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

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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

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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 was used to define the conventions of angular kinematic and kinetic variables. Kinematics and GRF data were filtered using a fourth-order Butterworth low-pass filter at cut off frequencies of 8 Hz and 50 Hz respectively. For joint moment calculations, both kinematic and GRF data were both filtered with the same cut-off frequency of 8 Hz [14,24].

A mixed model analysis of variance (ANOVA) was performed to detect differences between the replaced limb, non-replaced limb of TKA patients and the right limb of controls on the second step of stair ascent [25] (SAS 9.3, SAS Institute Inc. Cary, NC, USA). Because two of the conditions were measured on the same participant, it was necessary to consider the effect of correlations on the residuals between the replaced and non-replaced limbs of TKA patients. Statistical models were run on the data, with and without correlation, and correlation was included between the replaced and the non-replaced limbs when the log likelihood test was significant (a reduction of at least 5 points between the two statistical models) [25]. When the ANOVA revealed a significant main effect, post-hoc comparisons with Bonferroni adjustments were utilized to compare means between conditions ($P < 0.05$). In addition, differences of demographics between the two participant groups were determined using the independent sample t-test.

Results

There were no differences of age, height, mass, and BMI between TKA and control participants (Table 1). For the functional tests, controls had greater passive knee ROM than both the replaced ($P = 0.0003$) and non-replaced knees ($P = 0.028$) of TKA patients. The non-replaced knee had greater passive ROM than the replaced knee ($P = 0.0099$). There were no differences for the TUG between groups, though TKA patients took longer to ascend ($P = 0.0358$) and descend ($P = 0.0293$) stairs compared with controls. However, there were no differences in ascent velocity or GRF variables between groups during the stair ascent biomechanics test.

At the knee, the control limb was more flexed at contact compared with both the replaced ($P = 0.033$) and non-replaced ($P = 0.0078$) limbs of TKA patients (Table 2). The loading response peak knee extension moment of the control limb and the non-replaced limb of TKA patients was greater than the replaced limb of TKA patients ($P = 0.0006$ and 0.045 respectively, Fig. 1a). The push-off peak abduction moment was smaller in the control limb compared with the replaced limb of TKA patients ($P = 0.0177$, Fig. 1b).

The hip was more flexed at contact in the replaced limb of TKA patients when compared with the non-replaced ($P = 0.0046$) and control limbs ($P = 0.0169$, Table 3). The ankle had a greater peak eversion angle in the control limb ($P = 0.006$) and the non-replaced limb ($P < 0.0001$) of TKA patients compared with the replaced limb.

Differences of frontal plane joint moments were apparent for the ankle and the hip among the three limbs (Table 3). The loading response peak inversion moment was greater in the control limb compared to both the replaced ($P < 0.0001$) and the non-replaced ($P = 0.0241$) limbs of TKA patients. It was also greater for the non-replaced limb compared with the replaced limb of TKA patients ($P = 0.0374$). The push-off peak inversion moment was greater in the control limb ($P = 0.0004$) and the non-replaced limb ($P = 0.0159$) compared with the replaced limb. The loading response peak hip abduction moment was smaller in the control limb compared with the replaced limb ($P = 0.0203$) while the push-off peak hip abduction moment of the control limb was smaller than both the replaced ($P = 0.0017$) and the non-replaced limbs ($P = 0.0426$).

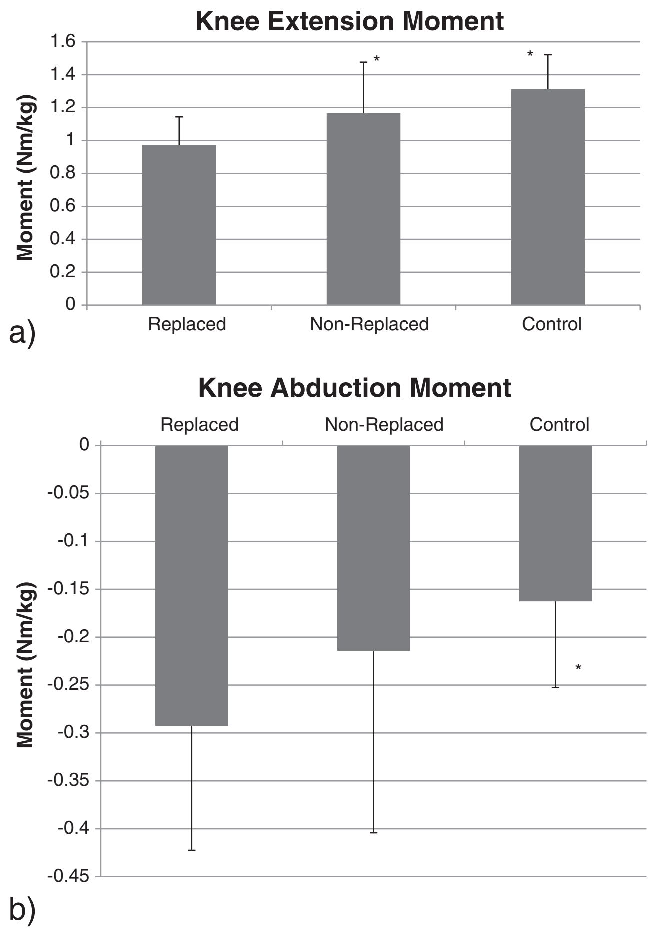

Fig. 1. Knee moments of replaced, non-replaced and control limbs: (a) Loading response peak knee extension moment and (b) push-off peak knee abduction moment. *Denotes significant differences from replaced limb.

Discussion

The purpose of this study was to compare lower-limb biomechanics of the replaced limb to the non-replaced limb of TKA patients and the control limb of healthy participants during stair ascent. We hypothesized that there would be no differences in the sagittal plane variables between the replaced and the non-replaced limbs, but that both would be different compared to the control limb. For the ankle and

Table 2
GRF and Knee Variables During Stair Ascent: Mean ± STD.

Variables	Replaced	Non-Replaced	Control
Loading Response Peak Vertical Ground Reaction Force (BW)	0.99 ± 0.02	1.01 ± 0.02	1.03 ± 0.03
Push-Off Peak Vertical Ground Reaction Force (BW)	1.14 ± 0.02	1.19 ± 0.02	1.12 ± 0.03
Knee Contact Flexion Angle (degrees)	65.9 ± 3.5[b]	65.1 ± 2.7[b]	68.9 ± 4.0
Knee Extension ROM (degrees)	55.1 ± 5.4	56.2 ± 5.4	55.8 ± 5.6
Push-Off Peak Knee Extension Moment (Nm/kg)	0.37 ± 0.27	0.35 ± 0.30	0.49 ± 0.33
Minimum Knee Abduction/Adduction Angle (degrees)	−1.22 ± 3.5	−1.8 ± 5.7	−0.54 ± 4.9
Loading Response Peak Knee Abduction Moment (Nm/kg)	−0.36 ± 0.16	−0.31 ± 0.14	−0.26 ± 0.16

[a] Denotes significant difference from the non-replaced limb.
[b] Denotes significant difference from control limb.

Table 3
Ankle and Hip Variables During Stair Ascent: Mean ± STD.

	Variables	Replaced	Non-Replaced	Control
Ankle	Ankle Contact Angle (degrees)	12.5 ± 5.4	12.9 ± 5.5	17.3 ± 6.9
	Ankle Plantar Flexion ROM (degrees)	31.8 ± 8.6	33.2 ± 8.4	33.7 ± 8.6
	Loading Response Peak Plantar Flexion Moment (Nm/kg)	−0.52 ± 0.12	−0.56 ± 0.18	−0.65 ± 0.25
	Push-Off Peak Plantar Flexion Moment (Nm/kg)	−1.08 ± 0.08	−1.14 ± 0.17	−1.12 ± 0.14
	Peak Eversion Angle (degrees)	−8.17 ± 4.4[a,b]	−12.1 ± 4.4	−12.9 ± 4.4
	Loading Response Peak Inversion Moment (Nm/kg)	0.12 ± 0.11[a,b]	0.22 ± 0.13[b]	0.33 ± 0.11
	Push-Off Peak Inversion Moment (Nm/kg)	0.11 ± 0.13[a,b]	0.24 ± 0.15	0.32 ± 0.12
Hip	Hip Contact Angle (degrees)	61.1 ± 4.3[a,b]	59.0 ± 5.2	55.9 ± 6.2
	Hip Extension ROM (degrees)	49.7 ± 3.7	49.1 ± 3.6	49.3 ± 3.9
	Peak Hip Flexion Moment (Nm/kg)	0.42 ± 0.22	0.38 ± 0.17	0.44 ± 0.16
	Peak Hip Adduction Angle (degrees)	7.22 ± 4.2	8.33 ± 6.2	9.45 ± 4.7
	Loading Response Peak Hip Abduction Moment (Nm/kg)	−0.87 ± 0.22[b]	−0.78 ± 0.24	−0.68 ± 0.19
	Push-Off Peak Hip Abduction Moment (Nm/kg)	−0.72 ± 0.22[b]	−0.62 ± 0.29[b]	−0.46 ± 0.12

[a] Denotes significant difference from non-replaced limb.
[b] Denotes significant difference from control limb.

hip, we expected to see similarities in sagittal plane variables among all limbs.

The replaced limb of TKA patients had reductions in the loading response peak knee extension moment compared to the control limb, and the push-off peak knee extension moment was also smaller but not significantly different. These findings suggest that the deficits of the replaced limb in TKA patients is greater during the first half of the stance phase and is apparent compared to both control and non-replaced knees. Peak plantar flexion moments at the ankle are also important for raising the center of gravity (COG) during stair ascent. There were no differences in either of the peak plantar flexion moments between replaced and control limbs. In addition, the hip push-off peak flexion moment was not different for replaced and control limbs. These results suggest that the TKA patients did not compensate for knee deficits by increasing ankle or hip moments. These findings support our hypothesis and show that in the sagittal plane, deficits are apparent in the replaced limb of TKA patients compared to a control limb.

Similar differences in the extension moment between replaced and control knees have been reported in previous studies [26–29]. Most often these differences are attributed to a quad avoidance gait as a result of weaker quadriceps contraction that is seen in many unstable and injured knees [29,30]. It is well understood that TKA patients experience a reduction in quadriceps muscle strength following surgery, leading to reduction in knee extension moments. Greater emphasis on restoring quadriceps strength via rehabilitation may aid in restoring knee extensor strength and knee extension moments.

The loading response peak knee extension moment was also reduced in the replaced knee compared to the non-replaced knee. No other differences were observed for sagittal plane ankle or hip moments. Only one previous study has compared knee extension moments between the replaced and non-replaced limbs of TKA patients, and they reported no difference between the two limbs [20]. The findings in this study suggest that there were differences between the replaced and non-replaced knees in TKA patients. Both peak knee extension moments were comparable in the non-replaced limb and a control limb. In addition, no differences were observed in any of the ankle or hip sagittal plane moments. The non-replaced limb of TKA patients in this study is more similar to the control limb than the replaced limb. To our knowledge, this study was the first to compare the non-replace knee to a control knee during stair ascent.

The TKA patients in this study ascended the stairs at similar velocities compared to controls and also had similar values of GRF variables. This finding is in contrast to other studies, which have reported reductions in stair ascent velocities in TKA patients compared to controls [26–29]. The similar ascent velocities of the TKA patients and controls in this study suggest a very high level of recovery of TKA patients following surgery. TKA patients ascended the stairs at 0.67 m/s, while the fastest mean ascent velocity reported in previous literature was 0.52 m/s [29]. Thus, the differences in loading response peak knee extension moment for TKA patients in this study cannot be explained by differences in ascent velocities or GRFs alone between the groups. These results further demonstrate the deficits of replaced knees shown in those TKA patients even when they were able to ascend stairs at similar velocities compared to controls. Similar ascent velocities may also help to explain our finding of comparable knee extension moments in the non-replaced limb and control limb, both of which were elevated compared to the replaced limb. TKA patients in this study may have compensated for deficits in the replaced knee by elevating knee extension moments in the non-replaced limb to levels similar to a control limb in order to achieve similar ascent velocities.

During stair ascent, the lower limb must rise to achieve placement on the subsequent step. During the stance phase, the contact angles of the knee and hip provide useful information regarding how this placement is achieved in TKA limbs compared to control limbs. The knee contact angle is often reported in TKA populations and has been shown to be reduced compared with control limbs [26–29]. Similar results were observed in this study, TKA patients had reduced knee flexion at contact in the replaced limb compared to controls. Hip flexion contact angle provides useful information regarding compensatory strategies for TKA patients. In order to compensate for the deficits due to the reduced flexion of the replaced knee, TKA patients flexed the hip more at initial contact in order to be able to elevate their COG during ascent, compared to the control limb. The deficits associated with the stiffer knee contact angle may cause a reduced moment arm for the knee extensors in generating knee extension moment and therefore provides further support for the deficit associated with reduced knee extension moment of the replaced knee during loading response. To our knowledge, this study may be the first that reported greater hip flexion contact angles of TKA patients compared to controls during stair ascent.

No differences were observed for knee contact angle between the replaced and non-replaced limbs. The hip contact flexion angle was, however, increased in the replaced limb compared to the non-replaced. Only Kelman et al [21] compared sagittal plane angles of replaced and non-replaced limbs during stair ascent and reported no differences between the two groups. More studies are needed to depict a more comprehensive picture of these variables between replaced and non-replaced knees. Additionally, the non-replaced knee had a reduced contact angle compared to a control limb, while the hip contact angle was similar between the two groups. This finding suggests that the non-replaced knee is stiffer at contact compared to control knees, and compares better to the replaced limb.

We also anticipated observing differences in frontal plane knee variables between the non-replaced and the control limb, and similarities between the replaced and the control limb. The current study showed no differences for the loading response peak knee abduction moment among the groups. However, TKA participants in this study showed an elevated push-off peak knee abduction moment in only the replaced limb compared with controls. Additionally, there were no differences between groups for peak frontal plane knee angles. Therefore, our hypothesis about frontal variables was only partially supported. Knee abduction moments have been shown to be a good surrogate measure for knee joint loading and play a role in progression and severity of medial compartment knee OA [10–12]. These findings suggest that TKA patients have elevated knee loading following joint arthroplasty. In addition, frontal plane knee variables play an important role in stability and propulsion in stair ascent [13,19], thus TKA patients may be placing increased load on the replaced limb as a means to increase stability in the frontal plane during push-off. Other studies have reported similar results for loading response peak knee abduction moments when comparing TKA patients and controls during stair ascent [27,28]. The elevated push-off peak knee abduction moment in the replaced limb compared to control limbs was in contrast to previous literature which showed that the replaced limb of TKA patients had similar or reduced internal knee abduction moments compared to control limbs [27,28,31]. However, TKA patients in this study were able to ascend the stairs at similar velocities as controls. Thus, reductions in the internal abduction knee moment values may have been a result of a reduced stair ascent velocity in previous studies. This study is the first that has shown similar stair walking velocities between TKA patients and controls, and also found an elevated push-off peak knee abduction moment of the non-replaced knee of TKA patients, suggesting that the TKA patients in this study showed some compensation in the replaced knee compared to control knees.

Few studies have analyzed frontal plane hip joint mechanics in patients following TKA. In support of our hypothesis, both peak hip abduction moments in this study were higher in the replaced limb of TKA patients compared to the non-replaced and control limbs. The push-off peak hip abduction moment was also higher in the non-replaced limb compared to the control limb. Frontal plane variables at the hip play a key role in stability and propulsion during stair ascent [13,19]. TKA patients may need to rely on the hip joint even more than control patients during stair ascent as a means to compensate for deficits at the knee joint. The reduction in the loading response peak knee extension moment and frontal plane ankle moments further suggest the importance of greater hip abduction moments to aid in stair ascent. Nadeau et al [13] suggested that during stair ascent lateral elevation of the hip is necessary to avoid the intermediate step in stair walking and that future studies should investigate frontal plane hip variables in both healthy and pathological populations. Only one other study has reported these variables in TKA patients, and they found no differences in frontal plane hip moments [32]. Results from this study suggest that TKA patients used the hip joint more for stability and propulsion than their healthy control counterparts. This result may also be a compensatory mechanism for instability and weakness in the distal knee joint. This potential compensation is of concern from a clinical standpoint as it may lead to further problems at the hip joint, including overload and fatigue which may lead to trochanteric and thigh pain from the lateral hip to the lateral aspect of the knee.

Clinical functional tests can be very beneficial in understanding recovery following orthopedic procedures. When paired with detailed biomechanical assessments, these tests can provide clinicians with the ability to relate them to more detailed and specific biomechanical deficits. In the current study, controls had the greatest passive knee ROM, followed by the non-replaced limb of TKA patients, with the replaced limb of TKA patients having the least ROM. There were no differences in TUG test times between TKA patients and controls. However, during the stair ascent and descent tests, the TKA patients took more time to ascend and descend the 11-step staircase compared to controls during the functional stair test. This finding shows the benefit of more demanding clinical tests in order to bring to light differences that may otherwise be masked between groups. Previous research is lacking when it comes to pairing clinical tests with biomechanical gait assessments, and it has been suggested that studies employing both types of testing could expand the current understanding of recovery following TKA [33]. One previous study included clinical tests with biomechanical assessments, but did not include any clinical tests on stairs [7]. More demanding clinical tests can provide general deficits, though detailed biomechanical gait analysis can further pinpoint specific deficits.

The sample size of TKA patients in this study is relatively low, but was similar and even greater than several previous studies [20,26–28]. Additionally the wide range of time from surgery (6 to 72 months) may have led to patients with varying levels of recovery, although all TKA patients had to be recovered enough to be able to ascend stairs without usage of a handrail. All TKA patients in this study had posterior stabilized designed arthroplasty surgeries that were performed by the same surgeon, which may be considered as a strength of this study.

Conclusions

In conclusion, it is apparent that even in TKA patients who have good recovery, there are biomechanical deficits during stair ascent. These deficits include reduced knee extension moment in the replaced limb compared to non-replaced and control limbs, and reduced knee flexion at contact in both the replaced and non-replaced limbs compared to a control limb. Additionally, the replaced limb had increased frontal plane knee and hip moments compared to a control limb and the non-replaced limb saw similar differences compared to the control limb. These differences were observed at similar ascent velocities between groups, suggesting that there are still apparent biomechanical deficits in the replaced limb and compensation in the non-replaced limb. More studies analyzing these movements are needed in order to better understand the causes of these deficits and how rehabilitation strategies can be targeted to restore more normal stair ascent patterns following joint arthroplasty surgery.

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