk factors inherent to the use of HRA, and to evaluate the effectiveness of improvements in surgical technique.

There are limitations to our study. First, we did not collect serum Co and Cr ion levels for every patient as the value of measuring serum ion concentrations to monitor wear of the bearing was still a hypothesis and had not been established in the literature. However, all patients at risk of edge-loading (CPR distance of 10 mm or less) were asked to have these done and these data, combined with the studies of patients enrolled prospectively, help to determine the role of component design and positioning of the acetabular component. Only nine out of 238 (3.8%) patients with unilateral devices had serum ion levels greater than the guideline of 7 µg/l suggested by the Medicines and Healthcare Products Regulatory Agency (MHRA).[24] Seven of these nine patients had CPR distances < 10 mm.

Second, the surgical technique evolved over time, altering the survivorship results. However, these changes in surgical technique (which were integrated in our multivariate analysis) progressively enhanced survivorship, therefore the figures presented in this study (overall survivorship of 89.4% at 15 years) are conservative; the long-term data are mostly affected by the first-generation fixation techniques. Despite the absence of patient selection (the designer surgeon endeavoured to test the system's effectiveness by taking on the most difficult cases in the pre-crosslinked-polyethylene era), the results are on par with those of total hip arthroplasty (THA) in comparable age groups reported in hip registries with available 15-year data.[14,25]

These results extend the excellent midterm results already reported by other specialized centres with more strictly selected patient cohorts.[10,12] Our overall survivorship results at 15 years (89.4%) also match those of the Birmingham hip resurfacing (BHR) reported in the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) (89.8%).[26] However, caution should be advised when making this type of comparison, as many variables besides implant design, including the quality of the surgery performed, are not present in registry data and yet influence the long-term survivorship of HRA. In men with a diagnosis of osteoarthritis, we found a 97.4% survival at ten years, which is comparable to results published in one study of HRA,[27] and in the most recent studies of cementless THA undertaken with crosslinked polyethylene bearings. The latter tends also to give excellent results in young patients, with an absence of wear-related revisions at ten to 15 years.[28,29] However, we found no reports of THA with comparably high activity levels. One other study of HRA reports excellent 15-year survivorship results but did not include the details of severity of the disease nor the learning phase of the senior surgeon with MoM HRA.[11]

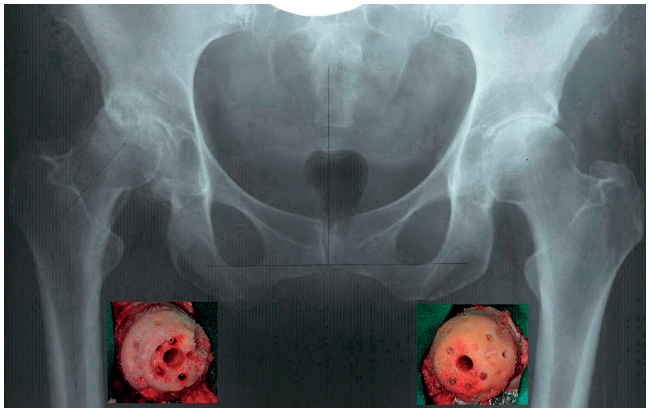

Fig. 2a

Fig. 2b

a) Radiograph of a 60-year-old woman with bilateral osteoarthritis. The patient underwent staged bilateral hip resurfacing arthroplasties (HRA) 1.5 years apart. Insets show the femoral heads just prior to cementation of the femoral component. Note the clean and dry surfaces of the bone with minimal blood staining. b) Radiograph 16.5 years (right) and 15 years (left) after HRA. There is no evidence of osteolysis or loosening. The patient's University of California, Los Angeles (UCLA) scores are 10 on both hips for pain, walking, and function, with a current UCLA activity score of 5, although it was higher in the first ten years. Her metal ion concentrations were 2.1 µg/l for cobalt and 1.3 µg/l for chromium despite a slightly low contact patch to rim (CPR) distance on the right side of 9.5 mm. The left side CPR distance is 13.0 mm.

It is also interesting to note that the five-year survivorship in this series (97.2%) largely surpasses the results we previously reported for the first 400 hips in this series and published at four years (94.4%).[3] This shows that the surgical modifications made to the preparation of the femoral head and cementing technique largely resolved the issue of femoral component loosening and emphasizes the need for optimizing technique in difficult cases (Fig. 2). There has been an effort by some to ascribe improvement in results to be due solely to the 'learning curve' and not to changes in technique. We believe the two are inseparable. Changes in technique are the result of an ongoing learning curve, careful follow-up of the patients, and detailed retrieval analyses.[30] The avoidance of neck notching and covering all the reamed bone were key factors influencing the decrease in occurrence and then elimination of femoral neck fractures in this series.[31]

Our study also shows that when multiple modes of failure are present in a series, the study of the risk factors requires separate analyses for each major mode of failure.

The overall Co and Cr serum concentrations found in this study fall within the range typically seen in well-functioning HRA devices.[32] Of note is the fact that none of the 11 revision procedures performed for excessive wear occurred within the first five years of surgery. Compared with many cases of ALTR reported in the literature, those reported in this series may have been milder in terms of size as they were mostly asymptomatic for many years. Also, of the 11 patients who underwent revision for wear (mean time to revision 10.2 years; 5.5 to 16.6), ten had HRA performed before 2006, which was three years before the calculation of the CPR distance was available to track hips at risk of edge-loading. Five of these patients had extremely low CPR values (> 7 mm) when they were finally calculated. The 11th patient who underwent revision for wear had her HRA carried out in 2007 and the revision performed 5.5 years later, our lowest time to revision for excessive wear. All but two patients with elevated ions had at least one device implanted with a low CPR distance, which shows the absolute necessity of computing this variable when reporting on the performance of HRA and metal-on-metal devices in general.[9] Several methods of measuring component abduction and anteversion angles have been validated.[33,34] A practical algorithm was developed by Langton et al[15] to compute CPR distance and has recently been made available online by Dr William Walter for the various HRA prostheses.[35] It should be noted that the CPR distance calculated in this way does not take into account component clearance, which affects the size of the contact patch, and assesses the risk of anterosuperior edge wear, but not the possibility of anterior impingement leading to posterior edge wear. However, the CPR distance remains the best predictor of high ion levels and edge wear.[8]

The occurrence of two cases of excessive wear (Serum Co of 12.9 µg/l and 7.6 µg/l, respectively) despite a CPR distance of > 10 mm raises the question of component tolerances which are measured by a Coordinate Measuring Machine individually for clearance control. Unfortunately, these device-specific quality-control results are lost when the measurements of components manufactured that day are grouped in a lot. As a result, the specific clearance of an implanted femoral and acetabular component pair cannot be determined. This has been the standard protocol for all manufacturers and is different from bearings made for other applications where each component retains its quality control measurements and each part has an individual number.

A young age (< 55 years) at the time of surgery was associated with a shorter time to revision for any reason. This has been the case for total hip arthroplasty since its inception[23] and correlates with the findings of the 2017 report of the AOANJRR.[26] In this study, the patients tended to be younger, with severe end-stage disease, and diagnoses other than osteoarthritis (specifically at the beginning of the series) when the surgical technique was still being developed, compared with the rest of the cohort.

The failure rate was higher in women for all modes of failure, primarily because of their smaller component size (which is associated with a reduced CAAA, increasing the chances of

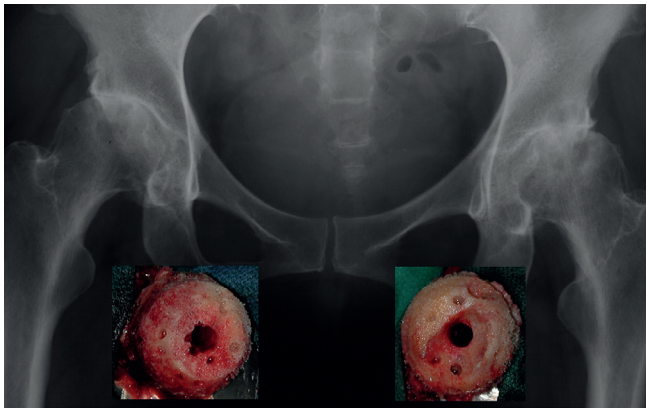

Fig. 3a

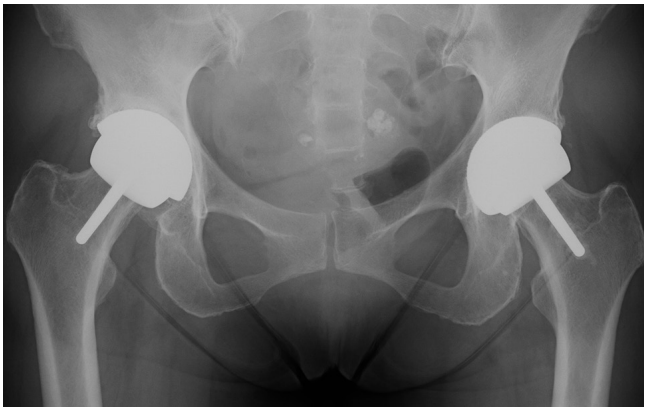

Fig. 3b

a) Radiograph of a 52-year-old woman with bilateral osteoarthritis secondary to developmental dysplasia of the hip (DDH). Insets show the femoral heads after preparation, prior to cementation of the femoral component. Note the large femoral defects, especially on the left side, prepared with second-generation technique. b) Anteroposterior pelvis radiograph taken 17 years after two-stage bilateral surgery. The left metaphyseal stem was cemented. Both sockets were contained in both pelvic planes and they are well fixed. The contact patch to rim (CPR) distance on the left side is 9.9 mm and on the right side is 10.5 mm. Serum cobalt and chromium values were 2.23 µg/l and 5.56 µg/l. The patient's University of California, Los Angeles (UCLA) score are 10 on both hips for pain, 10 for walking, 10 for function, and 9 for activity. Lifetime durability is projected.

edge wear, as well as a reduced surface area for fixation). In combination with smaller component size, a greater proportion of our female patients had dysplastic hips. Female gender itself was not a risk factor for revision when stratified for component size and aetiology. This result is certainly at odds with the conclusions of many publications that suggest women are poor candidates for HRA.[10,27] However, these publications, unlike our study, did not provide any satisfactory explanation as to why women have a higher rate of revision surgery than men. This is important when it comes to identifying suitable candidates for HRA. Our purpose is not to say that HRA survives in women as well as in men, as they do not. However, the 2017 report of the AOANJRR clearly shows the negative effects of DDH and a small component size on the survivorship of HRA, two variables closely associated with female gender in series of HRA.[26] In addition, Gaillard and Gross[36] have shown that the specific geometry of the acetabulum affected with DDH, in particular its oval shape along the posteroinferior to anterosuperior axis, is the cause of particular surgical problems. They also showed that implementation of specific surgical protocols, and in particular the orientation of the acetabular component or using a trispike component when initial fixation is insufficient, enhances mid-term survivorship to a level comparable to that of male patients.[37] Based on our results, most women are suitable candidates for MoM HRA, provided that proper acetabular component orientation and femoral surgical technique are achieved, while patients with severe dysplasia should be avoided.

Now that the consequences of malorientated sockets are known,[8,38] implantation techniques can be controlled to provide adequate coverage to ensure normal wear without edge-loading. Our recommendation with the device used in this study is to target a component abduction angle of 42° and component anteversion angle of 15°, while allowing ± 10°. However, this safety range is somewhat reduced with the smallest components (36 mm to 40 mm). In our series, over-reaming and removal of good quality cancellous bone, leaving primarily cortical bone exposed for fixation (this is apparent on radiographs), may have contributed to some cases of acetabular component loosening, although no data were collected at the time of surgery to support this statement. As in other reports, DDH was identified as a risk factor for revision.[11,39] The acetabular deformity associated with DDH has several implications for surgical technique as it most often influences the positioning of the component. There is a trade-off between optimizing component fixation, which is better achieved by preserving the existing acetabular orientation, and the need to optimize component orientation within minimal deviation from the ideal component implantation angles to prevent edge wear. Although full containment of the component is not usually possible in the AP plane because of the dysplasia, it is important to obtain containment in the coronal plane, if possible, to ensure a secure interference fit with the monobloc acetabular component thereby facilitating bony ingrowth. If the coverage of the component is deemed insufficient preoperatively or intraoperatively to afford secure fixation with a monobloc socket, we suggest using adjuvant screw fixation with a two-part THA socket. We also recommend under-reaming > 2 mm when there are thin and more flexible acetabular walls, as is the case in most women, in order to obtain secure containment in at least one plane (Fig. 3). McMinn et al[40] designed an interesting DDH socket for HRA that includes adjunctive fixation. We await the long-term results of this device.

Most underlying pathologies in this series, including other childhood disorders, slipped capital femoral epiphysis (SCFE), Legg–Calvé–Perthes (LCP) disease, and epiphyseal dysplasia, had excellent survivorship results.[41] Rheumatoid arthritis (RA) showed no failures.[42] The 'inflammatory type' of osteoarthritis, including ankylosing spondylitis, resulted in four revisions out of 14 hips but, with three different modes of failure, we were unable to show that this aetiology constitutes an actual risk factor for HRA. The RA or systemic lupus erythematous (SLE) patients had the classic systemic disease with positive RA or antinuclear antibody (ANA) factors. The 'other inflammatory' group included ankylosing spondylitis (human leukocyte antigen B-27 (HLA-B27) positive but RA negative) and inflammatory

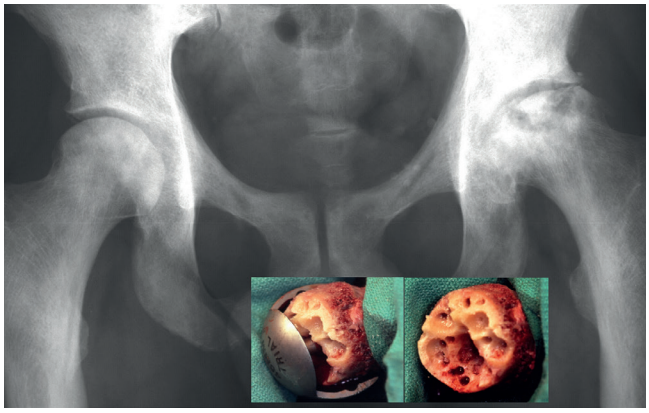

Fig. 4a

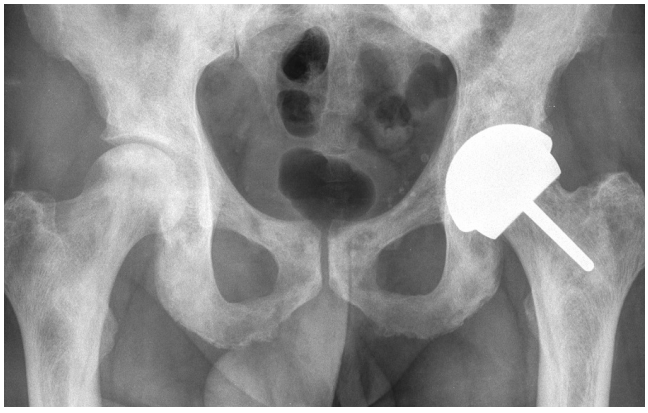

Fig. 4b

a) Radiograph of a 46-year-old bus driver with left hip Ficat stage IV osteonecrosis secondary to sickle-cell disease. Insets show the extent of the defects after reaming and preparation of the femoral head and the remaining defect extent shown with the trial component. b) Anteroposterior pelvis radiograph showing the patient 16 years after hip resurfacing arthroplasty (HRA). The stem was cemented in. The components are well fixed and positioned. There is a mild lateral impingement sign on the left femoral neck. The patient's University of California, Los Angeles (UCLA) scores are 10, 10, 10, and 6 for pain, walking, function, and activity, respectively. In the years following HRA, the patient had several sickle cell crises, but no other joint necrosis has developed.

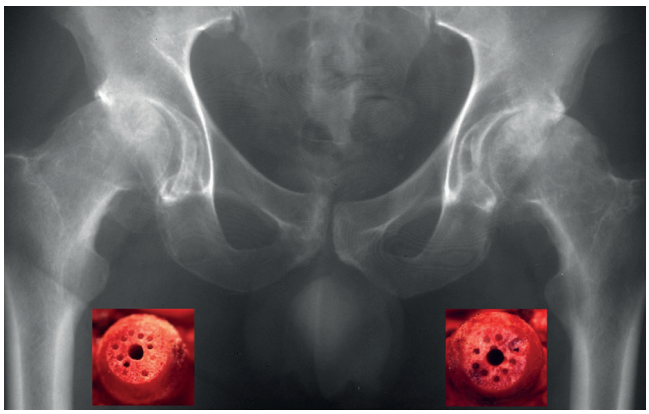

Fig. 5a

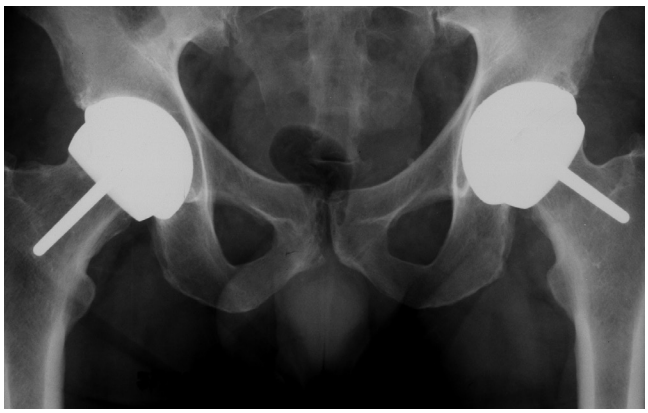

Fig. 5b

a) Radiograph of a 43-year-old professional ballet dancer with bilateral osteoarthritis. b) Radiograph 19.5 years after one-stage bilateral HRA. The patient returned to professional ballet for eight years and is still extremely active (University of California, Los Angeles (UCLA) activity score of 10 with pain, walking, and function scores of 10 on both sides. Radiological signs of impingement are visible on the lateral aspect of both femoral necks, certainly associated with the patient's extreme flexibility and ability to perform splits in both directions. Lifetime durability is projected.

OA (RA negative) with rapidly advancing and destructive hip disease and intense synovial reaction. Meanwhile, our results in patients with advanced Ficat stage osteonecrosis were better (93.5% at ten years and 90.3% at 15 years)[43] than those reported in other series[11] (Fig. 4) The efficacy of cementing the stem for patients with large defects is confirmed: there were no failures of the femoral component and no obvious adverse stress-shielding effects.[44] The design and the cementing technique used in this study (finger-pressurized doughy cement and 1 mm cement mantle) are better suited for the effective cementation of the metaphyseal stem than the technique used with the BHR, for example, which uses cement in liquid form, thereby limiting the control of bone penetration.

Today, there remains much confusion about the merits of HRA with MoM bearings because of the absence of discrimination between HRA and the poorly performing MoM THA (due to low CPR distance, taper wear, and other problems), as well as between HRA devices that perform well and poorly. Only a 3D assessment of functional coverage and calculation of the CPR distance can give satisfactory explanations about the issues faced by HRA. Most publications (> 200 since 2008) dedicated to metal-on-metal bearing performance do not include such an assessment.

Clearly, bone quality and quantity are factors that have led surgeons to deny patients the benefits of HRA. In addition, some manufacturers' withdrawal of small sizes largely excludes women as potential candidates for HRA. However, the long-term data presented in this study support the statement that MoM bearings are well suited for HRA when component design provides sufficient coverage of the femoral component by the acetabular component and surgical guidelines of safe implantation of the component are followed.

We have previously shown that patients resume a high level of activity, including return to sports, and that pain relief and

walking ability are maintained over time, while function and activity decrease in accordance with the ageing process.[45] Also, wear has been found to diminish with time in well-functioning devices, specifically those manufactured with precision, and promote fluid film lubrication when properly implanted.[22] Lifetime durability of HRA, which was not anticipated at the beginning, is now a possible outcome for many of our patients when operated on at an early age after a thorough patient assessment of risk factors and then implanted with improved surgical techniques.

The results of THA have improved in the 21st century, owing particularly to the introduction of highly crosslinked polyethylene and the performance of cementless collarless tapered stems. Even with modern stems, revision of the femoral component is sometimes needed, which is more challenging than with HRA. In addition, the bone mineral density of the proximal femur decreases,[46] leaving bone of diminished quality and a greater risk of late periprosthetic fracture. The rationale for using HRA in a young patient is still valid: HRA has the advantages of stability,[47] restoration of both the anatomy and biomechanics of the hip,[48] without stress-shielding,[49] and an absence of thigh pain and taper corrosion. HRA also permits high-level activity with less risk (Fig. 5) because of the potential for an easier revision, should it be necessary,[50,51] the results of which are comparable to primary total hip arthroplasty in terms of surgical effort, safety, and early clinical outcome.[50] HRA has become a viable and, for many, a preferable alternative to THA. Based on our experience we would recommend that MoM HRA be particularly considered for patients (male or female) with osteoarthritis, with a high functional demand, and without severe levels of dysplasia. The procedure should be performed using one of the few successful designs currently available, and in centres where specific training for this procedure has been conducted, including the application of the recent knowledge contained in the scientific literature.

Take home message

-Hip resurfacing arthroplasty is a viable concept and metal-on-metal bearings are well suited for this procedure when a well-designed and well-manufactured device is properly implanted.

- Lifetime durability is a possible outcome for many patients despite high levels of activity.

- Only a 3D assessment of functional coverage and the calculation of the contact patch to rim distance can give satisfactory explanations about the wear performance of metal-on-metal bearings.

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H. C. Amstutz: Designed the study, Performed all the surgeries, Collected the data, Checked the accuracy of the data, Reviewed the literature, Edited the manuscript.
M. J. Le Duff: Designed the study, Compiled and processed the data, Analyzed the statistics, Reviewed the literature, Drafted the manuscript, Provided the illustrations, Handled the publication process.

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