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In-vivo 3-Dimensional gait symmetry analysis in patients with bilateral total hip arthroplasty

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ABSTRACT

Although three-dimensional (3D) asymmetry has been reported in unilateral THA patients during gait, it is not well understood whether asymmetric hip kinematics during gait persist in bilaterally operated THA patients. The purpose of this study was to compare the in vivo 3D kinematics and component placement between bilateral and unilateral THA patients during gait. Eight bilateral and thirty-three unilateral THA patients were evaluated for both hips during treadmill gait using a validated combination of 3D computer tomography-based modeling and dual fluoroscopic imaging system (DFIS). The in vivo 3D kinematics of the unilateral THA group was first assessed. The magnitudes of kinematics and component placement difference between implanted hips in the bilateral THA group and between the implanted and non-implanted hips in the unilateral THA group were compared. The study results showed asymmetric gait kinematics in the unilateral THA group. Although the magnitude of kinematics differences between sides for both the bilateral and unilateral THA groups did not change significantly for hip rotations ($p > 0.05$), the bilaterally operated THA group has significantly lower magnitude of hip gait translation difference. Significant reduction in the magnitude of the acetabular cup adduction, stem adduction, and combine hip anteversion and adduction difference was observed in the bilateral THA group ($p < 0.05$). Our findings demonstrated that despite significant improvements of component placement and reduced magnitude of hip gait translation difference between implanted hips in the bilateral THA group, asymmetric hip kinematic rotations persisted in patients with bilateral THA during gait.

1. Introduction

Total hip arthroplasty (THA), one of the most effective methods of treatment for end-stage hip osteoarthritis, provides pain relief and restores hip function, however, asymmetric gait deficits, including reduced hip range of motion in the sagittal plane, decreased peak hip extension, and increased hip internal rotation have been reported in unilateral THA patients (Tsai et al., 2015a, 2015b). In addition, the effects of component malposition or misalignment on asymmetric hip kinematics during gait were also reported (Tsai et al., 2015b). Gait abnormality may negatively influence the normal wear of the components implanted (Madsen et al., 2004), increase the risk of falls for THA patients, interfere with the quality of life, and increase the economic burden on the health care system (Dimitriou et al., 2015; Seeman et al., 2010; Trudelle-Jackson et al., 2002). Therefore, detailed understanding of hip joint biomechanics would be important for improving gait symmetry in bilaterally operated THA patients.

Several studies have previously reported on kinematic evaluation of patients following THA during gait (Kolk et al., 2014; Madsen et al., 2004; Tsai et al., 2014). Moreover, hip gait symmetry in unilateral THA patients have also been studied (Tsai et al., 2015a, 2015b). However, relatively few studies have reported on hip symmetry motions in bilaterally operated THA patients during gait (Husby et al., 2010; Winiarski et al., 2014). The measurements reported on previous studies mainly focused on asymmetrical loading. In addition, due to technical limitations, data regarding hip internal-external rotations and head translations were limited. Thus, there is a paucity of reports regarding the potential differences in 6 degree of freedom (6DOF) in vivo hip kinematics during gait and component positioning between the implanted sides in bilaterally operated THA patients.

The purpose of this study was to compare the in vivo 3D kinematics during gait, as well as component positioning between bilaterally and unilaterally operated THA patients utilizing a combined CT based modeling and dual fluoroscopic imaging system

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(DFIS) approach (Lin et al., 2013; Tsai et al., 2013) to measure the hip 6DOF kinematics during treadmill gait.

2. Methods

2.1. Patients

Eight bilateral and thirty-three unilateral patients with metal-on-polyethylene THA were evaluated in this study with the institution's Internal Review Board approval. All patients enrolled in this study received cementless THA for primary end-stage osteoarthritis, using a posterolateral approach. Gender, operated side, age, BMI, acetabular cup diameter, and femoral head diameter were compared. No significant differences were found in the above variables between the two groups, expect for the operated side (Table 1). Most of the unilateral THA patients had the right hip (20 hips) replaced. All patients had well-functioning bilateral and unilateral THA's. No patient had a history of surgical complication, dislocation or component subluxation on the implanted hips. The average follow-up periods for the left and right hips in the bilateral THA group were 13.7 months (±12.7 range 3.5–38.7) and 16.3 months (±10.4 range 5.6–30.8) ($p = 0.5$), respectively.

2.2. Study design

In this study, two different groups were compared. One group consisted of 8 bilaterally operated THA patients. The other group, consisted of 33 unilaterally operated THA patients. First, hip gait symmetry was assessed in the unilateral THA group by comparing 3D hip kinematics between the implanted and non-implanted (native) hips during gait. Then, the magnitudes of gait kinematics and component positioning difference were quantified and compared between groups. The magnitude of difference between hips was used for analysis in order to avoid the possibility of having equal distributions between the left and right hips in the bilateral THA group.

2.3. CT-based modeling and measurement of hip positioning

All forty-one patients received a computerized tomography (CT) scan (Sensation 64, Siemens, Germany) from the L5 vertebra to the mid-femur for creation of surface models of the acetabular cup, femoral stem, and bones of the implanted and non-implanted hips (Fig. 1a) using a previously established protocol (Tsai et al., 2013). In order to compare the anatomical measures between THA and native hip in the unilateral THA group, the native hip and femur bones were mirrored with respect to the sagittal plane and aligned with the hip and femur bones of the implanted side, following an established approach (Tsai et al., 2015c). Difference in the acetabular cup anteversion and inclination, as well as femoral anteversion and inclination between THA and the native hip were reported. Offsets of the hip joint center along local femoral axes (anterior-posterior, superior-inferior, and lateral-medial) were also calculated. To compare the geometric parameters between the implanted left and right hips in the bilateral THA group, the surface models of the implanted right pelvic and femur bones were mirrored with respect to the sagittal plane and aligned to the

Table 1
Demographic data of bilateral and unilateral total hip arthroplasty (THA) patients.

	Bilateral THA	Unilateral THA	p
Number of patients	8	33	–
Gender	2 male, 6 female	10 male, 23 female	0.767
Operated side	8 left, 8 right	13 left, 20 right	**0.032**
Age (years)	63.1 ± 8.6 (50.0–71.0)	61.2 ± 8.4 (47.0–73.0)	0.563
BMI (kg/m^2)	26.7 ± 5.5 (18.5–35.0)	26.9 ± 4.1 (19.7 – 35.8)	0.960
Acetabular cup diameter (mm)	54.0 ± 1.8 (52.0–56.0)	53.3 ± 2.6 (50.0–60.0)	0.483
Femoral head diameter (mm)	36.0	35.6 ± 1.5 (32.0–40.0)	0.511

Average ± SD (range) and p value *t*-test were calculated. No significant difference in demographic data was found between the two groups.

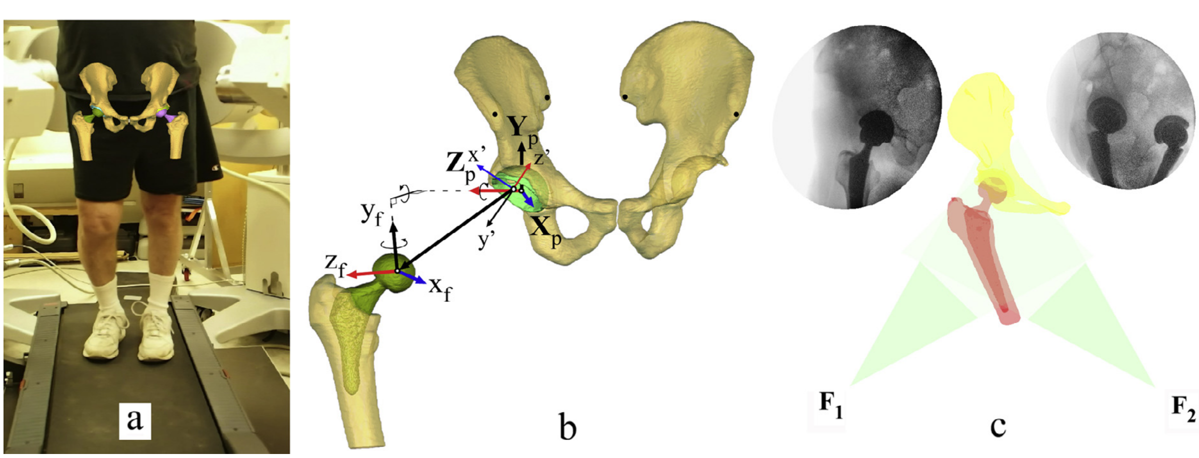

Fig. 1. (a) Three-dimensional hip models of a bilateral THA patient reconstructed from CT images overlapping with a photo of DFIS experimental setup used for in-vivo hip kinematics analysis during treadmill gait. (b) The origin of the pelvic coordinate system located at the center of the acetabular sphere. The origin of the femoral coordinate system was at the center of the femoral head. Two local coordinates of the acetabular cup were defined for describing the hip joint rotations (Xp-Yp-Zp), and the hip translations (x′-y′-z′). The 3D vector from the origin of the acetabulum to the center of the femoral head in the acetabular coordinate system was measured as the hip translation. (c) A virtual DFIS environment of the experiment demonstrating registration of in-vivo hip kinematics.

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