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Joint mechanical asymmetries during low- and high-demand mobility tasks: Comparison between total knee arthroplasty and healthy-matched peers

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ABSTRACT

Chronic inter-limb joint mechanical asymmetry has been reported following total knee arthroplasty (TKA) during low-demand mobility tasks such as level walking. However, no study has compared the inter-limb asymmetry during a high-demand mobility task such as decline walking. The objective of this cross-sectional study was to compare inter-limb asymmetry differences during both level and decline walking tasks at six months following TKA compared to asymmetry present in an age, gender, body mass index and activity level matched healthy cohort. Kinetic and kinematic gait analysis was conducted on 42 patients with TKA and 15 healthy-matched peers. Our inter-limb asymmetry results demonstrated significantly ($p < 0.05$) greater combined limb support moment (M_S) (mean differences [MD] = 0.17; 95% CI = 0.07, 0.22), knee extensor moment (M_K) (MD = 0.05; 95% CI = 0.02, 0.09) and vertical ground reaction force (vGRF) (MD = 0.03; 95% CI = 0.01, 0.08) differences during decline walking compared to level walking in patients with TKA. Greater M_S (MD = 0.24; 95% CI = 0.13, 0.35), M_K (MD = 0.08; 95% CI = 0.03, 0.18), vGRF (MD = 0.04; 95% CI = 0.01, 0.08) and knee joint angle (MD = 2.4; 95% CI = 0.37, 3.80) differences were present in patients with TKA compared to healthy-matched peers during decline walking. Greater M_S (MD = 0.13; 95% CI = 0.05, 0.20) and plantarflexor moment (MD = 0.06; 95% CI = 0.04, 0.16) differences were present in patients with TKA compared to healthy-matched peers during level walking. Post-TKA inter-limb asymmetry during level walking worsens as the physical demands of the task are increased. Thus, even patients with good self-reported outcomes after TKA exhibit substantial deficits in their mobility reserves that could limit their independence and community mobility as they age.

1. Introduction

Total knee arthroplasty (TKA) is one of the most common elective orthopaedic procedures performed in the United States. Projections estimate the number of procedures is expected to grow 673%–3.48 million by 2030 [1]. This surge can be explained in part by the growing obesity epidemic, however rates of procedures in relatively younger patients that want to preserve an active lifestyle, has dramatically increased [2].

Although approximately 70–90% of patients report improved quality of life following surgery [3], a significant percentage of patients report residual knee pain, weakness, functional deficits and dissatisfaction [4,5]. Inter-limb asymmetry comparisons during gait further indicate continual presence of abnormal joint mechanics following TKA [6], despite self-reported outcomes indicating high perceived functional ability. Walking gait analysis reveals large disparities between patients with TKA and healthy peers [6].

Abnormal joint mechanics that persist after TKA include reduced surgical limb loading, less knee flexion excursion and lower knee moments relative to healthy peers during level walking [6]. Level walking is the most predominant human mobility task and one of the most essential activities to restore following surgery [7]. While many patients report improved walking ability, increased loading of the contralateral limb is associated with accelerated degenerative changes [8]. As a result, 35% of patients will undergo a second surgery to replace the contralateral knee (92%) or hip (8%) following the primary TKA procedure [8].

Although level walking is most frequently studied [9], there are

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relatively low mechanical demands placed on the knee during normal gait [10]. Investigating tasks that require low demand at the knee may not fully identify limitations in physical performance following surgery. During decline walking, a larger knee demand is required alongside a well-coordinated muscular response within the lower limbs [11,12]. Implementation of these control strategies can be very challenging for individuals with muscle or joint impairments as commonly observed after TKA [11,13]. Evaluating inter-limb asymmetry between tasks is clinically relevant as increased demand on the nonsurgical limb is a rate limiting factor on poorer physical performance [14,15].

The purpose of the study was to (1) compare the inter-limb asymmetry between low- (level) and high- (decline) demand walking tasks in patients with TKA at six months following surgery and healthy-matched peers (HMP) and (2) compare inter-limb asymmetry between TKA and HMP participants during the two walking tasks. We hypothesized that significantly greater inter-limb asymmetry would be present during decline walking when compared to level walking, and that significantly greater inter-limb asymmetry would be present during both tasks in patients with TKA relative to HMP.

2. Methods

2.1. Participants

A cross-sectional study was conducted with 42 participants who underwent primary unilateral TKA surgery between January 2015 and September 2016 and 15 healthy peers that were matched *a priori* on age, gender, body mass index (BMI) and activity level (Table 1). All participants in this study met the following inclusion criteria: 45–75 years of age; BMI less than 40; University of California, Los Angeles (UCLA) activity scale of greater than three; nonsurgical knee pain less than or equal to 4 out of 10 on a visual analog scale for walking or stair climbing; no comorbidities that would affect balance or walking ability; no prior knee joint replacement procedure and no plans of undergoing a TKA on the contralateral limb within 12 months after the initial procedure. The HMP had no confirmed diagnosis of knee arthritis, history of joint replacement or other lower-limb joint surgery that would interfere with their walking ability. All TKA participants were evaluated at six months (mean, 6.4 ± 0.5 mo.) from surgery as physical function typically stabilizes at this time [14,16,17]. All surgical procedures were performed by one of three orthopaedic surgeons and participants were recruited from the University of Utah Orthopaedic Center (Salt Lake City, UT, USA). Healthy-matched peers were recruited from the University of Utah, Center of Aging registry (Salt Lake City, UT, USA). The study was approved by the University of Utah Institutional Review Board and all subjects consented to participation prior to enrollment.

Table 1
Descriptive and self-reported outcome scores.

Characteristics	TKA (n = 42)	HMP (n = 15)	P-Value
Age, y	62.3 (8.1)	65.3 (5.6)	0.19
Sex, n (% male)	22 (52.4)	9 (60.0)	0.61
Mass, kg	84.5 (17.0)	81.2 (15.4)	0.51
Height, m	1.73 (0.1)	1.75 (0.1)	0.47
BMI (kg/m^2)	26.2 (8.6)	26.4 (3.5)	0.93
PF-CAT T-Score	47.6 (5.4)	52.8 (5.5)	0.00
PI-CAT T-Score	50.6 (8.5)	46.1 (8.0)	0.08
DEP-CAT T-Score	47.2 (7.1)	48.7 (5.3)	0.48
UCLA Activity Scale, mean (range)	6.2 (5–7)	7.2 (6–8)	0.06
RPE Scale (level)	1.7 (0.7)	1.6 (0.7)	0.67
RPE Scale (decline)	3.5 (0.9)	2.6 (0.9)	0.01
NKPRS Score (level)	0.6 (1.1)	0.0 (0.0)	0.03
NKPRS Score (decline)	1.2 (1.6)	0.0 (0.0)	0.00

Note: Values represented as mean (SD) unless stated otherwise. TKA, total knee arthroplasty; HMP, healthy-matched peers; BMI, body mass index; PF-CAT, physical function computerized adaptive testing; PI-CAT, pain interference computerized adaptive testing; DEP-CAT, depression computerized adaptive testing; UCLA, University of California Los Angeles; RPE, rating of perceived exertion; NKPRS, numeric knee pain rating scale.

2.2. Clinical metrics

All participants completed a battery of questionnaires to quantify perceived functional status. Participants completed the Patient Reported Outcomes Measurement Information System (PROMIS) computerized adaptive test (CAT) domains of physical function (PF-CAT), pain interference (PI-CAT) and depression (DEP-CAT) (Table 1) [18–20]. These instruments have been validated as a source for self-reported outcome administration in orthopaedic specialties [21]. Physical activity level was measured by the UCLA scale prior to testing. Rating of perceived exertion (RPE) and numeric knee pain rating scale (NKPRS) were also recorded following completion of each session.

2.3. Procedures

Gait analysis was performed in the Motion Capture Core Facility at the University of Utah, using a dual-belt instrumented treadmill (Bertec Corp; Columbus, OH, USA). Participants were fitted with a safety harness, donned with compressive clothing and instrumented with 50 retro-reflective markers defining eight body segments based on a modified Plug-In-Gait marker set (Vicon, Oxford Metrics Ltd., London, UK) (Fig. 1).

First, a stationary trial was captured with each participant in a neutral standing position to align with the global laboratory coordinate system. Each participant's local joint coordinates were aligned to their standing position to control for inter-subject variation in anatomical alignment during the static trial. Second, all participants were provided a warm-up period, approximately three to five minutes, to become accustomed to walking on the treadmill. Third, once participants verbally confirmed they felt comfortable with the task, they were instructed to "walk as normal as possible" as if ambulating on a flat surface and as if walking downhill. Treadmill velocities were constrained to 1.0 m/s (level) and 0.8 m/s (decline), respectively [6,11]. For data collection consistency, decline walking trials were collected first and level walking trials second. Trials in which participants lost their balance, used their upper limbs for support on the surrounding bars or stepped onto the adjacent force platform were excluded. A trial was considered acceptable when all markers were visible and the participant's foot landed successfully on the force platforms without any disturbance to their gait. For each outcome variable, 10 successful steps were averaged and used for statistical analysis.

2.4. Data processing

Marker trajectory was recorded using a 10-camera motion analysis system (Vicon, Oxford Metrics Ltd., London, UK) sampling at 200 Hz and analog data was collected on a treadmill instrumented with two force platforms sampling at 1000 Hz. Post processing and extraction of joint mechanical variables were accomplished using Visual3D software (C-motion, Inc., Germantown, MD, USA). Marker trajectory and analog data were low-pass filtered at 6 Hz and 25 Hz respectively using a fourth-order Butterworth digital filter based on residual analysis [10]. Each body segment was embedded with an orthogonal coordinate system with the positive x-axis directed to the right, the positive y-axis anteriorly and the positive z-axis superiorly. To account for anatomical variations between participants, all data were normalized to body mass. Three-dimensional angular kinematics were calculated using a Visual3D model with a Cardan sequence (x, y, z), which defined the orientation coordinate system of the distal segment with respect to the proximal segment. A combined limb support moment (M_S) of the lower limbs were computed as the absolute summation of the hip (M_H), knee (M_K) and ankle (M_A) net joint moments [10]. We operationally defined the M_S as an absolute summation of all sagittal plane moments