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Postural balance during quiet standing in patients with total hip arthroplasty and surface replacement arthroplasty

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Abstract

Background. Primary total hip arthroplasty leads to better functional capacities but a general weakness of abductor muscles often persists. A larger head component may improve the postural balance in the medial–lateral direction. The aims of this study are (1) to compare postural stability in patients after total hip and surface replacement arthroplasties and (2) to evaluate the effect of the biomechanical reconstruction on postural stability.

Methods. Six months post-surgery, three groups of ten subjects (total hip and surface replacement arthroplasties and control) performed quiet standing tasks in both dual and one leg stance and a hip abductor muscles strength test. The root-mean-square amplitude of centre of pressure and centre of mass displacement in the anterior–posterior and medial–lateral directions were calculated for dual stance task.

Findings. Statistical analyses showed greater centre of pressure and centre of mass displacement amplitude in the medial–lateral direction during the dual stance for the total hip arthroplasty compared to the surface replacement and control subjects ($P < 0.05$). All control subjects completed the one leg stance compared to nine in the surface replacement and five in the total hip arthroplasty group. No statistical difference was found between the groups in the hip abductor muscles strength.

Interpretation. The better anatomical preservation, absence of femoral stem and the larger bearing component could account for the return to better postural stability in surface replacement patients in comparison to total hip patients. Further studies are needed to determine the impact of each of these factors on the postural balance.

Keywords: Postural control; Postural balance; Postural mechanism; Surface replacement arthroplasty; Total hip arthroplasty; Muscular strength; Femoral offset

1. Introduction

In the past, hip replacement was mostly performed in elderly sedentary population whereas in present time, patients requiring hip replacement are both increasingly young and active (Crowninshield et al., 2006). These new patients' characteristics are particularly important for the prosthesis performance and durability as well as for the reduction of later complications (Crowninshield et al., 2006). There is therefore a growing interest for the development of newer prostheses restoring better patient's anatomy (Amstutz et al., 1998; Girard et al., 2006) and physiological loading (Amstutz et al., 1998; Daniel et al.,

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2004) as well as for the development of newer surgical techniques (Asayama et al., 2006; Lawlor et al., 2005) and more durable bearing surfaces (Goldsmith et al., 2000; Harris and Muratoglu, 2005).

At the moment, two main types of hip replacements are available: the total hip arthroplasty (THA) with a standard femoral head, (head diameter of 22, 28 or 32 mm) and the surface replacement arthroplasty (SRA). The THA procedures involve patient femoral head and neck removal and replacement by an implant. It is a frequent and successful procedure that relieves pain and improves hip function as early as three to six months post-surgery (Laupacis et al., 2002). Patients' anatomy reconstruction and muscle function restoration depend on the surgeon's ability to reconstruct the hip joint (Kalteis et al., 2006; Parratte and Argenson, 2007) and the implant design (Crowninshield et al., 2006). However, because of its femoral head diameter, THA is associated with high rate of post-operative impingement, instability and dislocation (0.4–7.2%) (Berry et al., 2004; Jolles et al., 2002). In contrast, by conserving parts of the femoral head and neck, SRA has been considered to better preserve hip anatomy (Girard et al., 2006) and to offer superior clinical function (Vendittoli et al., 2006) in comparison to THA. Indeed, the restoration of hip anatomy might improve the functionality of the hip joint; particularly of the abductor muscles (Amstutz et al., 2004; Asayama et al., 2005; Girard et al., 2006).

These latter points are crucial since it has been recognized that one of the main disabilities often reported in patients after conventional THA is a general weakness of abductor muscles (Asayama et al., 2005; McGrory et al., 1995; Perron et al., 2000). Therefore, an improvement of the functionality of hip abductor muscles with SRA may have several implications in daily living activities involving upright stance postural regulation since these muscles are strongly implied in medial–lateral balance control (Winter et al., 1996). Although studies have found that balance is affected up to one year after conventional THA (Majewski et al., 2005; Nallegowda et al., 2003; Trudelle-Jackson et al., 2002), none of them have investigated the specific advantages of the SRA in comparison of the THA. Therefore, the aims of this study are (1) to compare postural stability in patients after they underwent THA or SRA (2) to evaluate the effect of the biomechanical reconstruction on postural stability.

2. Methods

2.1. Patients

A total of thirty subjects divided in three groups (10 controls without hip pathology, 10 THA and 10 SRA) participated in the study. The control subjects were volunteers recruited from the community through the Marie Enfant Rehabilitation Centre and the Maisonneuve-Rosemont Hospital. All patients had unilateral hip disease and the average follow-up of operated subjects was six months (minimum five months, maximum eight months). Exclusion criteria for all subjects included the presence of any interfering pathology that may have affected balance and reported falls for the past six months. Groups' characteristics are presented in Table 1. All participants gave their written consent and the project was approved by the research ethics and scientific committees of our institution.

Each surgery was performed through a posterior surgical approach by three experimented surgeons (P.-A.V, M.L and A.-G.R.). In the SRA group, the Durom hip-resurfacing system (Zimmer, Warsaw, USA) was implanted (Fig. 1). For the THA group, a CLS Spotorno (Zimmer, Warsaw, USA) titanium uncemented femoral stem (Zimmer) was used with a 28 mm Metasul femoral head (Zimmer) articulated with a Metasul bearing insert fitted into an Allofit uncemented acetabular cup (Zimmer, Warsaw, USA) (Fig. 2). During each procedure, the surgeons tried to reproduce patients' hip anatomy using pre-operative templating with the opposite side as a reference and using intraoperative bony landmarks. Surgical technique for all procedure has been described in previous studies (Girard et al., 2006; Vendittoli et al., 2006) .

Table 1
Characteristics of control, total hip replacement (THA) subjects and surface replacement arthroplasty (SRA)

Subjects	Control	THA	SRA
Age (y)	45.1 (10.1)	51.1 (7.8)	43.1 (8.2)
Gender	4 F/6M	5 F/5M	4 F/6M
Weight (kg)	77.3 (14.8)	85.0 (17.4)	83.7 (18.8)
Height (m)	1.71 (0.08)	1.67 (0.90)	1.69 (0.08)
BMI (kg/m^2)	26.9 (2.9)	30.7 (6.3)	29.1 (4.5)

No significant differences were observed between the groups. Means (SD), $P < 0.05$.

Fig. 1. The hybrid Durom hip surface replacement arthroplasty system with chrome–cobalt femoral head and acetabular cup (Zimmer, Warsaw, USA).

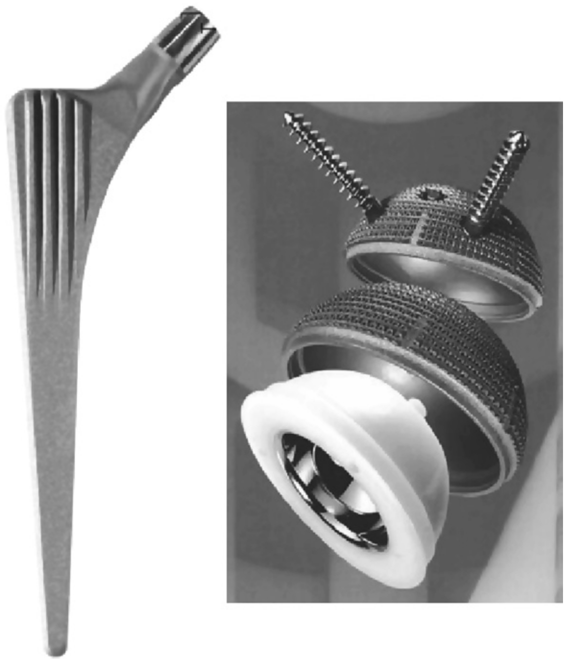

Fig. 2. The CLS femoral stem and the Allofit acetabular cup (Zimmer, Warsaw, USA).

2.2. Radiographic analysis

Standardised post-operative radiographs were analysed. Anteroposterior radiographs of the pelvis were taken with the legs positioned in 15° of internal rotation. The radiographs were rejected if the coccyx was not centred on the pubic symphysis and located proximally within 2–4 cm. This ensured proper positioning of the pelvis in both the frontal and sagittal planes. These were scanned (VIDAR VXR-12, Herndon, Virginia, USA) and analysed using Imagika software (Clinical Measurement Corporation, New Jersey, USA). The femoral offset, the horizontal and vertical centres of rotation and leg-length inequality were measured for the replaced and normal contralateral hip on post-operative radiographs. The femoral offset was defined as the perpendicular distance (mm) from the centre of rotation to the femoral shaft line. The vertical hip centre of rotation was determined by the perpendicular distance (mm) from the centre of rotation of the hip to the inter-teardrop line. The horizontal centre of rotation was evaluated by the distance between the vertical centre of rotation line and the teardrop. Finally, the limb length was evaluated by the perpendicular distance from the teardrop to the lesser trochanter line.

2.3. Postural tasks

All participants were asked to perform two postural tasks. For the first task, patients were requested to maintain a quiet standing posture with eyes open and feet at shoulder width for 120 s. For the second task, patients had to maintain a one leg stance position for 10 s. The operated leg was tested twice with an inter-trial resting period of 30 s. The abductor muscles' strength of both legs was also assessed using a Penny & Giles hand-held myometer (Penny and Giles, Christchurch, UK). The hand-held myometer recorded the peak force generated (*N*). To limit the inter-examiner variability, the peak force value generated by the abductor muscles of the operated limb was expressed as the percentage of the peak force generated by the abductor muscles of the sound limb. For dual leg stance, ground reaction forces and moments were collected with an AMTI force plate (Advance Mechanical Technology Inc., MA, USA) recording at a sampling frequency of 60 Hz. The time histories of the center of pressure (COP) profiles were calculated from the orthogonal forces and moments recorded by the force plate while the center of mass (COM) displacement was estimated from the zero-point-to-zero-point integration technique (Lafond et al., 2004; Zatsiorsky and King, 1998). The COP and COM displacement profiles were reported as the root-mean-square amplitude (in mm) of COP (RMS_{COP}) and COM (RMS_{COM}) in the anterior–posterior and medial–lateral directions.

2.4. Statistics

One-way ANOVAs were performed to compare the differences between the groups for the dual stance task as well as for the abductor muscles relative strength. The root-mean-square (RMS) amplitude (in cm) of COP (RMS_{COP}) and COM (RMS_{COM}) in the anterior–posterior and in the medial–lateral directions and the abductor muscles strength percentage were used as dependent variables. The statistical significance was set at $P < 0.05$ and Newman–Keul post-hoc analyses were conducted when necessary. Mean differences between the THA and SRA groups for the radiographic analysis were evaluated by Student's *t*-test ($P < 0.05$). A Pearson product–moment correlation for the abductor muscles strength and RMS_{COP} in the medial–lateral direction was measured in the groups. A Pearson's chi-square test was assessed to test the null hypothesis of independence between groups and one leg stance task completion.

3. Results

As shown in Table 1, no significant differences were found in the groups' characteristics.

3.1. Radiographic analysis

Differences were observed between the groups in the biomechanical reconstruction. As shown in Table 2, the femoral offset differential between the operated limb and the sound limb was significantly different between the groups ($P < 0.001$). The femoral offset in the THA group increased on the operated side and reached 121.6% (SD: 10.2%) relative to the contralateral limb compared to the SRA group

Table 2
Biomechanical restoration of the operated hip compared to the sound limb in the total hip arthroplasty (THA) and surface replacement arthroplasty (SRA) groups

Subjects	THA	SRA	P value
Femoral offset (mm)	6.4 (2.1)	−2.4 (2.9)	<0.001
Femoral offset (%)	121.6 (10.2)	94.5 (6.7)	<0.001
Horizontal centre of rotation (mm)	−4.0 (2.7)	−0.5 (2.5)	0.008
Vertical centre of rotation (mm)	3.7 (5.2)	0.2 (3.4)	0.09
Leg-length inequality (mm)	2.7 (4.1)	−0.2 (2.7)	0.09

Means (SD), $P < 0.05$.

that showed a negative offset differential ($P < 0.001$) and consequently a relative offset that reach 94.5% (SD: 6.7%) of the contralateral limb ($P < 0.001$). The horizontal centre of rotation was significantly more medialized in the THA group compared to the SRA ($P = 0.008$). The vertical centre of rotation was more proximal in both groups with a larger but non significant value in the THA compared to the SRA ($P = 0.09$). The length of the operated leg in the THA group was increased while it was decreased in the SRA group ($P = 0.09$).

3.2. Postural variables

During static dual stance, the statistical analyses revealed significantly larger RMS_{COP} and RMS_{COM} amplitudes in the medial–lateral direction for THA subjects compared to SRA and control subjects (see Table 3). No significant differences were observed between groups in the anterio-posterior direction for both RMS_{COP} ($P = 0.70$) and RMS_{COM} ($P = 0.58$). Statistical analysis showed significant dependence between groups and one leg stance completion ($P = 0.01$). Five of the ten patients in the THA group did not complete the task compared to one for the SRA subject. In the control group all subjects completed the task.

3.3. Strength variable

Statistical analyses revealed no difference in the abductor muscles strength of the prosthetic hip relative to the non prosthetic hip in the SRA, THA and control (left limb relative to right limb) groups, respectively, (mean: 90%, SD: 15%; mean: 88%, SD: 12% and mean: 103%, SD: 19%; $P = 0.13$). The correlation between RMS_{COP} in the medial–lateral direction and strength of hip abductor muscles did not reach the statistical significance in any of the three groups. In the THA group, the correlation was positive in the prosthetic hip ($r = 0.07$) and in the non prosthetic hip ($r = 0.32$). In the SRA group, the correlation was larger on both side (prosthetic: $r = 0.40$ and non prosthetic hip: $r = 0.47$). A negative correlation was found in the control group (left: $r = -0.36$; right: $r = -0.42$).

Table 3
Root-mean-square (RMS) of the center of pressure (COP) and center of mass (COM) (mm) in medio-lateral and anterio-posterior directions in control, total hip arthroplasty (THA) and surface replacement arthroplasty (SRA) and groups

Variables	Control	THA	SRA
RMS_{COP} anterio-posterior	6.14 (2.42)	5.18 (2.77)	5.52 (2.42)
RMS_{COP} medial–lateral	2.43 (0.94)	3.52 (1.66)[a]	2.05 (0.64)
RMS_{COM} anterio-posterior	5.88 (2.46)	4.71 (2.63)	5.29 (2.42)
RMS_{COM} medial–lateral	2.20 (0.96)	3.25 (1.45)[a]	1.95 (0.64)

[a] Different from control (RMS_{COP}: $P = 0.05$; RMS_{COM}: $P = 0.02$) and SRA (RMS_{COP}: $P = 0.04$; RMS_{COM}: $P = 0.03$). Means (SD), $P < 0.05$.

4. Discussion

The purpose of this study was to compare postural stability in THA or SRA patients and to evaluate the effect of the biomechanical reconstruction on postural control.

4.1. Postural control strategies

The striking point of our results relies on the larger RMS_{COP} and RMS_{COM} observed in the medial–lateral direction in THA group compared to control and SRA groups. These results are in agreement with previous studies reporting persisting deficits in postural stability 6–12 months after surgery in THA (Majewski et al., 2005; Nallegowda et al., 2003; Trudelle-Jackson et al., 2002). These deficits were demonstrated by lower stability and endurance on the operated limb compared to the contralateral limb during a one leg stance task (Trudelle-Jackson et al., 2002) and by stiffness in the trunk's control during quiet standing (Majewski et al., 2005). Furthermore, studies on muscular fatigue showed that a decrease in muscles strength, particularly in the hip abductors, leads to significantly larger COP displacement and velocity in the medial–lateral direction (Gribble and Hertel, 2004; Salavati et al., 2007). Therefore, the larger RMS_{COP} and RMS_{COM} observed in the THA group could be related to difficulty in controlling the COM due to the weakness of their abductor muscles.

Indeed, the postural control in the medial–lateral direction necessitates the activation of the hip adductor/abductor muscles to transfer the body weight from one leg to the other. This is called the load/unload mechanism (Winter et al., 1996). The correlation between the abductor muscles strength and the RMS_{COP} in the medial–lateral direction can give insights about how the patients are using this postural mechanism. In the SRA, the similarity of the correlation between the prosthetic and non prosthetic side put forward the symmetrical contribution of both hip abductor muscles to the RMS_{COP} amplitude. However, the positive correlations also imply that patients with weaker abductor muscle strength could minimize the COP displacement in the medial–lateral direction in order to enhance postural control. This strategy was previously reported in elderly during prolonged standing (Freitas et al., 2005). Nevertheless, this result also demonstrates that the recovery of strong hip abductor muscles allows the SRA to return to a more normal postural control.

Conversely, the prosthetic abductor strength in the THA group seems to be unrelated to the RMS_{COP} compared to the sound limb. This could show a trend in the THA to rely mostly on the sound leg to assure postural control. It may also explain their larger RMS_{COP} since asymmetric loading of the limbs during quiet standing is related to postural instability (Anker et al., 2007; Blaszczyk et al., 2000). This tendency to avoid the load of the prosthetic hip is also strengthened by the failure to complete the one leg stance task in five of the THA patients. Indeed, this result illustrates their difficulty to achieve a task that requires a larger contribution of the abductor muscles or, at least, it reflects a fear to load the prosthetic hip without the possibility to counterbalance with the sound limb. Since both patients' group showed similar abductor muscles strength recovery (i.e. approximately 90% of the sound limb's strength) we think that this strength factor on its own could not fully account for the lower postural stability observed in the THA compared to the SRA. Somehow, the prosthetic characteristics of the SRA could account for their more normal postural control.

4.2. *Effect of biomechanical reconstruction on postural stability*

Three main factors are differentiating THA and SRA arthroplasties: hip biomechanical restoration, presence or not of a metallic femoral stem for load transmission and bearing diameter. Regarding biomechanical restoration, it has been proposed that increasing the femoral offset could be advantageous for the patients after hip arthroplasty (Asayama et al., 2005). Indeed, by lengthening the hip abductor's moment arm the abductor muscles could be more efficient to produce movement (Asayama et al., 2005). However, in spite of the limited number of patients, our results showed that the SRA group had better postural control regardless of their reduced femoral offset compared to the THA group. This result is in line with those of Girard et al. (2006) proposing that a slight decrease in the femoral offset, which could be inherent to the procedure itself, did not affect the clinical outcomes in SRA. Also, the closer to contralateral hip biomechanical parameters' restoration found in the SRA group is in concordance with the proposition that SRA could allow a better precision in reconstructing the normal biomechanical environment of the hip joint (Girard et al., 2006).

Second, since the femoral head and neck are preserved during SRA implantation, more physiological load transmission to the proximal femur occurs (Kishida et al., 2004), and this may also improve proprioception (Amstutz et al., 1998; Amstutz et al., 2004; Kishida et al., 2004). The absence of a stem in the medullar canal also avoids the development of thigh pain or discomfort, which could be particularly important in young or active patients (Engh et al., 2003).

Third, it has been proposed that better tribologic properties (tight clearance low surface roughness and larger components diameter) enhance the bearing lubrication (Liu et al., 2006; Smith et al., 2001) and this could lead to reduce or avoid bearing micro separation during gait similar to the non prosthetic hip joint (Komistek et al., 2002). As a consequence, it generates a more physiological loading than smaller femoral heads (Amstutz et al., 1998), improves stability and reduces impingement between the prosthetic components (Amstutz et al., 1998; Amstutz et al., 2006; Amstutz et al., 2004; Daniel et al., 2004).

The results of the present study suggest that the use of metal-on-metal SRA prosthesis has a better ability to allow the return to normal postural stability than THA. Patients' functional capacities were not assessed in pre-surgery. It is therefore possible that functional differences prior to the surgery had interfered with the functional capacities post-surgery. It is also not possible to determine which of the three main factors differentiating standard THA and SRA (femoral anatomy reconstruction, load transfer via a metallic femoral stem and the bearing size) is mainly responsible for the found differences. Further studies comparing standard THA or SRA and THA with anatomical diameter metal-on-metal bearing would help determine the effect of each factor.

5. Conclusion

Functional assessments of postural control during double stance have demonstrated higher postural stability in patients with SRA compared with patients who underwent a conventional THA. These results may suggest that the preservation of the femoral head and neck, the larger head component and the better biomechanical reconstruction could be important factors allowing the return to normal postural stability in SRA patients. Therefore, SRA could be beneficial in patients whose lifestyle requires a fast improvement of the postural control. However, longer clinical follow-up is needed to determine the mid and long term postural control recovery of SRA versus THA.

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