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Lower Limb Biomechanics in Individuals With Knee Osteoarthritis Before and After Total Knee Arthroplasty Surgery

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ABSTRACT

We investigated the biomechanical changes that occur in the lower limb following total knee arthroplasty (TKA). Lower limb joint kinematics and kinetics were evaluated in 32 patients before and 12 months following TKA and 28 age-matched controls. Analysis of variance with Bonferroni-adjusted post-hoc tests showed no significant changes in knee joint kinematics and kinetics following TKA despite significant improvements in pain and function. Significant increases in peak ankle plantarflexion and dorsiflexion moments and ankle power generation were observed which may be a compensatory response to impaired knee function to allow sufficient power generation for propulsion. Differences in knee gait parameters may arise as a result of the presence of osteoarthritis and mechanical changes associated with TKA as well as retention of the pre-surgery gait pattern.

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Total knee arthroplasty (TKA) is a common procedure for the management of knee osteoarthritis (OA) [1,2]. However, recent studies have indicated that despite experiencing significant reductions in pain, many TKA patients do not achieve normal joint function when walking following surgery [3–8]. In most cases, gait remains slower than asymptomatic controls, with the treated knee exhibiting abnormal biomechanics [6,8]. Moreover, abnormal pre-surgery gait has been reported to affect the post-surgery gait pattern, with many patients retaining their pre-surgery knee joint loading pattern [9,10].

While several gait changes specifically associated with knee function have been reported, only a few studies have attempted to capture how gait changes at joints proximal and distal to the knee due to abnormal knee function following TKA [5,11]. Oullet and Moffat [5] reported increased hip flexion and reduced ankle plantarflexion in 16 patients following TKA, which was suggested to be an adaptive strategy to compensate for the weak knee extensor muscles. Similarly, Mandeville et al [11] reported an increase in the hip moment contribution to total lower limb support in 21 patients following TKA compared to controls, suggesting that the hip may compensate for the diminished knee extensor contribution during walking [11]. These studies, however, had relatively small sample sizes and relatively short duration of follow-up (2 and 6 months, respectively). Moreover, assessment of other important gait parameters that provide information about muscle action and function, such as joint power, has yet to be thoroughly investigated following TKA. A more comprehensive biomechanical investigation during locomotion is needed to better understand the compensatory role of other joints of the lower limb following TKA.

Given the importance of maintaining adequate mobility in older people following TKA, identifying specific gait impairments following surgery may also help inform rehabilitation strategies. The purpose of this study, therefore, was to identify biomechanical changes in the lower limb in the sagittal plane following TKA. We hypothesised that altered gait function at the hip and ankle joints would be present following TKA to compensate for the impaired knee function.

Materials and Methods

Two groups of participants were recruited: a surgical group and an age-matched control group. This project was part of a larger study that investigated gait (swing phase mechanics particularly minimum foot clearance), balance and falls risk in people before and after knee arthroplasty. A power calculation to determine the sample size, therefore, was based on minimum foot clearance parameters. Data from a previous study [12] which investigated the toe clearance of elderly fallers and non-fallers were used to determine the number of participants required. A sample size calculation indicated that for 80%

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power and a *P* value of 0.05 at least 25 participants were required. To mitigate the possible effect of subject drop out for the surgical group, a total of 32 participants were considered to be sufficient.

The surgical group included 32 patients who were scheduled for TKA surgery and were tested prior to the surgery and at 12 months following their surgery. To be included in the study, participants needed to be able to walk at least 45 m independently, and potential participants were excluded if they had uncontrolled systemic disease or a pre-existing neurological or other orthopaedic condition affecting their ability to walk. Participants were recruited from the La Trobe University Medical Centre and the Warringal Private Medical Centre. Surgeries for the participants from the surgical group were performed by three experienced surgeons using the following prostheses: Scorpio NRG (Stryker, USA), Active TKR (ASDM, Australia), Triathlon (Stryker, USA) and Genesis II (Smith and Nephew, Hamburg/Schenefeld, Germany). The control group included 28 asymptomatic participants with no clinical diagnosis of OA, rheumatoid arthritis or history of knee trauma or pain. Participants from the control group were recruited from retirement villages in northern Melbourne and through newspaper advertisements. Ethics approval was obtained from the Faculty of Health Sciences Human Ethics Committee, La Trobe University. Participants were informed about the nature of the study and signed a consent form prior to participation.

Gait analysis was performed using a 3D motion analysis system (VICON, Oxford Metrics) with ten (MX3 and MX40) cameras operating at a sampling rate of 100 Hz. Two 1000-Hz force plates (Kistler, type 9865B, Winterthur, Switzerland and AMTI, OR6, USA) were used to capture ground reaction forces and identify gait cycle events. To assess motion, moments and powers of the hip, knee and ankle in the sagittal plane, retro-reflective markers were attached to anatomical landmarks in accordance with the Oxford Foot Model (OFM) marker set and Plug In Gait (PIG) as described by Stebbins et al [13]. Prior to evaluation, a relaxed standing calibration trial was captured. Several markers, used only in the static trials, were removed prior to the dynamic trials as described in Stebbins et al [13]. The locations of the joint centres were calculated from PIG and the OFM.

Participants attended the gait laboratory prior to undergoing TKA and at 12 months following the surgery, and function of the operated limb was assessed. No patients were lost to follow up. The control group was tested once and the instrumented leg was selected to match the proportion of left and right limbs evaluated in the surgical group. Participants were asked to walk at a comfortable walking pace along a 12 m walkway and five trials where the participant's foot landed on the centre of the force plate without any interference to their gait were collected for each leg. For each trial, gait events were detected using vertical ground reaction force data to determine initial foot contact and toe off. Multiple trials were practiced until participants were comfortable and walking with consistent velocity. Peak values of interest of each trial were extracted separately and the average of the five trials was used in the analysis. Gait variables were normalised to the gait cycle and timing of peak angular variables was then expressed as a percentage of the gait cycle. Joint moments are reported as external joint moments and were normalised to body weight and height (%BW*Ht). Joint powers were normalised to body weight and are reported as Watt/kg (W/kg).

Knee Pain, Function and Stiffness

Physical function, pain and stiffness were assessed using the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) [14]. This index, using 10 mm visual analogue scale, assesses the severity of the knee pain during 5 daily activities (range 0–500), stiffness (range 0–200), and the severity of impairment of lower-extremity function during 17 activities (0–1700). Zero score represents no pain or difficulty with physical function and higher scores represent worse functional health. All three subcategories are summed to give a global WOMAC score (range 0–2400). Pain during walking was also recorded on a 100 mm visual analog scale (VAS), where 0 represents no pain and 10 represents worst possible pain.

Data Analysis

Kinematics and kinetics of the hip, knee and ankle in the sagittal plane were analysed. More specifically, the following gait parameters were extracted: angle at initial contact and range of motion of all three joints, peak hip extension during stance, peak knee extension and knee flexion during stance, peak knee flexion during swing, peak ankle plantarflexion during early stance and late stance and peak dorsiflexion during push off. Joint moments in the sagittal plane included: peak hip flexion and extension moments, peak knee flexion and extension moments and peak dorsiflexion and plantarflexion moments. Joint powers included: hip power generation (H1), hip power absorption (H2), hip power generation (H3), knee peak power absorption at loading phase (K1), knee peak power generation (K2), peak knee power absorption late stance (K3), peak ankle power generation early stance (A1), peak ankle power absorption late stance (A2) and peak ankle power generation at push off (A3) (see Fig. 3). Spatio-temporal parameters of gait including gait velocity, stride length and cadence were also extracted.

Comparisons were made for all selected gait variables between the groups at baseline (control versus surgical group pre-operatively) and at 12 months (control versus surgical group post-operatively) and within the surgical group (pre-operatively versus post-operatively) using a mixed-design ANOVA, with one fixed factor (surgical or control group) and one repeated measure (pre-surgery and post-surgery gait pattern). Analysis of variance with Bonferroni-adjusted post-hoc tests was used to assess the differences for the gait variables with gait velocity entered as a covariate. Paired t-tests were used to compare differences in pain, stiffness and function (WOMAC scores) as well as the pain level during walking. T-tests were also used to explore the differences in the spatiotemporal parameters (gait velocity, stride length, cadence) between the groups. Data with skewed distributions were appropriately transformed prior to inferential parametric analysis. All statistical tests were conducted using SPSS version 17 for Windows (SPSS Inc, Chicago, IL).

Results

Participant characteristics are summarised in Table 1. No differences were found between the groups for age or height (Table 1), however the knee OA group had a significantly larger mean BMI (30.4 (5.1) vs 25.3 (4.5) kg/m^2; $P<0.001$). The surgical group walked significantly slower (1.13 ± 0.19 m/s versus 1.37 ± 0.17 m/s; $P<0.001$) with shorter stride length (1.19 ± 0.15 m versus $1.36 \pm$

Table 1
Participant Characteristics.

	Surgical Group (n = 32)	Control Group (n = 28)	
Parameters	Mean (SD)	Mean (SD)	*P* Value
Age (yr)	68.3 (6.4)	65.1 (11.2)	0.186
Gender % (n)	45% (14) F 54% (18) M	54% (15) F 46% (13) M	0.456
Height (cm)	167.7 (8.7)	168.8 (10.5)	0.664
Body mass (kg)	85.4 (12.7)	72.6 (16.8)	0.001*
Body mass index (kg/height^2)	30.4 (5.1)	25.3 (4.5)	<0.001*

Values are reported as mean ± SD unless otherwise noted.
* Significant at $P<0.05$.

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