Clinical Biomechanics 30 (2015) 53–58

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Bilateral symmetry in lower extremity mechanics during stair ascent and descent following a total hip arthroplasty: A one-year longitudinal study☆

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ARTICLE INFO

Article history:
Received 29 April 2014
Accepted 11 November 2014

Keywords:
Total hip arthroplasty
Limb symmetry
Stair climbing
Hip osteoarthritis
Walking mechanics

ABSTRACT

Background: Total hip arthroplasty is the standard treatment to reduce pain and improve function in people with advanced hip osteoarthritis; however, persisting asymmetrical gait patterns have been identified in level walking. Therefore, this study evaluated limb asymmetries during stair ascent and descent in patients pre-operatively through 1 year after a hip replacement. It was hypothesized that lower extremity mechanics would improve on the surgical side, but asymmetries would persist through one year.

Methods: Kinematics and kinetics were collected during seven ascending and descending trials pre-operatively, 6 weeks, and 1 year post-operatively for 42 hip replacement patients. Data were analyzed using 2 ∗ 3 (Limb ∗ Time) within-subject repeated measures analyses of variance (ANOVAs) to determine significant differences between limbs across time ($P < .05$).

Findings: Significant changes across time, independent of limb included: peak hip flexion, extension, and adduction during ascent. Peak hip flexion and extension, hip flexion moment, adduction and abduction moments, and propulsive vertical ground reaction force were different during descent ($P < .05$). Independent of time, significant asymmetries between limbs were observed in peak hip flexion, hip abduction, and hip extension moments during ascent, and in peak hip abduction moment during descent ($P < .05$).

Interpretation: Abnormal movement patterns on the surgical side increase demands on other joints and could lead to permanent joint damage. These side-to-side differences in joint mechanics should be addressed during the early post-operative period through additional interventions in an attempt to normalize the differences and potentially improve long-term joint health throughout the lower extremity.

1. Introduction

Symptomatic hip osteoarthritis (OA) affects 9.2% of people over the age of 45 and this prevalence increases with age (Arden and Nevitt, 2006; Lawrence et al., 2008). End-stage hip OA is a debilitating condition that limits mobility and physical function, and for many patients, palliative care provides no pain relief or lifestyle improvement (Croft et al., 2002). Total hip arthroplasty (THA) has therefore become the standard of care to reduce pain and improve function in individuals with advanced hip OA (Kiebzak et al., 1997). In the United States, over 285,000 hip replacements are performed each year to address this painful and functionally limiting pathology (JRH, 2011).

Most THA patients report improvement in outcomes with respect to pain relief, improved functional mobility during daily activities, overall health and quality of life following surgery (Berend et al., 2004; Espehaug et al., 1998; Jones et al., 2001; Kiebzak et al., 1997; Laupacis et al., 1993; Montin et al., 2008; Ogonda et al., 2005). Despite these positive post-operative self-reported measures, asymmetrical gait patterns between limbs during level walking have been reported up to 1-year after surgery. Prior gait analysis studies of THA patients have reported unequal spatiotemporal variables and asymmetric gait mechanics between limbs following surgery (Isobe et al., 1998; McCrory et al., 2001). Decreased peak hip flexion and peak extension as well as the associated range of motion (Miki et al., 2004) have also been found for the surgical limb during post-operative level walking (Queen et al., 2011b). Additionally, reduced muscle strength (Shih et al., 1994) and decreased energy expenditure have been observed for the operative limb in comparison with the non-operative limb (Loizeau et al., 1995) which confirms the presence of post-operative functional asymmetries following THA. In addition, post-operative ipsilateral muscle weakness

☆ Source of funding: No funding was received for this study.
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http://dx.doi.org/10.1016/j.clinbiomech.2014.11.004
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(Reardon et al., 2001) and atypical joint motion have been associated with asymmetrical limb loading (Talis et al., 2008).

As a result of these issues, much research has focused on asymmetries during level walking after THA (Beaulieu et al., 2010; Isobe et al., 1998; McCrory et al., 2001; Queen et al., 2011b); however, few studies have examined the functional adaptations of the surgical limb adopted during more challenging tasks, such as stair climbing (Queen et al., 2013a; Shrader et al., 2009). Mechanically, stair ascent requires larger hip range of motion combined with greater muscle force at the hip in order to lift the subject's body mass, and therefore, may emphasize asymmetries otherwise undetected during level walking (Costigan et al., 2002; Talis et al., 2008). Compared to level walking, it has been reported that ascending stairs increases implant torque by 83% (Bergmann et al., 2001) and generates greater sagittal plane moments, placing greater strain on the hip extensor mechanism (Kirkwood et al., 1999; Nadeau et al., 2003).

Previous studies in the area of knee osteoarthritis and total knee replacement (TKA) have examined stair climbing. These studies have reported that improvements in stair climbing ability were directly related to an increase in lower limb muscle strength and decreased pain (Hicks-Little et al., 2011; Unver et al., 2014; Whitchelo et al., 2014). The few kinematic studies that have examined stair climbing capabilities in hip replacement populations have found both angular and loading asymmetries (Shrader et al., 2009). THA patients 3 months following surgery exhibit reduced abduction and extension moments and irregular muscle firing of the hip while ascending stairs, which alter hip mechanics and hip joint loading following surgery (Shrader et al., 2009). Overall, a 20% difference in vertical ground reaction forces between the surgical and non-surgical limbs has been reported during tasks as physically demanding as stair climbing (Talis et al., 2008). Furthermore, previous studies have reported that THA patients ascend stairs with increased hip flexion angles and decreased hip extension angles, and descend stairs with decreased hip flexion moments 18 months post-op when compared to healthy controls (Queen et al., 2013a).

Further assessment of limb symmetry during stair climbing is necessary to identify the subtle, but clinically important, biomechanical strategies adopted in post-operative THA patients that highlight areas of focus for early post-operative physical therapy in order to optimize surgical outcomes. While previous research on stair ascent and descent early after THA has focused on kinematic comparisons between approaches or treatment groups, these have been limited in statistical power. Little is known regarding the functional adaptations adopted by THA patients immediately following surgery compared to pre-operative mechanics. Therefore, the purpose of this study was to evaluate limb asymmetry during stair ascent and descent in patients across time from prior to surgery through 6 weeks and 1 year post-THA. It was hypothesized that stair climbing mechanics would improve on the surgical side during the first year of recovery following THA. In addition, it was hypothesized that significant side-to-side asymmetry would exist pre-operatively and that these asymmetries would persist up to 1 year following THA.

2. Methods

2.1. Subjects

An a-priori power analysis was completed utilizing data that was collected in the laboratory environment to provide estimates of normative values for stair climbing as well as expected bilateral differences in THA patients (Queen et al., 2013a, 2014). To complete the analysis an $\alpha = 0.05$, $\beta = 0.20$, and clinically relevant difference of 15% were utilized as standard coefficients for all of the variables of interest in the study. The results of the power analysis suggested that between 10 and 35 subjects were necessary to observe statistically significant findings. As a result of this analysis, a total of 42 subjects (22 men, 20 women) were recruited and fully completed the study. The mean age, height, and weight were 55.8 (SD 8.9 years), 1.73 (SD 0.10 m), and 80.4 (SD 19.4 kg), respectively. To participate, all subjects had to be older than 35 years and had to be scheduled to have a primary THA within four weeks of pre-operative testing. Patients with lower extremity surgery in the past five years, serious neurological disorders, and current pain in any other lower extremity joint were excluded from consideration for the study. 75 total subjects were initially enrolled for the study, however 21 were excluded due to missing a time point at either 6 weeks or 1 year following surgery and 12 were excluded due to an inability to complete the stair climbing task in accordance with study design (only one foot on a step at a time) at one of the time points. All patients reviewed and signed the medical center's institutional review board-approved informed consent form prior to participation.

2.2. Data collection and stair negotiation analysis

Data collection consisted of preliminary questionnaires, anthropometric data, and stair climbing analysis. Harris hip scores (HHS) were obtained, as well as the 12-item Short-Form Health Survey (SF-12), UCLA Score, and Duke Activity Scale for Arthroplasty Patients (ASAP). Anthropometric measures recorded include bilateral foot length and width, height, weight, age, and time from surgical intervention. Reflective markers were placed by a single tester, using the methodology that has been previously reported, on 39 prominent anatomical landmarks with one offset marker placed posteriorly on the right scapula (Queen et al., 2011a, 2011b). Patients were then instructed to stand with a neutral posture within view of the motion capture system in order to record a static standing trial. Markers were recorded using an 8 camera real-time motion capture system (Motion Analysis Inc., Santa Rosa, CA, USA) sampling at 120 Hz. Once static data was obtained, 10 of the markers were removed for the remainder of study (Queen et al., 2011a). Dynamic assessment consisted of 7 stair ascending and 7 descending trials using a step-over-step technique at the patients' desired, self-selected speed. Stair dimensions were measured to be 29 cm in width and 17.5 cm in tread height. Ground reaction forces were measured using 4 force plates (AMTI, Watertown, MA, USA) embedded in the floor at 1200 Hz. The set of four stairs were mounted on 2 of the plates in order to obtain ground reaction force data during both stair ascending and descending (Fig. 1). For stair climbing trials, subjects were asked to walk barefoot to avoid changes in ground reaction forces due to footwear. The 3D coordinate data were filtered using a low-pass Butterworth filter at 7 Hz and the ground reaction force data were filtered using a low-pass Butterworth filter at 100 Hz using Visual 3D software (C-Motion, Bethesda, Maryland, USA). The global optimization method available in Visual 3D was used to minimize any soft tissue artifact. Joint angles were calculated as Cardan angles between adjacent local segments with an order of rotation of flexion–extension, abduction–adduction, and internal rotation–external rotation. Joint moments were calculated through an inverse dynamic approach and transferred into the local segment coordinate system and were expressed as internal moments.

The lower extremity variables of interest to determine significant differences between the surgical and non-surgical limbs or between the preoperative and post-operative time points included: bilateral peak hip flexion and extension, hip abduction and adduction kinematics and kinetics and peak vertical ground reaction forces (vGRFs). Variables were normalized from initial contact to toe off on both the surgical and non-surgical sides as a percentage of the stance phase, vGRF data was normalized to the body weight, while moments were normalized to height and weight for each subject. The timing of the analysis took place from initial contact of one foot on the second step to toe off of the contralateral foot on the third step. This procedure was repeated at 6 weeks and one year following surgery to examine the changes in mechanics across time. The choice of these two time points was based on the times that these patients returned for clinical assessments with the treating surgeon.