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Sit-To-Stand Biomechanics Before and After Total Hip Arthroplasty

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ABSTRACT

The purpose of this study was to evaluate changes in movement patterns during a sit-to-stand (STS) task before and after total hip arthroplasty (THA), and to compare biomechanical outcomes after THA to a control group. Forty-five subjects who underwent THA and twenty-three healthy control subjects participated in three-dimensional motion analysis. Pre-operatively, subjects exhibited inter-limb movement asymmetries with lower vertical ground reaction force (VGRF) and smaller moments on the operated limb. Although there were significant improvements in movement symmetry 3 months after THA, patients continued to demonstrate lower VGRF and smaller moments on the operated limb compared to non-operated and to control limbs. Future studies should identify the contributions of physical impairments and the influence of surgical approach on STS biomechanics.

Total hip arthroplasty (THA) is the treatment of choice for end-stage hip osteoarthritis (OA). This surgery effectively reduces pain [1–4] and improves function [1–8] compared to pre-operative levels. Despite the pain resolution and a high level of patient satisfaction after THA [9], abnormal movement patterns persist during dynamic tasks such as walking [10,11], stair climbing [12] and rising from a chair [13–16]. Rising from a chair, defined here as the sit-to-stand task (STS) task, is an important metric of biomechanical recovery after THA. This task is a fundamental daily activity performed approximately 60 times per day by healthy adults [17]. It is a demanding task that requires greater muscle strength and produces higher joint forces than walking and stair climbing [18,19]. Unlike most other dynamic movements, rising from a chair is a bilateral support task in which both feet are in contact with the ground. Therefore, compensatory movement strategies that favor one leg can be used to accomplish the task, which makes the STS task a sensitive measure for evaluating movement asymmetry in individuals with unilateral lower extremity pathology.

When rising from a seated position, patients after THA unload their operated hip and shift weight to the non-operated side [13,14,16]. A study by Lamontagne and colleagues has also shown that the operated hip has less motion in the sagittal plane, smaller internal extension moment and different mechanics in the frontal and transverse planes compared to both the non-operated side and control subjects when rising from a chair [15]. While previous studies have analyzed lower limb biomechanics during STS in the THA population [13–16]; only one small study by Caplan and colleagues [16] was longitudinal ($n = 7$), while the other studies have been limited to cross sectional designs. In addition, none of these studies have evaluated trunk movement during the STS task in patients before and after THA. Trunk movement plays an important role in completing the STS [20–22]. Proximal adaptations may be a principal determinant of successful strategies in a population with substantial pelvic and hip muscular weakness that remains years after THA [23]. Quantifying trunk movement during STS may lead to better understanding of how patients before and after THA use compensatory strategies to rise out of a chair.

The purpose of this study was to evaluate STS movement strategies before and 3 months after THA and determine whether subjects 3 months after THA have joint kinetics and trunk kinematics that differ from a control group of older adults without lower extremity joint pathology. Specifically, we hypothesized that: 1) at 3 months after THA, patients will show improvements in movement symmetry that is driven by increased vertical ground reaction force (VGRF) and increased moments about the hip and knee joints of the operated limb compared to the pre-operative time point and 2) at 3 months after THA, the operated limb would have lower VGRF, and smaller hip and knee moments compared to the control group.

Methods

Subjects

This was a prospective longitudinal study. Subjects with end-stage hip OA between the ages of 35 and 85, who were scheduled to undergo

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THA between March 2012 and April 2014 were either referred by local orthopedic surgeons or responded to newspaper advertisements. Prior to enrollment, subjects were screened for eligibility using a telephone interview conducted by our research staff. Subjects were excluded if they had 1) neurological disorders that affected their ability to walk or rise from a chair, 2) any cardiovascular problems that limited their ability to climb a flight of stairs or walk for 6 minutes, 3) uncontrolled hypertension, or 4) history of cancer in the lower extremity. Subjects with bilateral limb involvement were allowed to participate in the parent study, but were excluded from this analysis if they had a prior arthroplasty surgery within the previous year; or planned to have an additional lower extremity arthroplasty (Fig. 2). This was done to avoid the potential confounding influence of contralateral joint impairments on biomechanical symmetry. Three-dimensional motion analysis was completed at 2–4 weeks prior to THA and 3 months after THA. The 3 month follow-up was specifically chosen as this is the time many patients are cleared to return to higher level activity, can participate in muscle strengthening exercises, and no longer have hip precautions. Therefore, it is the time that more progressive exercise and rehabilitation interventions may begin.

All surgical procedures were performed by a modified Hardinge anterolateral, posterior, or direct lateral approach at a single Joint Center with a volume of approximately 800 THAs per year (Table 1). Patients from five surgeons were included in this study. Two surgeons performed the anterolateral approach, two different surgeons performed the posterior approach, and one surgeon performed the direct lateral approach.

A cross-sectional sample of older adults without symptomatic lower extremity joints pathology was also collected as control group. Subjects in the control group met all of the same inclusion and exclusion criteria as the THA population. Additionally, control subjects were excluded if they had a previous joint arthroplasty, were planning a joint arthroplasty or had pain greater than 4/10 in any lower extremity joint. Subjects in the control group only attended a single testing session. The study was approved by the Human Subjects Review Board at the University of Delaware and all subjects provided informed consent prior to participation.

Anthropometric Measures

Age, height, weight and sex were recorded, and body mass index (BMI) was calculated for subjects in the THA and control groups.

Motion Analysis

For the THA and control groups, the STS was collected using a three dimensional 8-camera motion capture system (VICON, Oxford Metrics, London, England) synchronized with two embedded force platforms (Bertec Corp., Worthington, OH, USA). Sixteen-millimeter spherical retro-reflective markers were placed bilaterally on anatomical structures that were used to define the trunk and lower extremity segments during the static trial. Markers were placed on the acromio-clavicular joint, iliac crest, greater trochanter, lateral femoral condyle, lateral malleolus, head of the 5th metatarsal, and 2 markers on the heel. To track segments movement during the dynamic trials, rigid thermoplastic shells with 4 markers were attached to the trunk (mid-thoracic area lateral to the spine) and bilaterally on the lower legs and thighs, and a shell with 3 markers was placed on the pelvis below the line between the 2 posterior superior iliac spines. The only difference in motion analysis for THA and control groups was in the method to compute the joint centers. For THA group, medial markers were used to compute knee and ankle joint centers during a static standing trial. Functional hip joint centers were determined using a built-in algorithm that calculates the most likely intersection of all axes (effective joint center) and most likely orientation of the axes (effective joint axis) between the pelvis and femur based on a separate dynamic trial in which subjects performed hip flexion, extension and abduction and circumduction during a single leg stance [24]. For the control group, knee, and ankle joint centers were computed by using virtual medial markers. These markers were created based on the joint width that measured between two femoral epicondyles and between two malleoli using a caliper. The hip joint centers were computed using the predictive method that places the hip joint center at one-quarter of the distance from the ipsilateral to the contralateral greater trochanter markers [25]. Given that the on-going THA study was conducted after the initiation of control group study, a different method was employed in THA study to measure joint centers that improves precision of center location, especially for the hip joint. The functional method improves hip joint center localization compared to predictive method and is recommended to be used for motion analysis in THA population [26].

Marker and force platform data were sampled at 120 Hz and 1080 Hz, and filtered at 6 Hz and 40 Hz, respectively, using a second-order phase corrected Butterworth filter. Visual 3D software (v5.00.25; C-Motion Inc., Germantown, MD, USA) was used to compute joint angles and moments for each limb by using kinematics and inverse dynamic analysis techniques. Joint angles were calculated using Euler X-Y-Z sequence corresponding to flexion/extension, abduction/adduction, and then rotation sequences. VGRF in newton was normalized to subject's body weight in newton (N/BW, i.e. % of BW). Joint moments were expressed as external moments normalized to body mass times height (Nm/kg · m).

Movement Task

An adjustable-height piano stool without armrests or backrests was used for this task (Fig. 1). The height of the stool was set to the subject's knee joint line when standing. Subjects were seated in the stool with the trunk in upright position and with no restrictions on their feet position. Subjects were also asked to hold the arms in the lap and to stand from the chair at their self-selected pace but not to turn or look behind for the stool while sitting down. Before collecting three STS trials, subjects were asked to practice the task twice. For subject's safety, the stool was secured to the floor with adhesive tape to prevent movement during the task. The start and end of the STS task were defined as follows: the *start–stand* event occurred when the velocity of the left acromio-clavicular marker exceeded a threshold of 0.1 m/s in the anterior direction and *end-stand* occurred when the left acromio-clavicular marker reached the highest position in the vertical direction.

Outcome Variables

Vertical ground reaction force (VGRF), sagittal and frontal hip and knee moments were calculated for each limb through the STS task. To characterize the loading pattern at the foot-floor interface, the peak VGRF for each limb was calculated and used in the analysis. Peak values for external hip and knee flexion moments, and peak external hip adduction moment, were assessed for each limb to identify any joint specific compensation during the movement. These moments represent the rotational force applied by external forces (ground reaction force)

Table 1
Subject Characteristics.

	THA (Pre-Operative)		Control Group	
Variable	Mean (SD)	Range	Mean (SD)	Range
Age (years)	63.8 (8.0)	42-82	67.9 (7.7)	51–81
Height (m)	1.74 (0.10)	153–1.89	1.67 (0.09)	1.53–1.87
Mass (kg)	89.2 (22.1)	51.4–146.5	71.4 (17.1)	44.0–126.3
BMI (kg/m^2)	29.4 (5.6)	19.9–43.5	25.3 (4.1)	17.6–36.1
Sex: male/female (n)	28/16	–	9/14	–
Affected side: right/left (n)	22 (49%)/ 23 (51%)	–	13 (56%)/ 10 (44%)	–
Surgical approach. P/AL/DL	30/14/1	–	N/A	–