The Journal of Arthroplasty 31 (2016) 278–283

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Influence of Total Knee Arthroplasty on Gait Mechanics of the Replaced and Non-Replaced Limb During Stair Negotiation

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ARTICLE INFO

Article history:
Received 20 March 2015
Accepted 26 June 2015

Keywords:
total knee replacement
TKA
biomechanics
contralateral
stair ascent

ABSTRACT

This study compared biomechanics during stair ascent in replaced and non-replaced limbs of total knee arthroplasty (TKA) patients with control limbs of healthy participants. Thirteen TKA patients and fifteen controls performed stair ascent. Replaced and non-replaced knees of TKA patients were less flexed at contact compared to controls. The loading response peak knee extension moment was greater in control and non-replaced knees compared with replaced. The push-off peak knee abduction moment was elevated in replaced limbs compared to controls. Loading and push-off peak hip abduction moments were greater in replaced limbs compared to controls. The push-off peak hip abduction moment was greater in non-replaced limbs compared to controls. Future rehabilitation protocols should consider the replaced knee and also the non-replaced knee and surrounding joints.

The main goal of a total knee arthroplasty (TKA) is to reduce pain and has shown to be successful for a majority of patients [1–3]. However, some patients still reported long-term pain following TKA [4]. In addition to reduction of pain, TKA should lead to improvements in quality of life and abilities to perform basic activities of daily living. Noble et al [5] reported that a majority of patients are satisfied with their knee arthroplasties though some patients have reported a decreased ability to perform simple activities of daily living and basic functional tests (e.g. timed up-and-go and six-minute walk) [6,7].

Despite their previous surgical outcomes, nearly 50% of patients with initial primary TKA will need an additional knee joint arthroplasty in the non-replaced limb potentially due to compensatory loading of the non-replaced limb [8]. Most TKA surgeries are carried out on patients as a result of moderate to severe knee OA, and the most common location of knee OA is the medial knee joint compartment. Peak knee internal abduction moment is commonly considered as a surrogate measure of medial knee joint loading, and plays a role in the progression and severity of medial compartment knee OA [9–12]. It is important to examine the knee abduction moment and related frontal-plane variables at the hip of both the replaced and non-replaced limbs following TKA during common activities of daily living.

Stair ascent is more demanding than level walking on lower extremity muscles and joints of both limbs and is a frequent activity of daily living for both younger and older adults [13–15]. The ability to climb stairs is also included in the most common knee scoring tools used to assess physical functions following a TKA [16–18]. In addition, the frontal plane mechanics play a key role in both propulsion and mediolateral stability during stair ascent, especially at the knee and hip joints [13,19].

A better understanding of how TKA influences gait mechanics of replaced and non-replaced limbs during stair ascent is necessary to advance rehabilitation protocols. Some studies have analyzed non-replaced knee biomechanics during stair ascent following TKA [20,21]. One reported similar sagittal hip, knee, and ankle angles between the replaced and non-replaced limbs during the first or second steps of stair ascent [21]. Joglekar et al [20] found no differences between maximum knee flexion angles for the non-replaced limbs of two different arthroplasty designs on the first step of stair ascent. Only one study examined knee joint kinetics between the replaced and non-replaced knees and found that the maximum internal knee extension moment and maximum knee power were similar in the non-operated knee of two different arthroplasty designs [20]. However, no comparisons were made between the operated and healthy control knees. The results from Kelman et al [21] seem to suggest that the non-replaced knee is comparable to the replaced for sagittal plane knee kinematics during the first step of stair ascent, but they did not include a comparison with a control limb. Currently, there is a lack of comprehensive

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to http://dx.doi.org/10.1016/j.arth.2015.06.052.

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http://dx.doi.org/10.1016/j.arth.2015.06.052
0883-5403/

information on differences of sagittal plane knee kinematics and kinetics between replaced and non-replaced knees during stair ascent, no data of TKA knees compared to control knees, and other surrounding joints (i.e., ankle and hip). There is currently no information regarding frontal plane knee joint (internal) abduction moment and related variables of non-replaced knees during stair ascent, which have been shown to be linked to the severity and progression of knee OA [10–12].

The purpose of this study was to compare lower-limb biomechanics of the replaced joint to non-replaced limb of TKA patients and a healthy control limb during stair ascent. We hypothesized that the sagittal plane knee variables would be similar in the replaced limb when compared to the non-replaced limb, but that both would be different compared to a control limb. We further hypothesized that frontal plane knee variables would be different in the replaced limb compared to non-replaced limb and a control limb, but similar between the replaced limb and a control limb. For the ankle and hip, we anticipated that sagittal plane variables would be similar for all limbs, but that frontal plane variables would be different between the non-replaced limb and the control limb.

Methods

Participants

Participants in this study included patients with TKA as well as controls with healthy limbs. All participants signed an informed consent document approved by the institutional review board. Thirteen TKA patients (Table 1) were referred to the primary investigators via phone interviews carried out by an orthopedic clinic. Potential patients from follow-up visits of an orthopedic clinic were contacted to participate. Roughly twenty-five TKA patients were contacted via phone and thirteen patients consented to participate in the study. TKA procedures were all performed by the same surgeon with posterior stabilized designs. TKA patients were between 6 and 72 months post-surgery with no additional lower extremity joint arthroplasties. All patients were prescribed home-based pre-rehabilitation quadriceps' strengthening exercises prior to TKA surgery. A standard rehabilitation protocol was prescribed following surgery, which included physical therapy programs that emphasize on initially regaining strength, ROM and ambulation, and then progressing to maximize ROM, strength and activities of daily living. Additionally, fifteen age, gender, and BMI matched controls (Table 1) were recruited through flyers, email recruitment and word of mouth. Exclusion criteria for both TKA and healthy control participants consisted of the following: BMI greater than 35, systemic inflammatory arthritis, and neurologic diseases. All participants had to be able to negotiate (i.e., ascend and descend) stairs without the use of a handrail.

Table 1
Demographic Data for Participants: Mean ± STD.

	Total Knee Arthroplasty		Controls
Subjects	13		15
Age (years)	65.6 ± 6.7		62.3 ± 7.5
Height (meters)	1.79 ± 0.1		1.79 ± 0.1
Mass (kg)	90.2 ± 9.9		87.2 ± 14
BMI (kg/m^2)	28.3 ± 3.4		27.1 ± 3.2
Time From Surgery (months)	24.5 ± 14		N/A
TUG (seconds)	7.1 ± 1.2		6.8 ± 1.2
Functional Ascent Time (seconds)	6.44 ± 0.94		5.65 ± 0.95[a]
Functional Descent Time (seconds)	6.06 ± 0.93		5.18 ± 1.1[a]
Testing Ascent Velocity (m/s)	0.67 ± 0.12		0.77 ± 0.18
Passive Knee ROM	Rep: 111.1 ± 13.9[b,c]	NR: 119.5 ± 16.7[c]	131.9 ± 10

[a] Denotes significant difference between groups.
[b] Denotes significant difference from the non-replaced limb (NR).
[c] Denotes significant difference from control limb.

An *a priori* power analysis using existing stair ascent data showed that a minimum of 9 participants were needed for each group to obtain an alpha of 0.05 and a beta of 0.80. The peak knee extension moment, an important variable in TKA patient populations, was utilized to calculate power [22].

Instrumentation

During data collections, a nine-camera motion analysis system (240 Hz, Vicon Motion Analysis Inc., Oxford, UK) was used to obtain three-dimensional (3D) kinematics during testing. Participants wore a standardized laboratory running shoe (Noveto, Adidas, USA) during the experiment. Reflective anatomical markers were placed on toes (i.e., most anterior aspect of the shoes), 1st and 5th metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, greater trochanters, iliac crests, and acromion processes. A cluster of four reflective markers on a semi-rigid thermoplastic shell was used as tracking markers and placed on lateral shank, lateral thigh, lateral pelvis and posterior-inferior trunk. Four individual tracking markers were placed on medial, posterior, lateral and dorsal-lateral heel counter of the shoe. An instrumented 3-step staircase (FP-stairs, American Mechanical Technology Inc., Watertown, MA, USA; 1st, 2nd and 3rd steps) with two additional customized wooden steps (4th and 5th steps) was used in the study. The instrumented staircase bolted independently to two force platforms (1200 Hz, BP600600 and OR-6-7, American Mechanical Technology Inc., Watertown, MA, USA) was used to measure the ground reaction force (GRF) and the moments of forces during stair gait.

Experimental Procedures

The TKA patients were asked to complete the 2012 Knee Society Survey, a questionnaire aimed to assess recovery following arthroplasty surgery [18]. TKA patients also completed a brief questionnaire detailing their knee arthroplasty type, surgeon, and rehabilitation protocols. All participants completed a physical activity readiness survey (PAR-Q) to assess cardiovascular risks to exercise [23]. Following completion of the surveys and questionnaires, participants performed a 3-minute warm up on the treadmill at a self-selected speed and completed a timed up-and-go test (TUG) and a stair ascent/descent test. After one practice trial, participants performed two testing trials of each test. Average times for the two trials were utilized for analysis. Additionally passive knee range of motion (ROM) was measured on both knees with participants lying supine on a treatment table. After completion of these functional tests, participants were fitted with the reflective markers and asked to perform stair ascent trials at a self-selected speed. Three practice trials were used for familiarization and to determine a speed range (average ± 5%) that was used to control each participant's walking speed during the experimental trials using two pairs of photo cells (63501 IR, Lafayette Instrument Inc., IN, USA) in line with the 1st and 4th steps and two electronic timers (54035A, Lafayette Instrument Inc., IN, USA). TKA patients performed 3–5 stair ascent trials at the self-selected speed in each of two test conditions with replaced and non-replaced limbs on the second step. Healthy controls performed 3–5 trials in one test condition with the right limb on the second step. All participants were required to take a least three steps prior to contact with the first step of the staircase. If the ascent speed of a test trial did not fall into the preferred range, or if the handrail was utilized, it was repeated.

Data Analyses

Visual3D biomechanical analysis software suite (5.0, C-Motion, Inc., Germantown, MD, USA) was used to compute the 3D kinematic and kinetic variables. A right-hand rule with a Cardan rotational sequence (X-y-z) was used for the 3D angular computations and a right hand rule