HIP

Gait after Birmingham Hip Resurfacing

AN AGE-MATCHED CONTROLLED PROSPECTIVE STUDY

A. V. Wiik,
R. Lambkin,
J. P. Cobb

From Charing Cross Hospital, Imperial College London, London, United Kingdom

Aims

The aim of this study was to assess the functional gain achieved following hip resurfacing arthroplasty (HRA).

Patients and Methods

A total of 28 patients (23 male, five female; mean age, 56 years (25 to 73)) awaiting Birmingham HRA volunteered for this prospective gait study, with an age-matched control group of 26 healthy adults (16 male, ten female; mean age, 56 years (33 to 84)). The Oxford Hip Score (OHS) and gait analysis using an instrumented treadmill were used preoperatively and more than two years postoperatively to measure the functional change attributable to the intervention.

Results

The mean OHS improved significantly from 27 to 46 points ($p < 0.001$) at a mean of 29 months (12 to 60) after HRA. The mean metal ion levels at a mean 32 months (13 to 60) postoperatively were 1.71 (0.77 to 4.83) µg/l (ppb) and 1.77 (0.68 to 4.16) µg/l (ppb) for cobalt and chromium, respectively. When compared with healthy controls, preoperative patients overloaded the contralateral good hip, limping significantly. After HRA, patients walked at high speeds, with symmetrical gait, statistically indistinguishable from healthy controls over almost all characteristics. The control group could only be distinguished by an increased push-off force at higher speeds, which may reflect the operative approach.

Conclusion

Patients undergoing HRA improved their preoperative gait pattern of a significant limp to a symmetrical gait at high speeds and on inclines, almost indistinguishable from normal controls. HRA with an approved device offers substantial functional gains, almost indistinguishable from healthy controls.

Cite this article: ***Bone Joint J*** **2019;101-B:1423–1430.**

Interest continues in hip resurfacing arthroplasty (HRA), despite concerns relating to metal ion release.[1-6] HRA remains an alternative to total hip arthroplasty (THA) that preserves proximal femoral bone stock, decreases stress shielding, and increases bone mineral density, with a lower dislocation rate and easier femoral revision.[7-11] Nevertheless, HRA remains little used today, with less than 1% of all hip arthroplasties as reported by the United Kingdom National Joint Registry (NJR), largely owing to fear of metal-on-metal (MoM) bearings following the withdrawal of several particular types of HRA.[12-15] A recent biomechanical cadaveric study highlighted the functional advantage of retaining the femoral neck by maintaining more normal capsular tension.[16] The Birmingham Hip Resurfacing (BHR) implant (Smith & Nephew, Memphis, Tennessee) has obtained an Orthopaedic Data Evaluation Panel (ODEP) 10A* rating, which signifies better than 95% survival at minimum ten years in more than three nondeveloping centres. Survivorship has been reported to rival conventional THA, even in nondesigner centres.[17-19] Currently, the United Kingdom Medicines and Healthcare products Regulatory Agency (MHRA) guidelines require regular follow-up for patients and an HRA with measurement of blood metal ions.[20] HRA is now only indicated in larger men who demand an active lifestyle.[21,22] Even with this restricted indication, the impact of HRA on higher levels of physical activity is still debated. The majority of kinematic studies have reported on the function of devices that have since been withdrawn.[23,24] There remains a serious debate regarding the extent to which HRA with a highly rated device restores normal hip function, something that conventional THA has never demonstrated.[25-28] This prospective

Correspondence should be sent to A. Wiik; email: a.wiik@imperial.ac.uk

doi:10.1302/0301-620X.101B11.BJJ-2019-0383.R1 $2.00

Bone Joint J
2019;101-B:1423–1430.

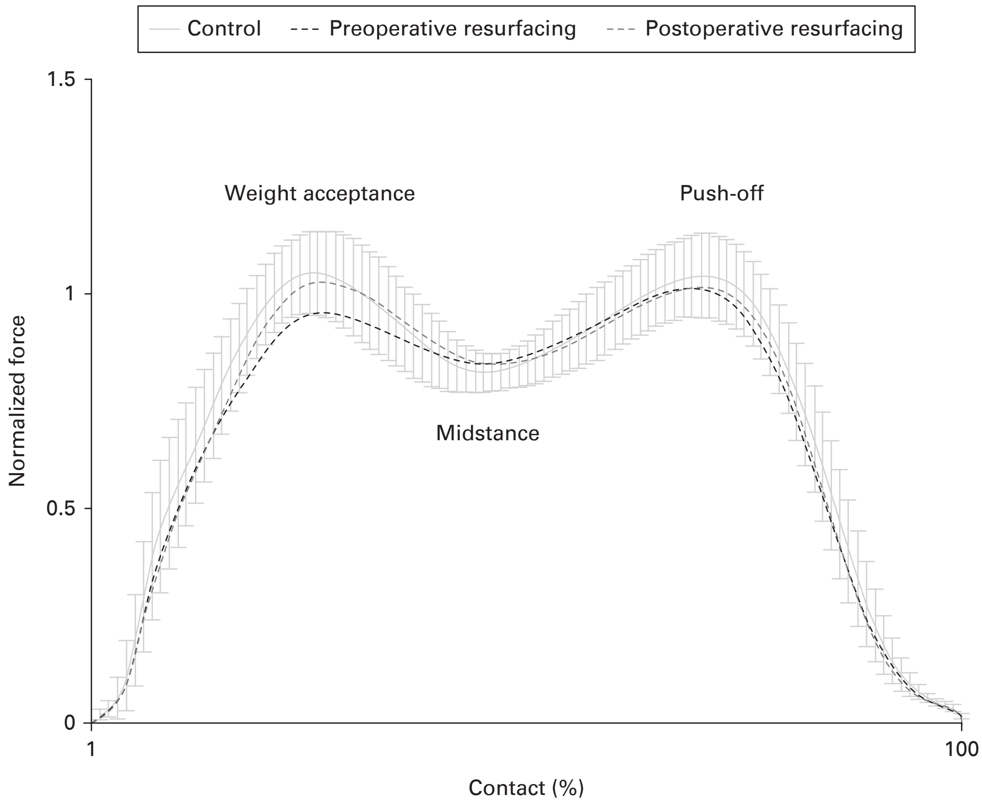

Fig. 1

Ground reaction forces during uphill walking (10% uphill at 4 km per hour). The central line is the mean and the whiskers are the 95% confidence interval (CI) of the controls.

Table I. Subject characteristics, radiological osteoarthritis (OA) severity, patient-reported outcome measures

Characteristic	Control (n = 26)	Hip resurfacing (n = 28)	p-value
Sex, male:female, n	16:10	23:5	0.091*
Mean age, yrs (range)	56 (33 to 84)	56 (25 to 73)	0.939†
Mean body mass index, kg/m² (range)	25 (20 to 32)	27 (22 to 43)	0.061†
Mean height, cm (range)	172 (158 to 196)	176 (160 to 204)	0.072†
Mean top speed, km/hr (range)	7.3 (6.5 to 8)	7.5 (6.5 to 8)	0.151†
Normalized mean top speed‡ (range)	0.50 (0.44 to 0.54)	0.50 (0.43 to 0.53)	0.823†
Mode preoperative OA severity§ (range)	N/A	2 (1 to 3)	N/A
Mean gait follow-up time, mths (range)	N/A	29 (12 to 60)	N/A
Mean preoperative Oxford Hip Score (range)	N/A	27 (9 to 37)	N/A
Mean postoperative Oxford Hip Score (range)	N/A	46 (40 to 48)¶	N/A

*Chi-squared test
†Unpaired Student's *t*-test
‡Normalized to height (Hof scaling)
§Tönnis grading: 1, mild; 2, moderate; 3, severe
¶Statistically significant difference from preoperative to postoperative ($p < 0.05$)
N/A, not applicable

gait study set out to determine the functional improvement attributed to HRA by testing patients to the limit of their ability by assessing higher walking speeds and negotiating steeper inclines. The primary objective was to: 1) assess the change in loading pattern following HRA; and 2) compare this function with the normal contralateral hip. The secondary objective was to compare these gait characteristics with a comparative healthy group, to determine the extent to which a normal gait pattern could be achieved.

Patients and Methods

Participants. In an ethically registered prospective comparative gait study (London-Camberwell St Giles Research Ethics Committee (10/H0807/101)), 28 self-selected patients awaiting

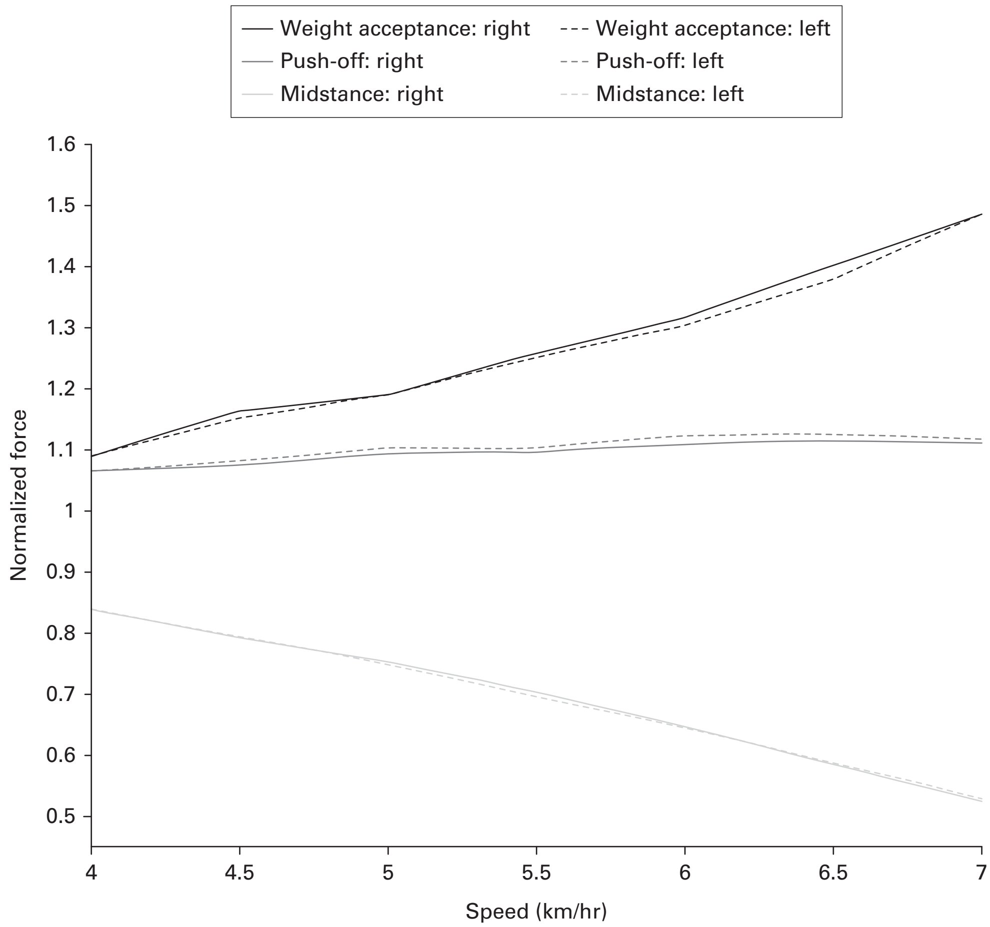

Fig. 2

Mean ground reaction force trends at increasing speeds for healthy controls: weight acceptance, push-off, and midstance.

HRA were recruited between 2011 and 2016. HRA patients were only invited to participate in this gait study if the inclusion and exclusion criteria were met. Specifically, participants had to be cardiovascularly fit with no other conditions that would limit their gait at higher speeds. Patients were excluded from the study if they had any other joint disease or replacements. All of the patients were operated through a posterior approach with release of the external rotators and gluteus maximus tendon followed by repair by the senior author (JPC). All patients received a BHR (Smith & Nephew) inserted according to the manufacturer's instructions, with a cemented femoral component oriented at 135° valgus with neutral version on the femoral neck, and an uncemented acetabular component with a preoperative plan of 40° of abduction and 20° of anteversion. All patients had a standardized postoperative rehabilitation programme involving range of movement and strengthening exercises. Patients were examined by the senior author (JPC) in clinic before and after surgery. Oxford Hip Scores (OHS) were taken at the time of the pre- and postoperative gait studies. The OHS is a validated 12-item questionnaire, which was reported to provide a commonly reported and identifiable metric.[29] Whole blood levels of cobalt and chromium were taken after the first year postoperatively. An active and healthy asymptomatic group of subjects, consisting of staff of the institution, were recruited and analyzed for comparative purposes. Informed written consent was obtained prior to their involvement.

Gait instrumentation. A validated instrumented treadmill (Gaitway Kistler; Kistler Instrument Corporation, Amherst, New York) with a previously reported protocol was used to collect patient gait data.[28,30] The treadmill has been shown to be reliable, reproducible, and able to assess higher-end function.[28,31] The vertical components of the ground reaction forces (GRF) were collected on calibrated tandem Kistler force plates at a sample frequency of 100 Hz. All participants were weighed with the force plate prior to assessment, to allow normalization for body weight. Once acclimatized and free of aids, participants were tested through their entire range of speed during level walking at 0.5 km per hour increments. After a short rest period, the patient had their walking uphill assessment with trials at 4 km per hour for 5%, 10%, and 15% inclinations. Data were recorded at all trial intervals of speed and inclination.

Gait variables. The variables selected for analysis had been identified in two recent studies as being both reliable and able to discriminate between types of subjects.[32,33] The peak GRF with the highest intraclass correlation coefficient (ICC) and area under the curve (AUC) were: weight acceptance, midstance,

Table II. Inclination and speed parameter means with mean absolute symmetry indices (SIs) displayed as percentages

Limb	4 km/hr; 10% incline	SI, %	4 km/hr; 15% incline	SI, %	5 km/hr; flat	SI, %	5.5 km/hr; flat	SI, %	6 km/hr; flat	SI, %	6.5 km/hr; flat	SI, %	7 km/hr; flat	SI, %
Mean weight acceptance, BWN (range)														
Preoperative HRA														
Preimplanted	0.99 (0.64 to 1.65)*	*8.4**	1.01 (0.85 to 1.35)*	*6.9**	1.13 (0.74 to 1.35)*	*10.8**	1.18 (0.82 to 1.39)*	*11.4**	1.25 (1.02 to 1.44)	*10.8**	1.31 (1.07 to 1.56)*	*11.8**	1.40 (1.28 to 1.66)	*11.6**
Normal side	1.07 (0.77 to 1.66)†		1.08 (0.96 to 1.46)†		1.23 (1.06 to 1.46)†		1.30 (1.06 to 1.71)†		1.38 (1.10 to 1.76)†		1.47 (1.17 to 1.86)†		1.55 (1.26 to 2.02)†	
Postoperative HRA														
Implanted	1.06 (0.94 to 1.23)‡	*3.9‡*	1.04 (0.68 to 1.30)	*4.7*	1.18 (1.07 to 1.30)‡	*4.9‡*	1.22 (1.10 to 1.36)‡	*5.8*‡*	1.28 (1.14 to 1.43)	*5.7*‡*	1.36 (1.19 to 1.52)‡	*6.2*‡*	1.43 (1.24 to 1.64)	*5.7‡*
Normal side	1.06 (0.94 to 1.24)		1.06 (0.71 to 1.32)		1.18 (1.09 to 1.32)‡		1.24 (1.15 to 1.38)‡		1.30 (1.20 to 1.50)‡		1.38 (1.21 to 1.60)‡		1.44 (1.31 to 1.62)‡	
Control														
Right	1.09 (0.99 to 1.09)	*2.3*	1.08 (0.94 to 1.22)	*2.6*	1.19 (1.02 to 1.39)	*3.4*	1.26 (1.10 to 1.40)	*2.5*	1.32 (1.18 to 1.47)	*2.8*	1.40 (1.22 to 1.60)	*2.8*	1.49 (1.32 to 1.72)	*3.3*
Left	1.09 (0.97 to 1.06)		1.08 (1.00 to 1.22)		1.19 (1.10 to 1.33)		1.25 (1.14 to 1.38)		1.30 (1.20 to 1.42)		1.38 (1.26 to 1.54)		1.49 (1.36 to 1.62)	
Mean midstance, BWN (range)														
Preoperative HRA														
Preimplanted	0.82 (0.54 to 1.05)	*9.3**	0.81 (0.69 to 0.83)	*9.9**	0.75 (0.52 to 0.83)	*9.5**	0.72 (0.49 to 0.80)	*12.9**	0.68 (0.55 to 0.77)	*14.0**	0.64 (0.44 to 0.80)	*17.5**	0.62 (0.41 to 0.81)	*20.7**
Normal side	0.76 (0.64 to 1.05)†		0.74 (0.63 to 0.78)†		0.69 (0.55 to 0.78)†		0.64 (0.48 to 0.74)†		0.59 (0.44 to 0.69)†		0.54 (0.35 to 0.70)†		0.51 (0.31 to 0.65)†	
Postoperative HRA														
Implanted	0.81 (0.69 to 0.87)	*4.1‡*	0.75 (0.36 to 0.82)‡	*5.1‡*	0.75 (0.61 to 0.82)	*4.7‡*	0.70 (0.56 to 0.85)	*6.5‡*	0.65 (0.51 to 0.78)	*7.0‡*	0.60 (0.46 to 0.87)‡	*7.3‡*	0.54 (0.38 to 0.73)‡	*9.0‡*
Normal side	0.79 (0.65 to 0.86)		0.73 (0.35 to 0.82)		0.73 (0.63 to 0.82)‡		0.68 (0.58 to 0.76)‡		0.62 (0.53 to 0.73)‡		0.57 (0.47 to 0.73)‡		0.51 (0.33 to 0.74)	
Control														
Right	0.80 (0.69 to 0.89)	*3.1*	0.76 (0.66 to 0.93)	*4.5*	0.75 (0.67 to 0.85)	*2.9*	0.70 (0.59 to 0.82)	*3.9*	0.65 (0.56 to 0.74)	*3.8*	0.59 (0.49 to 0.72)	*4.9*	0.52 (0.41 to 0.66)	*5.9*
Left	0.78 (0.74 to 0.95)		0.75 (0.60 to 0.95)		0.75 (0.65 to 0.86)		0.70 (0.57 to 0.79)		0.64 (0.53 to 0.75)		0.59 (0.48 to 0.74)		0.53 (0.40 to 0.66)	
Mean push-off, BWN (range)														
Preoperative HRA														
Preimplanted	1.05 (0.57 to 1.29)	*5.3**	1.07 (0.96 to 1.16)	*2.6*	1.02 (0.58 to 1.16)*	*7.4**	1.01 (0.53 to 1.14)*	*9.3**	1.04 (0.87 to 1.16)*	*8.5**	1.04 (0.87 to 1.18)*	*8.9**	1.03 (0.86 to 1.18)*	*8.5**
Normal side	1.08 (0.74 to 1.25)		1.09 (0.94 to 1.22)		1.08 (0.72 to 1.21)		1.10 (0.69 to 1.30)†		1.12 (0.94 to 1.30)†		1.12 (1.01 to 1.30)†		1.11 (0.94 to 1.35)†	
Postoperative HRA														
Implanted	1.04 (0.91 to 1.13)*	*3.6*	1.03 (0.91 to 1.14)*	*2.7*	1.05 (0.89 to 1.14)	*3.5‡*	1.05 (0.89 to 1.17)	*4.0‡*	1.06 (0.88 to 1.21)	*4.2‡*	1.06 (0.88 to 1.22)	*4.4‡*	1.07 (0.90 to 1.24)	*4.7‡*
Normal side	1.04 (0.91 to 1.17)*		1.03 (0.88 to 1.18)*		1.05 (0.87 to 1.18)		1.06 (0.90 to 1.21)		1.07 (0.87 to 1.26)		1.08 (0.84 to 1.30)		1.09 (0.89 to 1.35)	
Control														
Right	1.09 (0.94 to 1.04)	*2.6*	1.09 (0.93 to 1.25)	*3.5*	1.09 (0.97 to 1.22)	*2.9*	1.09 (0.98 to 1.28)	*3.6*	1.11 (0.95 to 1.24)	*3.3*	1.12 (0.90 to 1.26)	*3.5*	1.11 (0.93 to 1.31)	*4.2*
Left	1.11 (0.94 to 1.11)		1.11 (0.93 to 1.20)		1.10 (0.90 to 1.27)		1.10 (0.93 to 1.26)		1.12 (0.92 to 1.28)		1.13 (0.94 to 1.30)		1.11 (0.90 to 1.36)	

*Statistically significant difference between patient and control
†Statistically significant difference between patient limbs
‡Statistically significant difference from preoperative to postoperative
BWN, body weight normalized force; HRA, hip resurfacing arthroplasty

and push-off along with their associated symmetry index (SI) (Fig. 1).

An absolute SI was used in order to remove the 'averaging' effect that could occur if not used. This has been validated in an earlier study.[34]

$$Absolute\,SI = \frac{\left|X1 - X2\right|}{0.5 * \left(X1 + X2\right)} * 100\%$$

X1 was the implanted limb result and X2 was the contralateral normal limb result. This gives a measure of percentage

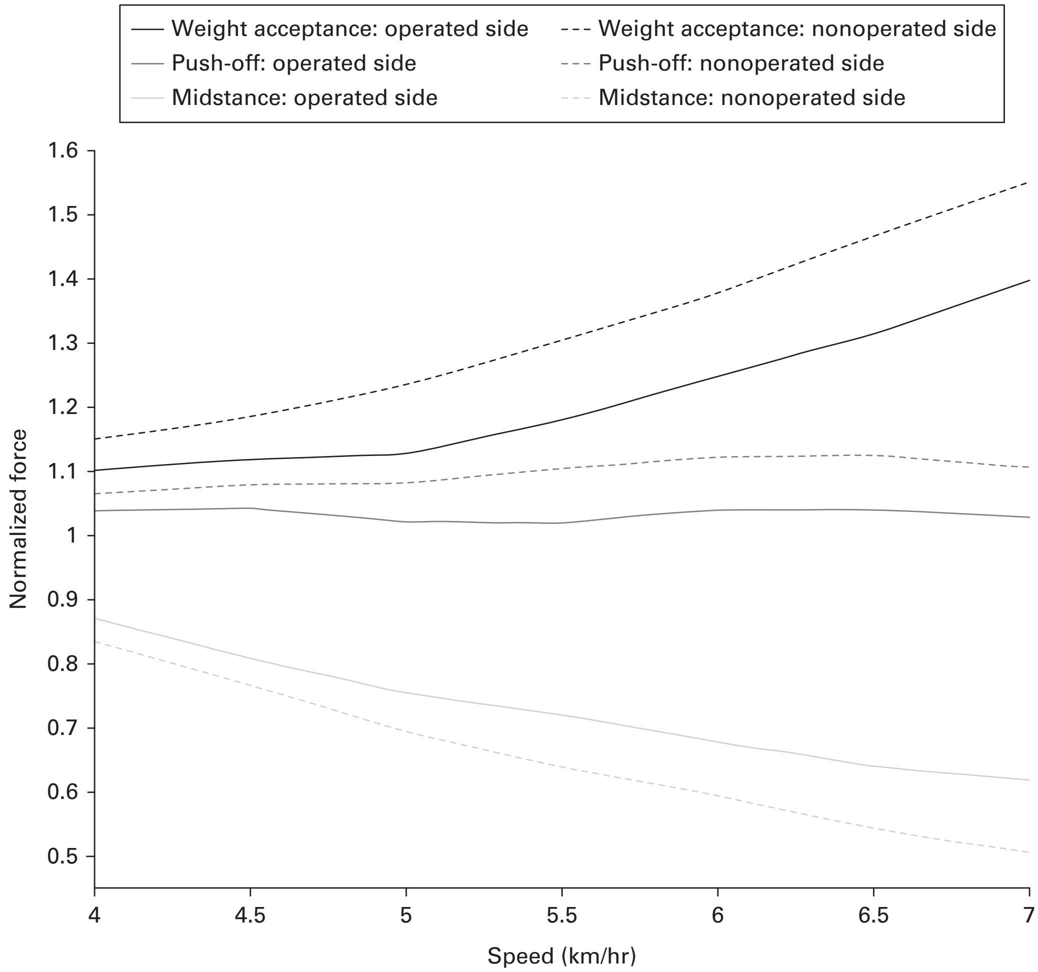

Fig. 3

Mean ground reaction force trends at increasing speeds for patients before surgery: weight acceptance, push-off, and midstance.

difference between limbs. For controls, X1 and X2 refer to right and left, respectively.

Radiographs. Plain orthogonal hip radiographs taken prior to surgery were assessed for disease aetiology, morphology, and severity.[35] Postoperative plain radiographs were also assessed for any coronal malalignment of the components.[36]

We recruited 26 subjects to the control group, who were compared with 28 patients who had undergone HRA and fulfilled our inclusion and exclusion criteria (Table I). Despite having a greater male:female ratio in the HRA group, with associated greater height and body mass index (BMI), no significant statistical differences for age, sex, BMI, height, and top walking speed were identified. All hip patients, except one, had osteoarthritis (OA). The single non-OA patient had steroid-induced osteonecrosis. Morphologically, six patients had acetabular dysplasia. In total, 18 patients had cam impingement and three patients had pincer femoroacetabular impingement. The most common disease severity was Tönnis grade 2, which represented moderately severe arthrosis. Hip patients preoperatively had a mean OHS of 27 points (9 to 37), which improved significantly to 46 (40 to 48) points after surgery ($p < 0.001$).

Statistical analysis. All trials were visually examined to ensure six consecutive strides were captured cleanly. Typically, ten or more strides were collected for multiple trials, so a MATLAB (MathWorks, Natick, Massachusetts) script was written to extract the data from the Kistler software in a formatted manner for analysis. Statistical analysis was completed with MATLAB. Kolmogorov–Smirnov testing showed data were normally distributed, therefore parametric tests were used. To determine differences between the demographics of the controls and hip patients, an unpaired Student's *t*-test was undertaken for continuous data, while categorical data, such as sex, utilized a chi-squared test. To determine differences between group's and limb's ground reaction forces, a one-way analysis of variance (ANOVA) with Tukey *post hoc* test was used, with significance set at a p-value < 0.05 throughout. Paired Student's *t*-tests were carried out to detect significant differences in OHS and GRF in the affected and unaffected limbs before and after HRA.

Results

The mean time to gait assessment after surgery was 29 months (12 to 60). The mean metal ion levels at a mean 32 months (13

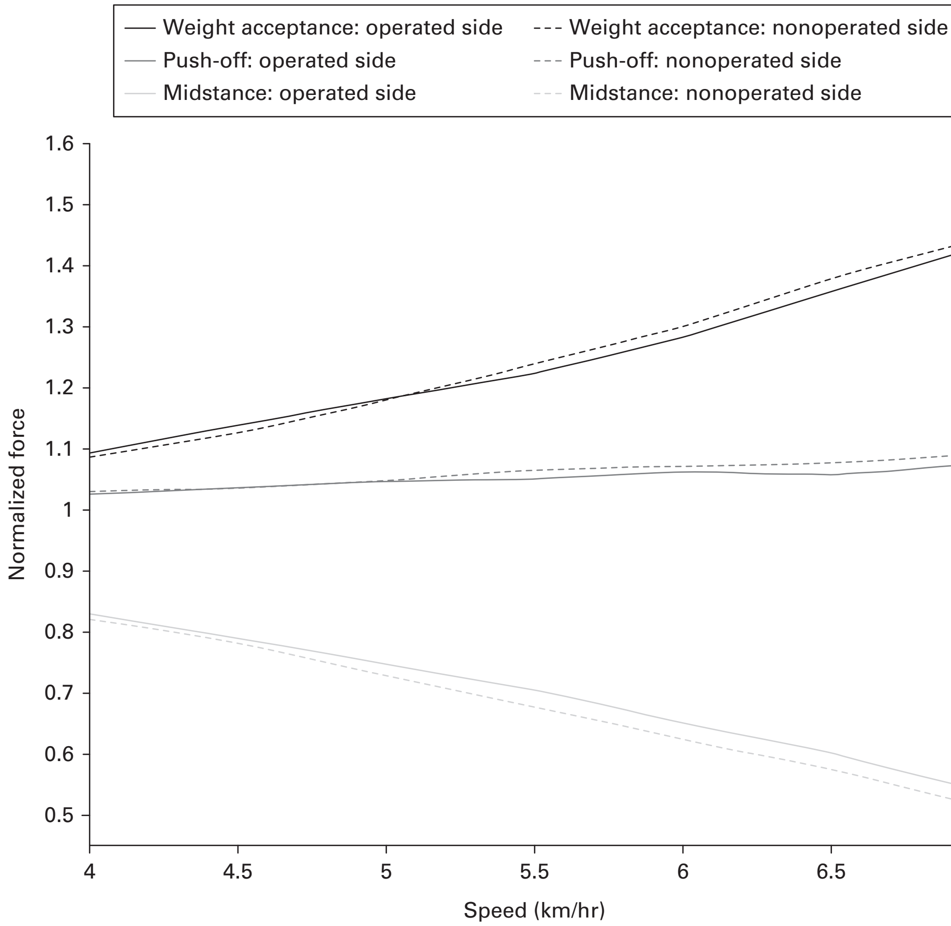

Fig. 4

Mean ground reaction force trends at increasing speeds for patients after surgery: weight acceptance, push-off, and midstance.

to 60) postoperatively were 1.71 µg/l (0.77 to 4.83) (ppb) and 1.77 µg/l (0.68 to 4.16) (ppb) for cobalt and chromium, respectively. One female patient with a 46 mm head had cobalt and chromium levels of 4.83 µg/l and 4.16 µg/l (ppb), respectively. A screening metal artefact reduction sequence (MARS) MRI scan did not demonstrate any adverse features at five years after surgery.

Gait analysis. Healthy controls exhibited symmetrical gait at all speeds and inclines (Fig. 2).

Prior to surgery, patients limped with an asymmetrical gait pattern (Table II and Fig. 3), favouring the contralateral normal side by up to 12% ($p = 0.001$) at weight acceptance with higher speeds. The affected limb was spared from peak loads at weight acceptance and push-off, when compared with healthy controls at all speeds and gradients (Fig. 2).

After hip resurfacing, the mean walking speed of the patients was marginally faster than controls (7.5 km *vs* 7.3 km per hour). This difference disappeared when speed was normalized for leg length, as the controls were slightly shorter than the patients (mean 172 cm *vs* mean 176 cm; Table I).

After HRA surgery, a marked improvement was seen in patients' gait pattern, returning towards symmetry (Figs 1 and 4). Symmetry was achieved by both the unloading of the contralateral normal hip and the near-normal loading of the operated hip during weight acceptance and push-off (Fig. 4). All variables became more symmetrical following surgery. This improvement reached statistical significance for every variable (Table II). When compared with healthy controls, gait symmetry and hip loading was restored, and were found to be indistinguishable except for weight acceptance SI at some speeds ($p = 0.008$, 5.5 km per hour; $p = 0.04$, 6 km per hour; $p = 0.02$, 6.5 km per hour) and in push-off force during uphill walking ($p = 0.02$ at 10% inclination and $p = 0.03$ at 15% inclination).

Discussion

This small prospective gait study set out to determine the impact of HRA on a patient's gait. It was found that patients who underwent HRA with a BHR had significant improvements in their gait pattern, rendering them almost indistinguishable from healthy controls. Our findings contradict published functional studies with different HRA devices, where significant asymmetries persisted in the affected limb when one device was used that is now the subject of class action litigation.[23,24] A randomized gait study with another product (Durom, Zimmer, Warsaw, Indiana) that has since been withdrawn failed to detect any superiority over THA.[37] The current study is supported by a recently published gait analysis of a randomized controlled trial of HRA *versus* THA using the BHR device.[38]

Despite the near-physiological findings in this study, statistically significant weakened push-off forces were still noted during uphill walking, which was not seen during level walking. This observation may relate to the posterior approach including gluteus maximus tendon release and repair. This may have weakened power in terminal extension, which is better tested on uphill walking. Interestingly, this finding was also noted in another study comparing differing stem lengths in conventional THAs with the posterior approach.[28] Another equivocal finding was the weight acceptance SI. Despite significant improvement after surgery, weight acceptance was still statistically less symmetrical than in healthy controls. Previous studies have demonstrated that while implant choice can affect load transfer through the hip,[30,39] skeletal changes cannot be completely undone.[39] The small single treatment arm design of the study is a major limitation. This was purposeful, however, as it is well known that patients seeking hip resurfacing tend to have higher physical demands, and bias would eventually arise if another treatment arm was introduced without randomization.[40] While the HRA group walked faster than the control group, this was not surprising given the greater number of male patients with a predictable height advantage. When taking height into consideration, there was no difference in normalized walking speed, which provides reassurance in this regard. Furthermore, sex and age analysis while walking on an instrumented treadmill have shown no difference in terms of gait pattern and capacity.[41] A second limitation is that despite having a robust metric with the treadmill, 80% of hip resurfacing patients achieved the top walking speed of 8 km per hour, substantially faster than any previously published study of hip arthroplasty. At speeds beyond 8 km per hour, healthy adults will break into a run, so the use of walking as a continuous variable is seriously limited in this regard. While running after HRA is widely reported,[42] it is not regularly undertaken by patients following THA.[43] For the purposes of this study, we chose to limit our metrics to walking.

The strength of the study is that the entire range of walking gait during an everyday activity has been reported prospectively both before and after surgery and compared with healthy controls. The prospective design has allowed us to observe the extent to which HRA restores normal gait. The follow-up of a mean 29-month period after surgery gives the reassurance that this is indeed the functional gain in the longer term. This finding is in keeping with the pragmatic randomized control trial comparing HRA *versus* THA, which showed HRA patients experiencing a substantial enhancement in quality of life (> 20% EuroQol five-dimension three-level questionnaire (EQ-5D-3L)) three years after surgery over THA.[15]

The objective metrics of gait correlate well with the significant improvement in the patient-reported outcome measure at last follow-up, consistent with previous studies of HRA.[2] The largely low metal ion levels are reassuring even with these high-performing hips and probably reflect the implant used. There were no cardiovascular events seen with our patients, in keeping with the evidence that higher walking speed is associated with enhanced life expectancy,[44] and the recent United Kingdom NJR analysis that showed that HRA offered some protective effect against heart failure when compared with other forms of hip arthroplasty.[45]

In conclusion, the current gait study demonstrated that BHR is effective at improving function significantly, restoring a gait pattern that is hard to distinguish from healthy controls. The continued use of certain HRA in active people with appropriate bone stock is validated by this study, although this conclusion may not be generalizable to other devices.

Take home message

- Birmingham Hip Resurfacing markedly improves patients' gait and performance.
- Hip resurfacing using an approved device offers an alternative option for patients requiring higher function.
- All hip resurfacing devices are not the same.

Twitter

Follow J. P. Cobb @orthorobodoc
Follow the authors @MSkLab1

References

1. **Hellman MD, Ford MC, Barrack RL.** Is there evidence to support an indication for surface replacement arthroplasty? A systematic review. *Bone Joint J* 2019;101-B (1 Suppl A):32–40.
2. **Ford MC, Hellman MD, Kazarian GS, et al.** Five to ten-year results of the Birmingham Hip Resurfacing implant in the U.S.: a single institution's experience. *J Bone Joint Surg [Am]* 2018;100-A:1879–1887.
3. **Amstutz HC, Le Duff MJ.** The mean ten-year results of metal-on-metal hybrid hip resurfacing arthroplasty. *Bone Joint J* 2018;100-B:1424–1433.
4. **Scholes CJ, Ebrahimi M, Farah SB, et al.** The outcome and survival of metal-on-metal hip resurfacing in patients aged less than 50 years: a prospective observational cohort study with minimum ten-year follow-up. *Bone Joint J* 2019;101-B:113–120.
5. **Brooks PJ, Samuel LT, Levin JM, et al.** Mortality after hip resurfacing versus total hip arthroplasty in young patients: a single surgeon experience. *Ann Transl Med* 2019;7:77.
6. **Jonas SC, Whitehouse MR, Bick S, Bannister GC, Baker RP.** An 18-year comparison of hybrid total hip replacement and Birmingham Hip Resurfacing in active young patients. *Hip Int* 2019. (Epub ahead of print) PMID: 30672350.
7. **McMinn DJ, Daniel J, Ziaee H, Pradhan C.** Indications and results of hip resurfacing. *Int Orthop* 2011;35:231–237.
8. **Farzi M, Morris RM, Penny J, et al.** Quantitating the effect of prosthesis design on femoral remodeling using high-resolution region-free densitometric analysis (DXA-RFA). *J Orthop Res* 2017;35:2203–2210.
9. **Gerhardt DM, Smolders JM, Rijnders TA, Hol A, van Susante JL.** Changes in bone mineral density and femoral neck narrowing in the proximal femur three to five years after hip resurfacing versus conventional total hip arthroplasty. *J Arthroplasty* 2015;30:308–314.
10. **Kishida Y, Sugano N, Nishii T, et al.** Preservation of the bone mineral density of the femur after surface replacement of the hip. *J Bone Joint Surg [Br]* 2004;86-B: 185–189.
11. **Ball ST, Le Duff MJ, Amstutz HC.** Early results of conversion of a failed femoral component in hip resurfacing arthroplasty. *J Bone Joint Surg [Am]* 2007;89-A:735–741.
12. **Laaksonen I, Donahue GS, Madanat R, Makela KT, Malchau H.** Outcomes of the recalled articular surface replacement metal-on-metal hip implant system: a systematic review. *J Arthroplasty* 2017;32:341–346.
13. **Curtin M, Murphy E, Bryan C, et al.** Medium term review of the ASR implant system: a single surgeon series. *J Orthop* 2017;14:231–235.
14. **Costa ML, Achten J, Parsons NR, et al.** Total hip arthroplasty versus resurfacing arthroplasty in the treatment of patients with arthritis of the hip joint: single centre, parallel group, assessor blinded, randomised controlled trial. *BMJ* 2012;344:e2147.
15. **Costa ML, Achten J, Foguet P, Young Adult Hip Arthroplasty Team.** Comparison of hip function and quality of life of total hip arthroplasty and resurfacing arthroplasty in the treatment of young patients with arthritis of the hip joint at 5 years. *BMJ Open* 2018;8:e018849.
16. **Logishetty K, van Arkel RJ, Ng KCG, et al.** Hip capsule biomechanics after arthroplasty: the effect of implant, approach, and surgical repair. *Bone Joint J* 2019;101-B:426–434.

17. **Moroni A, Miscione MT, Orsini R, et al.** Clinical and radiographic outcomes of the Birmingham Hip Resurfacing arthroplasty at a minimum follow-up of 10 years: results from an independent centre. *Hip Int* 2017;27:134–139.
18. **Ortiz-Declet VR, Iacobelli DA, Yuen LC, et al.** Birmingham Hip Resurfacing vs total hip arthroplasty: a matched-pair comparison of clinical outcomes. *J Arthroplasty* 2017;32:3647–3651.
19. **Seppänen M, Karvonen M, Virolainen P, et al.** Poor 10-year survivorship of hip resurfacing arthroplasty. *Acta Orthop* 2016;87:554–559.
20. **No authors listed.** Medicines and Healthcare products Regulatory Agency (MHRA). All metal-on-metal (MoM) hip replacements: updated advice for follow-up of patients, 2017. https://www.gov.uk/drug-device-alerts/all-metal-on-metal-mom-hip-replacements-updated-advice-for-follow-up-of-patients (date last accessed 12 July 2019).
21. **Sershon R, Balkissoon R, Valle CJ.** Current indications for hip resurfacing arthroplasty in 2016. *Curr Rev Musculoskelet Med* 2016;9:84–92.
22. **Matharu GS, Pandit HG, Murray DW, Treacy RB.** The future role of metal-on-metal hip resurfacing. *Int Orthop* 2015;39:2031–2036.
23. **Jensen C, Aagaard P, Overgaard S.** Recovery in mechanical muscle strength following resurfacing vs standard total hip arthroplasty - a randomised clinical trial. *Osteoarthritis Cartilage* 2011;19:1108–1116.
24. **Resende RA, Kirkwood RN, Rudan JF, Deluzio KJ.** How symmetric are metal-on-metal hip resurfacing patients during gait? Insights for the rehabilitation. *J Biomech* 2017;58:37–44.
25. **Beaulieu ML, Lamontagne M, Beaulé PE.** Lower limb biomechanics during gait do not return to normal following total hip arthroplasty. *Gait Posture* 2010;32:269–273.
26. **Lamontagne M, Varin D, Beaulé PE.** Does the anterior approach for total hip arthroplasty better restore stair climbing gait mechanics? *J Orthop Res* 2011;29:1412–1417.
27. **Kolk S, Minten MJ, van Bon GE, et al.** Gait and gait-related activities of daily living after total hip arthroplasty: a systematic review. *Clin Biomech* 2014;29:705–718.
28. **Wiik AV, Brevadt M, Johal H, et al.** The loading patterns of a short femoral stem in total hip arthroplasty: gait analysis at increasing walking speeds and inclines. *J Orthop Traumatol* 2018;19:14.
29. **Dawson J, Fitzpatrick R, Carr A, Murray D.** Questionnaire on the perceptions of patients about total hip replacement. *J Bone Joint Surg [Br]* 1996;78-B:185–190.
30. **Aqil A, Drabu R, Bergmann JH, et al.** The gait of patients with one resurfacing and one replacement hip: a single blinded controlled study. *Int Orthop* 2013;37:795–801.
31. **Aqil A, Wiik A, Zanotto M, et al.** The effect of hip arthroplasty on osteoarthritic gait: a blinded, prospective and controlled gait study at fast walking speeds. *J Arthroplasty* 2016;31:2337–2341.
32. **Wiik AV, Aqil A, Brevadt M, Jones G, Cobb J.** Abnormal ground reaction forces lead to a general decline in gait speed in knee osteoarthritis patients. *World J Orthop* 2017;8:322–328.
33. **Item-Glatthorn JF, Casartelli NC, Maffiuletti NA.** Reproducibility of gait parameters at different surface inclinations and speeds using an instrumented treadmill system. *Gait Posture* 2016;44:259–264.
34. **Patterson KK, Gage WH, Brooks D, Black SE, McIlroy WE.** Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization. *Gait Posture* 2010;31:241–246.
35. **Tönnis D, Heinecke A.** Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Joint Surg [Am]* 1999;81-A:1747–1770.
36. **Beaulé PE, Lee JL, Le Duff MJ, Amstutz HC, Ebramzadeh E.** Orientation of the femoral component in surface arthroplasty of the hip: A biomechanical and clinical analysis. *J Bone Joint Surg [Am]* 2004;86-A:2015–21.
37. **Lavigne M, Therrien M, Nantel J, et al.** The John Charnley Award: The functional outcome of hip resurfacing and large-head THA is the same: a randomized, double-blind study. *Clin Orthop Relat Res* 2010;468:326–336.
38. **Gerhardt DMJM, Mors TGT, Hannink G, Van Susante JLC.** Resurfacing hip arthroplasty better preserves a normal gait pattern at increasing walking speeds compared to total hip arthroplasty. *Acta Orthop* 2019;90:231–236.
39. **Caplan N, Stewart S, Kashyap S, et al.** The effect of total hip and hip resurfacing arthroplasty on vertical ground reaction force and impulse symmetry during a sit-to-stand task. *Clin Biomech* 2014;29:1164–1169.
40. **Haddad FS, Konan S, Tahmassebi J.** A prospective comparative study of cementless total hip arthroplasty and hip resurfacing in patients under the age of 55 years: a ten-year follow-up. *Bone Joint J* 2015;97-B:617–622.
41. **Jansen EC, Vittas D, Hellberg S, Hansen J.** Normal gait of young and old men and women. Ground reaction force measurement on a treadmill. *Acta Orthop Scand* 1982;53:193–196.
42. **Fouilleron N, Wavreille G, Endjah N, Girard J.** Running activity after hip resurfacing arthroplasty: a prospective study. *AM J Sports Med* 2012;40:889–94
43. **Hoorntje A, Janssen KY, Bolder SBT, et al.** The effect of total hip arthroplasty on sports and work participation: a systematic review and meta-analysis. *Sports Med* 2018;48:1695–1726.
44. **Studenski S, Perera S, Patel K, et al.** Gait speed and survival in older adults. *JAMA* 2011;305:50–58.
45. **Sabah SA, Moon JC, Jenkins-Jones S, et al.** The risk of cardiac failure following metal-on-metal hip arthroplasty. *Bone Joint J* 2018;100-B:20–27.

Author information:
A. V. Wiik, MBBS(Hons), MD(Res), NIHR Academic Clinical Lecturer
R. Lambkin, BSc, Gait Technician
J. P. Cobb, MCh, FRCS, Professor and Chair of Orthopaedics, Imperial College
Imperial College London, MSK Lab, Department of Surgery and Cancer, Charing Cross Hospital, London, UK.

Author contributions:
A. V. Wiik: Designed the study, Analyzed the data, Wrote the manuscript.
R. Lambkin: Collected, processed, and analyzed the data.
J. P. Cobb: Designed the study, Analyzed the data, Wrote the manuscript.

Funding statement:
All of the authors report institutional grants (paid to Imperial College London) from the Theresa Sackler Foundation, Uren Foundation, Biomedical Research Council, and National Institute for Health Research, related to this study.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Acknowledgements:
The authors wish to thank Mathew Furtado for administrative support and Michalis Iosifidis and Raeen Farrokhnik for data processing support.

Ethical review statement:
Ethical approval with London-Camberwell St Giles Research Ethics Committee (10/H0807/101)

This article was primary edited by G. Scott.