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Does component alignment affect gait symmetry in unilateral total hip arthroplasty patients?

Tsung-Yuan Tsai, Jing-Sheng Li, Dimitris Dimitriou, Young-Min Kwon *

Department of Orthopaedic Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA 02114, USA

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ABSTRACT

Background: Component malposition in total hip arthroplasty patients has been associated with adverse clinical outcomes. However, whether the component alignment influences hip dynamic performance following total hip arthroplasty remains unclear. The purpose of this study was to investigate the relationship between the component alignment and in vivo hip kinematics during gait.

Methods: Nineteen unilateral total hip arthroplasty patients received CT scan for creation of 3D hip models. The component alignment between the non-implanted and implanted hips were measured and compared. Three-dimensional hip kinematics for both hips of the total hip arthroplasty patients during gait was quantified using a dual fluoroscopic imaging technique. The differences between the implanted and non-implanted hip kinematics during gait were calculated. A forward stepwise multiple linear regression was performed to evaluate the relationships between the changes in implanted hip kinematics and the differences in component alignment with respect to the non-implanted hips.

Findings: An average 5.1° (SD 6.5°; range −11.1° to 18.3°) increase in internal rotation was observed in the implanted hip than the contralateral non-implanted hip and significantly correlated with a linear combination of the increase of cup anteversion, cup medial translation and leg lengthening ($R = 0.81$).

Interpretation: Results suggested that the total hip arthroplasty patients compensated the changes in hip geometry by altering the dynamic movement during gait. Restoration of the native hip geometry, including acetabular cup anteversion, position and leg length could be one of the factors that influence the hip kinematics symmetry in total hip arthroplasty patients during gait.

1. Introduction

Total hip arthroplasty (THA) is a highly successful orthopedic procedure for patients with end-stage hip osteoarthritis in restoring hip function. Although significant improvement in the hip functional capacity has been reported after THA (Long et al., 1993; Perron et al., 2000; Queen et al., 2011), reduced range of hip flexion, decreased peak hip extension, asymmetric limb loading and hip joint moment during gait were observed (Ewen et al., 2012; McCrory et al., 2001; Miki et al., 2004; Queen et al., 2014; Shakoor et al., 2003). Persisted asymmetric motion and joint loading could contribute to differential muscle fatigue, kinematic and kinematic imbalance (Kumar, 2001), and higher interfacial stresses, which may increase the risk of injury (Beaulieu et al., 2010; Chiu et al., 2010) and affect the longevity of components (Kleemann et al., 2003).

Adverse clinical outcomes, such as hip impingement (Renkawitz et al., 2012), edge loading (De Haan et al., 2008), dislocation (Barrack, 2003), and revision surgery (Hirakawa et al., 2001), have been associated with malposition or misalignment of the components during THA. In addition, the femoral head to neck offset, head–neck ratio and cup anteversion were reported to affect the range of hip flexion after surgery (D'Lima et al., 2000; Girard et al., 2012; Malviya et al., 2010). However, the effects of component alignment on the hip motion during gait in THA patients have not been reported.

The purposes of this study were therefore to evaluate if acetabular and femoral component alignments affect in-vivo hip kinematics in unilateral THA patient during gait and the correlation in between. The null hypothesis was that no effect of component alignment on in-vivo hip kinematics and no significant correlation between the component alignment and changes in dynamic hip motion between legs in unilateral THA patients during gait.

2. Materials & methods

2.1. Patient demography

Nineteen patients with one-sided end-stage hip osteoarthritis who underwent unilateral THAs were recruited in this study (5 males and 14 females, with 13 right and 6 left THAs) with the institution's Internal Review Board approval. The average age was 60.6 years (Table 1). The average follow-up time was 10.6 months from surgical date. All the

* Corresponding author.
E-mail address: ymkwon@mgh.harvard.edu (Y.-M. Kwon).

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Table 1
Demographics of the recruited unilateral THA patients.

N = 19	Average, standard deviation (range)
Age (year)	60.6, 8.8 (47 to 73)
Gender	5 male: 14 female
Implanted side	6 left: 13 right
Follow-up (month)	10.6, 4.6 (3.6 to 22.6)
Body mass (kg)	76.6, 17.4 (54.4 to 111.1)
Body height (cm)	168.2, 7.8 (154.9 to 180.3)
BMI (kg/m^2)	26.9, 4.7 (19.7 to 35.8)
Native femoral head diameter (mm)	45.7, 3.4 (40.5 to 52.0)
Cup diameter (mm)	52.7, 2.2 (50.0 to 56.0)
Stem head diameter (mm)	35.6, 1.8 (32.0 to 40.0)

patients received cementless metal on polyethylene THA with tapered femoral stem (DJO Surgical, Encore Medical, Austin, Texas, USA; Zimmer, Warsaw, Indiana, USA). The acetabular cup and femoral head sizes were from 50 to 56 mm and 32 to 40 mm. All patients included in this study had no history of dislocation or subluxation or report of any surgical complication.

2.2. CT-based 3D modeling and measurement of hip orientations

Each patient received a CT scan (Sensation 64, Siemens, Germany) from the fifth vertebra to the mid-femur for construction of the subject-specific surface models of the acetabular cup, femoral stem and the hip bones (Fig. 1) with previously published and validated protocol (Tsai et al., 2014a). Cup anteversion and inclination of the implanted and non-implanted hips were obtained and compared using direct digitization on the 3D hip models following a previous protocol (Murray, 1993). To compare the femoral anteversion and adduction between the implanted and non-implanted femur, the non-implanted femur were mirrored and aligned with the femur of the implanted side (Fig. 1) using a customized surface-to-surface registration method (Tsai et al., 2015). A 3D deviation analysis between the mirrored implanted femur and the contralateral femoral model showed that the average (standard deviation) of the distances was 0.69 (0.26) mm.

2.3. Quantification of hip positions and determination of coordinate system

Pelvic hip joint center (HJC) and femoral head center (FHC) of the implanted and non-implanted sides were measured and compared. The centroid of the best-fitted sphere to the horseshoe surface of the bony acetabular cup was determined as HJC (Tsai et al., 2014a). The FHC was determined at the center of the best sphere to the femoral head (Tsai et al., 2014a). For THAs, the HJCs and the FHCs were defined as the centroid of the best fitted sphere to the cup and femoral head. The differences in the HJC locations between sides along the local axes were considered as cup lateralization, medicalization and vertical elevation. The differences in the FHC locations between sides along the local axes were calculated as changes in femoral Anterior/Posterior (A/P) offset, femoral vertical (Superior/Inferior, S/I) offset and femoral horizontal (Lateral/Medial, L/M) offset. The differences in HJC, FHC and cup orientations between the implanted and non-implanted hip were combined as the overall effects of the THA on the hip positions and orientations. The combined S/I translation of the cup and femoral stem was considered as the change of leg length.

The pelvic and femoral coordinate systems were defined following a previous publication (Tsai et al., 2014b) for description of the hip joint rotations and femoral head translations with respect to the acetabular cup. The orientation of the coordinate system was corresponding to anatomic planes. The X-, Y- and Z-axes of the right hip point anteriorly, superiorly and to the right. To determine the femoral coordinate system of the implanted side, the mirrored non-implanted femur with a copy of the native femoral coordinate system was aligned with the remaining implanted femur using the surface-to-surface registration method. The

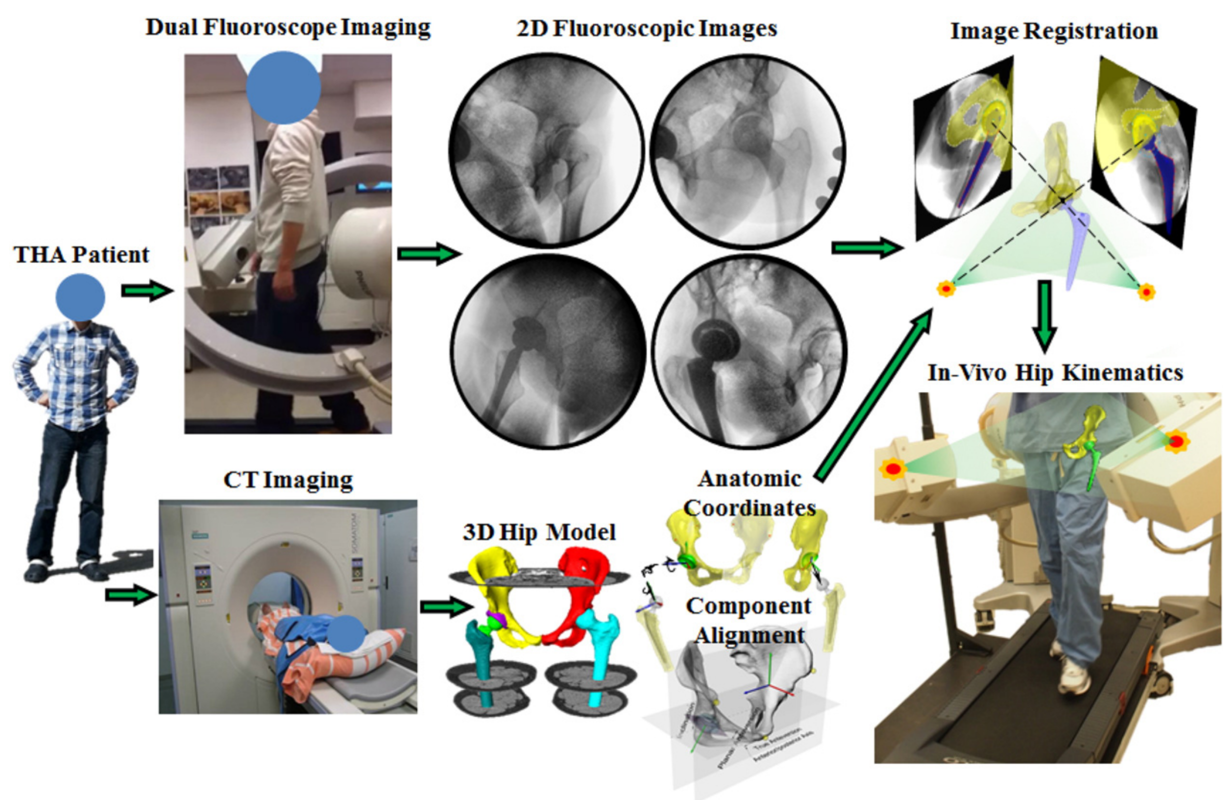

Fig. 1. Graphical flowchart of the dual fluoroscopic imaging based tracking procedure. Subject has to receive CT for 3D joint modeling and fluoroscope imaging for 2D joint images during motion. Image registration of the 3D models to 2D images was achieved in self-developed scripts. The registered bone positions were used for measurement of the hip kinematics during gait.