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ORIGINAL PAPER

The gait of patients with one resurfacing and one replacement hip: a single blinded controlled study

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Abstract

Purposes Post arthroplasty gait analysis has up till now been performed on subjects walking slowly on flat ground rather than challenging them at faster speeds or walking uphill. We therefore asked: (1) Is there a measurable difference in the performance of hip resurfacing arthroplasty (HRA) and total hip arthroplasty (THA) limbs at patients' self-determined fastest walking speeds and steepest inclines? and (2) Is there a relationship between the observed differences between the gait of HRA and THA implanted limbs and patient walking speeds and inclines.

Methods In an ethically approved study we recruited patients with bilateral hip arthroplasties: one HRA and one THA. Nine subjects were assessed using an instrumented treadmill at a range of speeds and inclines by a blinded observer. The ground reaction forces of subjects were recorded and an age, sex and BMI matched control group was used for comparison.

Results Increasing walking speed correlated strongly with between leg differences in weight acceptance (r=0.9, p=0.000) and push-off force (r=0.79, p=0.002). HRA implanted limbs accepted significantly more weight at top walking speeds (1208 N±320 versus 1279 N±370, p=0.026) and pushed off with greater force when walking uphill (818 N±163 versus 855±166, p=0.012). HRA limbs more closely approximated to the gait of the normal control group.

Conclusions Arthroplasty implants do have an impact on the gait characteristics of patients. Differences in gait are more likely to be evident when assessment is made at fast speeds and walking uphill. This study suggests that HRA may enable a more normal gait.

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Introduction

Hip resurfacing arthroplasty (HRA) was introduced to provide superior function for the more active patient, however selection bias may have skewed results in favour of HRA [1–3]. Three recent prospective randomised controlled trials have failed to detect a difference between HRA and total hip arthroplasty (THA). All were only powered to detect a 10 % difference in slow walking speeds or used conventional functional scores, which have well documented ceiling effects [4–6].

Instrumented treadmills have the advantage of allowing subjects to be tested at a range of speeds and walking inclines. They have been used and validated as a tool for gait assessment [7–9], with increasing speed being used to demonstrate clinically important differences that are not detectable at slower speeds [10, 11]. As HRA has been advocated for the more active patient, in whom higher walking speeds are particularly relevant, the use of this technology seemed appropriate. We have used this faster walking measurement to distinguish HRA from THA, but in a cohort study where selection bias might still occur [12].

Patients with both one resurfacing and one total hip replacement who have high functional scores should overcome this presumed selection bias, as both implants would

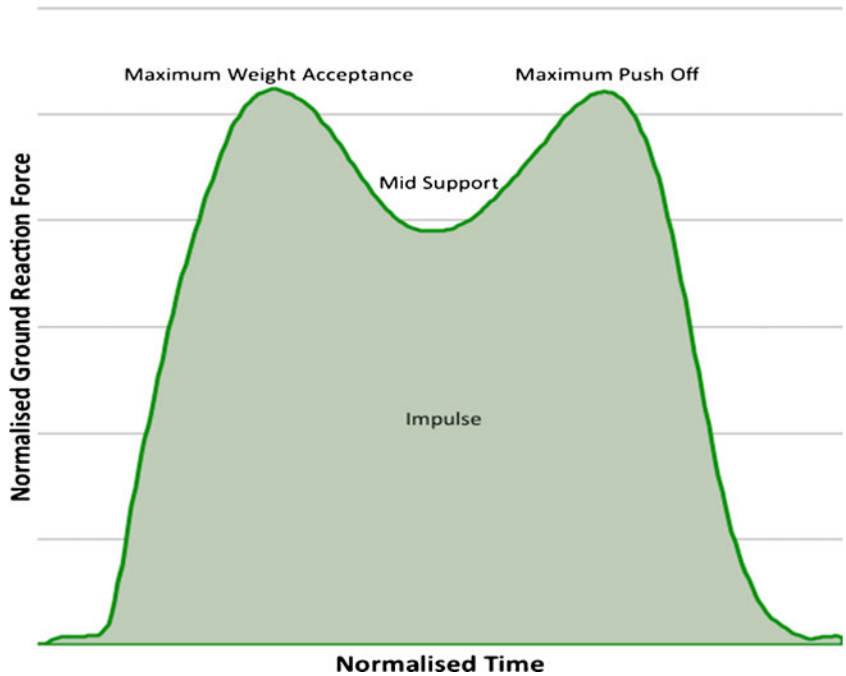

Fig. 1 The ground reaction force outcome measures being examined

have an equal opportunity to be loaded by the same weight in the same person. Thus potential gait differences could then be attributed to the implants.

We therefore asked two relevant questions:

(1) Is there a measurable difference in the performance of HRA and THA limbs at patients' self-determined fastest walking speeds and steepest inclines?
(2) Is there a relationship between the observed differences between the gait of THA and HRA implanted limbs and patient walking speed and inclines?

Participants and methods

Ethical approval was sought and gained prior to commencement of the study. We retrospectively identified all patients who had one THA and one HRA on the contralateral side. Patients at least six months following the most recent surgery were identified from the surgical logs of two surgeons, JPC and SMA. Both surgeons used a posterior approach to the hip and repaired the external rotators on closure. Patients were assessed using the Oxford hip score (OHS) to ensure they had good functioning hips. Some patients had a THA first, presumably because this was prior to HRA increasing in popularity or availability. Some had a THA as their second procedure, perhaps due to increasing subject age and concerns over bone strength. A brief and careful medical history was obtained from patients to ensure they were free from confounding disease in their lower limbs.

Twelve candidate patients were identified, but on questioning three patients were excluded. One patient had hallux rigidus on the side of the resurfacing arthroplasty. One patient had osteoarthritis of the ankle on the side of the THA. The last excluded patient had a knee arthroplasty on the side of the total hip replacement. In total this left nine patients who all consented to have their gait analysed. A

Table 1 Ground reaction forces on the flat at 4 km/h

Variable	Maximum weight acceptance (N)		Mid stance force (N)		Maximum push off force (N)		Impulse (N·s)	
	THA	HRA	THA	HRA	THA	HRA	THA	HRA
Mean	919	913	706	687	875	867	456	454
Standard deviation	194	216	221	201	198	198	137	143
n	9	9	9	9	9	9	9	9
Min. force	671	604	412	430	638	630	276	253
Max. force	1237	1287	1106	997	1188	1171	687	665
Paired *T*-test	0.649		0.168		0.541		0.802	

THA total hip arthroplasty, *HRA* hip resurfacing arthroplasty further group of nine controls were obtained from a database of already tested asymptomatic normal subjects. There were three females and six males in both the study and control groups. The study group was slightly older (mean 67 years, range 55–76 versus control 64 years, range 53–82, $p=0.52$). The mean body mass index (BMI) of the study group was slightly higher (28 kg/m^2 v 25 kg/m^2, $p=0.11$).

Participants had a range of THA bearing couples from metal on polyethylene to ceramic on ceramic with a range of head sizes (28–38). All subjects were content with both hips and pain free. The mean average Oxford score of included patients was 44 (36–48). Radiographs of all subjects were examined to ensure that implanted components were well fixed without signs of loosening.

The mean time from THA operation to gait assessment was four years (1–17 years) and that for HRA was six years (0.7–10 years, $p=0.31$).

Patients were assessed using a treadmill instrumented with piezo-electric force plates underneath the tread (Kistler Gaitway®, Kistler Instrument Corporation, Amherst, NY). Data was collected from the force plates during the stance phase of the gait cycle generating four variables for analysis: maximum weight acceptance, mid support, maximum push-off force and impulse (Fig. 1).

'Maximum weight acceptance' and 'maximum push off' were the first and second peaks of the gait cycle with the 'mid-support' force being the lowest point between the peaks. Impulse was defined as the total force throughout the stance phase of the gait cycle, or the area under the curve in Fig. 1.

Testing followed a six-minute acclimatisation period where patients walked at a gentle 4 km/h. This acclimatisation period has previously been shown to be sufficient to remove inconsistencies in recorded ground reaction forces encountered due to a lack of warming up [13]. The average of each step was used for each speed and inclination.

Flat ground walking was assessed at a range of speeds starting at 4 km/h up to the patients self determined top walking speed (TWS). Following completion of flat walking, subjects were asked to walk uphill at a fixed speed of 4 km/h, at inclinations increasing at five degree increments until they wished to stop. This final inclination was called their top walking incline (TWI).

Assessment was performed with two trained observers using a standardised testing protocol. Assessors were blinded to the sides of the different types of arthroplasty, and patients were tested with their surgical scars covered.

Force differences were normalised for weight and averaged across speeds for comparison. A Kolmogorov-

Table 2 Leg differences in ground reaction forces for arthroplasty subjects at TWS and TWI

Variable	Ground reaction forces at TWS								Ground reaction forces at TWI							
	Maximum weight acceptance (N)		Mid stance force (N)		Maximum push off force (N)		Impulse (N·s)		Maximum weight acceptance (N)		Mid stance force (N)		Maximum push off force (N)		Impulse (N·s)	
	THA	HRA	THA	HRA	THA	HRA	THA	HRA	THA	HRA	THA	HRA	THA	HRA	THA	HRA
Mean	1208	1279	527	471	836	858	348	364	818	855	381	385	818	855	381	385
Standard deviation	320	370	241	151	188	203	95	110	163	166	93	96	163	166	93	96
Min. force	780	731	257	257	570	543	238	227	634	654	253	238	634	654	253	238
Max. force	1751	1883	1084	734	1124	1161	532	582	1120	1177	503	513	1120	1177	503	513
Paired *T*-test	0.026[a]		0.181		0.185		0.034[a]		0.058		0.229		0.012[a]		0.647	

TWS top walking speed, *TWI* top walking incline, *THA* total hip arthroplasty, *HRA* hip resurfacing arthroplasty

[a] Statistical significance at 95 % CI

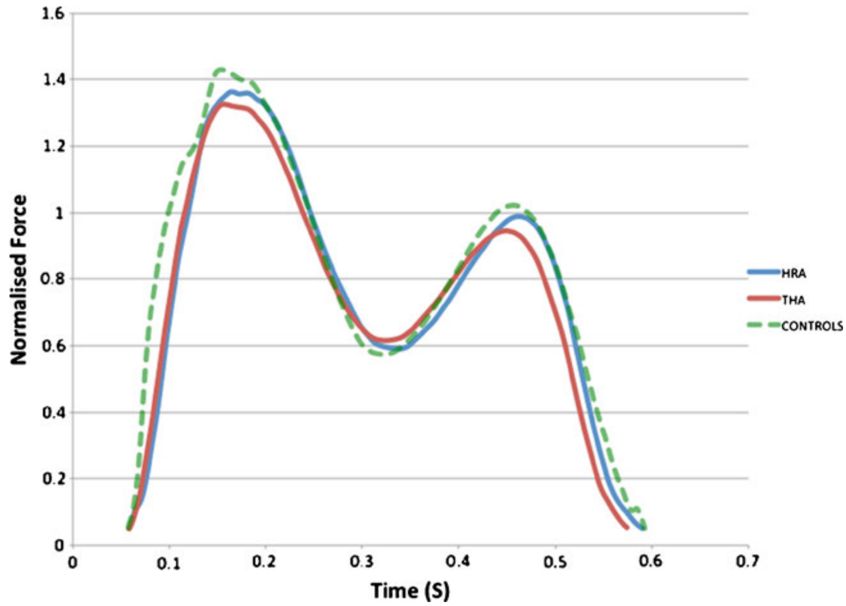

Fig. 2 Ground reaction forces for hip resurfacing arthroplasty (HRA), total hip arthroplasty (THA) and control limbs at top walking speed

Smirnov test showed data was normally distributed. A paired *t*-test was used to assess the significance of any detectable difference at TWS and TWI for means of each of the four key ground reaction force (GRF) variables. A paired *t*-test was also conducted for the 4 km/h walking speed and zero incline to determine if there are differences at baseline. Pearson product–moment correlations were computed to assess the relationship between increasing speeds and the differences between the implanted legs for the key variables. SPSS (IBM SPSS Statistics, version 20) was used to perform all the statistical analyses.

Gait curves of normal and arthroplasty limbs were plotted for visual comparison. The control group left and right legs were averaged to create a single force curve to make visual comparison easier.

Results

At slow speeds weight acceptance of both legs was similar (HRA 913 N±216 vs THA 919 N±194, $p=0.6$), as were the other ground reaction forces (see Table 1). However, at top walking speed, the legs with resurfacings were closer to normal in all studied variables, with the difference between types of arthroplasty reaching most significance in maximum weight acceptance (HRA 1279 N±370 vs THA 1208 N±320 $p=0.026$, Table 2). The impulse force difference also reached significance (HRA 364 N·s±110 vs THA 348 N·s±95, $p=0.034$).

The gait cycle of THA and HRA implanted legs were visually compared with those of the age, sex and BMI matched control group. In all these four measured key gait

Table 3 Leg differences in ground reaction forces for control subjects at TWS and TWI

Variable	Ground reaction forces at TWS								Ground reaction forces at TWI							
	Maximum weight acceptance (N)		Mid stance force (N)		Maximum push off force (N)		Impulse (N·s)		Maximum weight acceptance (N)		Mid stance force (N)		Maximum push off force (N)		Impulse (N·s)	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Mean	1178	1164	399	388	788	780	337	336	771	775	526	528	741	720	385	387
Standard deviation	816	781	257	255	623	567	233	232	633	634	423	417	594	502	298	313
Min. force	1848	1792	594	513	1052	1059	475	495	1038	1040	638	655	1009	996	539	544
Max. force	350	348	113	89	142	159	83	87	151	148	97	102	154	166	99	94
Paired *T*-test	0.479		0.640		0.628		0.795		0.595		0.831		0.185		0.617	

TWS top walking speed, *TWI* top walking incline, *L* left leg, *R* right leg

[a] Statistical significance at 95 % CI

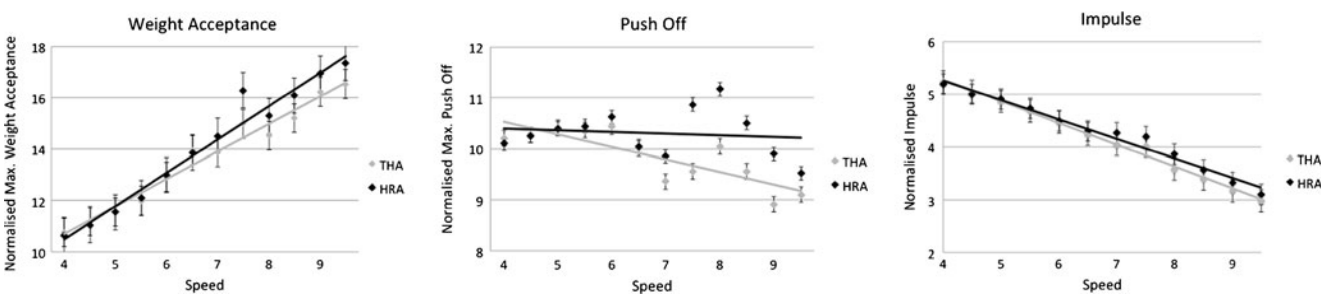

Fig. 3 Graphs showing the effect of increasing speeds (km/hr) on the normalized ground reaction forces ($x10^2$) with HRA and THA implanted limb

GRFs, the HRA implanted legs more closely resembled the control group (Fig. 2; Table 3).

As arthroplasty subjects walked faster, gait differences became more apparent (Fig. 3). Pearson's R data analysis revealed a strongly positive correlation between increasing speed and ground reaction force differences between the types of arthroplasty in three GRFs: maximum weight acceptance (r=0.9, p=0.000), maximum push off (r=0.79, p=0.002) and impulse (r=0.75, p=0.005). With increasing speed, the greatest differences were observed in maximum weight acceptance (Fig. 4).

At their steepest achievable incline, differences between the implanted legs were also marked (Fig. 5). The difference in maximum push off was most significant (HRA 855 N±166 vs THA 818 N±163, p=0.012, Table 2). Pearson's R data analysis revealed a moderate positive correlation between increasing steepness and difference in impulse, which just failed to reach significance (r=0.34, n=5, p=0.051).

Discussion

This small study set out to detect significant differences in the gait that might exist between THA and HRA by using patients with one of each device in situ. The principle limitation is that of sample size, i.e. we were only able to find nine subjects with high hip scores and no comorbidities that might invalidate the comparison. However, despite the small sample size, our primary hypothesis was confirmed, that is, there do appear to be measurable and significant differences in the performance of HRA and THA at higher speeds and on inclines. Furthermore, the strong correlations between observed differences and increasing speed confirms that this difference does not exist at a single speed but is a pattern as speed increases. Out of the nine patients only seven were able to walk uphill. Uphill walking took place after the fast walking trial. Tiredness may therefore have been the reason why two of the patients did not consent to carry on and this further reduction of numbers may have been a reason for just failing to reach significance with correlating force differences with increasing steepness.

The self determined top walking speeds (TWS) of subjects were considerably higher than that of other studies testing arthroplasty subjects (6.8 km/h, range 5.5–9.5 km/h). At TWS, the weight acceptance was 71 N or 8 % of body mass greater in HRA implanted limbs. There were strong correlations between the differences in weight acceptance, push-off and impulse as speed increased,

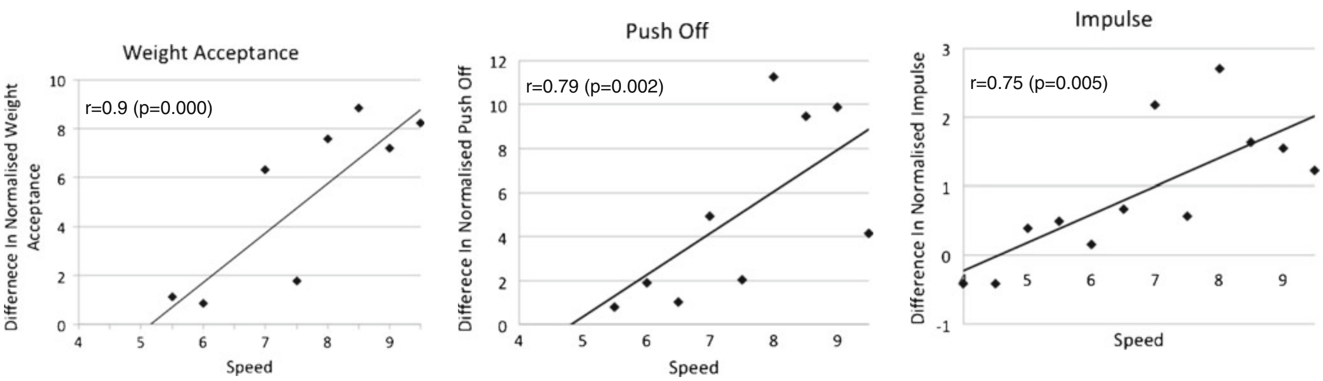

Fig. 4 Graphs show the differences between the normalised ground reaction forces ($X10^3$) between limbs with increasing speeds (km/hr). Correlations were calculated using Pearson's R data analysis

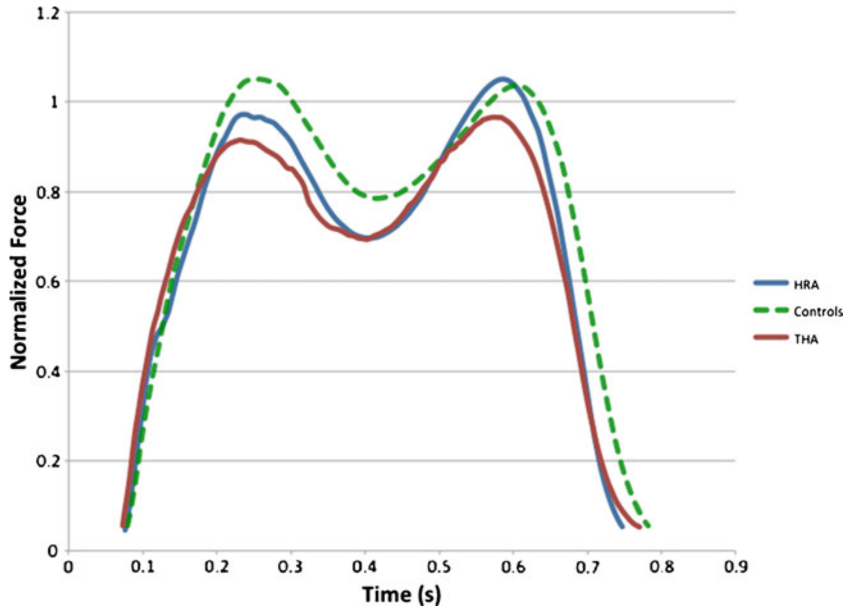

Fig. 5 Ground reaction forces for hip resurfacing arthroplasty (HRA), total hip arthroplasty (THA) and control limbs at top walking inclines

confirming the supposition that by testing at low speeds, differences might be missed [14].

Speed dependent gait variability is not a new subject in the medical field and has been highlighted in the field of cerebral ataxia [10]. It is therefore reasonable to assume that faster speeds may distinguish the good from the very good arthroplasty in functional terms. The data concurs with previous studies, which failed to detect any significant difference between THA and HRA at slow speeds (up to 5.5 km/h) [4]. For more active patients who wish to return to an active lifestyle, this eight percent of body weight difference in performance at higher speeds may be clinically relevant.

This is the first report of the performance of hip arthroplasty patients on steep inclines. The median incline managed by these patients with bilateral hip arthroplasty was 20°(10–25°). At TWI, the maximum weight acceptance was 4 kg, or five percent of body weight more in the HRA implanted limbs. This size of difference may also be clinically relevant in those patients who wish to return to walking on variable terrain. This small study could not demonstrate a linear correlation between increasing gradient and increasing difference in gait between THA and HRA. However, when testing people at their TWI at 4 km/h, the difference in their maximum push-off reached significance, while on flat ground it was undetected.

The age- and sex-matched, asymptomatic control group walked faster on flat ground, and achieved steeper inclines than the arthroplasty group. The 'normal' gait cycle curve was visibly different from that of either arthroplasty limb. So while subjects were satisfied with their operation and had quite good functional scores, as surgeons we should not be complacent in assuming that arthroplasty restores normal function, particularly at higher speeds or on inclines. However the gait cycle of HRA implanted limbs was closer to 'normal' at TWS and TWIs. This suggests that the statistically detected differences in gait between types of arthroplasty were in favour of HRA.

Hip resurfacing in its current state remains a controversial surgical option for the active patient. This small study, which appears to be free from selection bias, suggests that HRA does indeed enable superior levels of function when treadmill walking at variable speeds, and gradients are used as a surrogate for global function. These activities are not unreasonable expectations for all patients who wish to remain active. The decision of which implant to use however should not be based on potential gait advantages alone and must be joint decisions made between surgeon and patient based on safety as well as function aspirations of the patient.

Conflict of interest 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.

Ethical review statement Ethical approval was sought and gained prior to commencement of the trial. All investigations were conducted in conformity with ethical principles of research, and informed consent for participation in the study was obtained.

This work was performed at, Imperial College London, Charing Cross Campus, UK.

References

1. Baker RP, Pollard TC, Eastaugh-Waring SJ, Bannister GC (2011) A medium-term comparison of hybrid hip replacement and Birmingham hip resurfacing in active young patients. J Bone Joint Surg Br 93(2):158–163. doi:10.1302/0301-620X.93B2.25625
2. Mont MA, Seyler TM, Ragland PS, Starr R, Erhart J, Bhave A (2007) Gait analysis of patients with resurfacing hip arthroplasty compared with hip osteoarthritis and standard total hip arthroplasty. J Arthroplast 22(1):100–108. doi:10.1016/j.arth.2006.03.010
3. Treacy RB, McBryde CW, Shears E, Pynsent PB (2011) Birmingham hip resurfacing: a minimum follow-up of ten years. J Bone Joint Surg Br 93(1):27–33. doi:10.1302/0301-620X.93B1.24134
4. Lavigne M, Therrien M, Nantel J, Roy A, Prince F, Vendittoli PA (2010) 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 468(2):326–336. doi:10.1007/s11999-009-0938-z
5. Costa ML, Achten J, Parsons NR, Edlin RP, Foguet P, Prakash U, Griffin DR (2012) 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 344:e2147. doi:10.1136/bmj.e2147
6. Petersen MK, Andersen NT, Mogensen P, Voight M, Soballe K (2011) Gait analysis after total hip replacement with hip resurfacing implant or Mallory-head Exeter prosthesis: a randomised controlled trial. Int Orthop 35(5):667–674. doi:10.1007/s00264-010-1040-6
7. Houdijk H, van Ooijen MW, Kraal JJ, Wiggerts HO, Polomski W, Janssen TW, Roerdink M (2012) Assessing gait adaptability in people with a unilateral amputation on an instrumented treadmill with projected visual context. Phys Ther 92(11):1452–1460. doi:10.2522/ptj.20110362
8. Hofstad CJ, van der Linde H, Nienhuis B, Weerdesteyn V, Duysens J, Geurts AC (2006) High failure rates when avoiding obstacles during treadmill walking in patients with a transtibial amputation. Arch Phys Med Rehabil 87(8):1115–1122. doi:10.1016/j.apmr.2006.04.009
9. Hofstad CJ, Weerdesteyn V, van der Linde H, Nienhuis B, Geurts AC, Duysens J (2009) Evidence for bilaterally delayed and decreased obstacle avoidance responses while walking with a lower limb prosthesis. Clin Neurophysiol Off J Int Fed Clin Neurophysiol 120(5):1009–1015. doi:10.1016/j.clinph.2009.03.003
10. Wuehr M, Schniepp R, Ilmberger J, Brandt T, Jahn K (2012) Speed-dependent temporospatial gait variability and long-range correlations in cerebellar ataxia. Gait Posture 37(2):214–218. doi:10.1016/j.gaitpost.2012.07.003
11. Schniepp R, Wuehr M, Neuhaeusser M, Kamenova M, Dimitriadis K, Klopstock T, Strupp M, Brandt T, Jahn K (2012) Locomotion speed determines gait variability in cerebellar ataxia and vestibular failure. Mov Disord Off J Mov Disord Soc 27(1):125–131. doi:10.1002/mds.23978
12. Wiik A, Lewis A, Amis A, Cobb J (2012) Hip resurfacing arthroplasty enables faster walking and longer stride length than total hip arthroplasty. In: American Academy of Orthopedic Surgeons, San Francisco. Paper no. 657
13. Matsas A, Taylor N, McBurney H (2000) Knee joint kinematics from familiarised treadmill walking can be generalised to overground walking in young unimpaired subjects. Gait Posture 11(1):46–53
14. Cobb J (2010) Letter to the editor: the functional outcome of hip resurfacing and large-head THA is the same: a randomized, double-blind study. Clin Orthop Relat Res 468(11):3134. doi:10.1007/s11999-010-1512-4