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Effects of sex and obesity on gait biomechanics before and six months after total knee arthroplasty: A longitudinal cohort study

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ABSTRACT

Background: Gait biomechanics, sex, and obesity can contribute to suboptimal outcomes from primary total knee arthroplasty. The aims of this study were to i) determine if sex and/or obesity influence the amount of change in gait biomechanics from pre-surgery to six months post-surgery and; ii) assess if gait returns to normal in men and women.
Methods: Three-dimensional gait analysis was performed on 43 patients undergoing primary total knee arthroplasty for knee osteoarthritis (pre- and six months post-operative) and 40 asymptomatic controls. Mixed linear regression models were fit to assess which factors influenced change in gait biomechanics within the arthroplasty cohort, and interaction terms were included to assess if biomechanics returned to normal following surgery.
Findings: Male peak knee adduction moment ($p < 0.001$) and impulse ($p < 0.001$) decreased six months following arthroplasty, whilst gait in women remained unchanged after surgery. Obesity did not influence gait changes in men or women. Gait of female arthroplasty participants did not differ from female controls after surgery except for sagittal plane knee range of motion ($p = 0.003$), whilst men differed from controls for peak knee adduction moment ($p = 0.011$), knee range of motion ($p < 0.001$), and peak knee flexion moment ($p < 0.001$).
Interpretation: Sex, but not obesity, influenced changes in gait biomechanics after arthroplasty. Men retained abnormal gait patterns after surgery, whilst women did not. Further research should determine the long-term implications of gait abnormalities seen in men after arthroplasty.

1. Introduction

Knee osteoarthritis (OA) often results in end-stage disease with symptoms that can no longer be managed conservatively, driving the need for total knee arthroplasty (TKA). However, up to 20% of patients report being dissatisfied with their knee replacement [1–3], which is often due to complications associated with a TKA revision [4]. Revisions occur at a rate of 6% after five years [5] and approximately half are due to loosening and implant instability [6]. Accordingly, there is interest in understanding the factors that influence TKA outcomes to improve patient satisfaction and prosthesis longevity. Notably, altered gait biomechanics such as greater sagittal and frontal plane knee joint loading [7,8] have been related to implant migration and are a focus of current research efforts.

Many studies have explored how gait biomechanics in the sagittal plane change following TKA [9–13], but few have focussed on the frontal plane. This is surprising given that restoration of neutral frontal plane knee alignment is a major aim of TKA [14] because of its influence on both frontal plane loading [15,16] and risk of revision surgery [17]. Importantly, the peak pre-operative knee adduction moment (KAM) has been associated with migration of the tibial implant six months following TKA [8]. Our previous systematic review synthesised changes in gait biomechanics after TKA [9], and there was inconsistency in findings. For example, only two studies compared whether KAM 'normalised' (e.g. was similar to healthy individuals) following TKA, with one reporting that it did [18] and the other finding residual differences [19]. Additionally, changes in varus-valgus thrust, a measure of dynamic frontal knee alignment that is associated with both

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knee pain in people with knee OA [20,21] and the peak KAM [22,23], have only been investigated in a single study of 15 patients following TKA. This study found a significant reduction one year following TKA [24]. Further research is needed to understand how frontal plane kinetics and kinematics change following TKA, and whether these parameters are restored to normal.

Whilst a range of factors have been linked to poorer outcomes following TKA [25–27], sex and obesity (body mass index (BMI) > 30 kg/m^2) have been identified as patient-specific risk factors [25,28–34]. Female sex has been associated with increased pain and reduced function six months following TKA [28], and male sex has been related to an 8–23% increased risk of revision TKA and mortality [32]. Obesity is associated with an increased risk of implant loosening [8,35–37] and a TKA revision procedure [29,31,34,38]. It is possible that sex and obesity both influence the degree to which gait biomechanics change following TKA. Only one study has investigated whether changes in gait biomechanics after TKA differ across sexes [10], finding that sex influenced changes in frontal and sagittal plane gait one year after TKA. It is possible that obese patients do not experience as much improvement in gait biomechanics following TKA as non-obese people because of difficulties in obtaining neutral prosthesis alignment during surgery [39]. There have been no studies evaluating whether obesity influences change in gait biomechanics after TKA.

The primary aim of this study was to determine whether frontal and sagittal plane knee biomechanics change from pre TKA to six months following TKA, and if sex and/or obesity influence the amount of change. The secondary aim was to explore whether frontal and sagittal plane knee biomechanics have returned to normal at six months post-TKA, by comparing TKA patients to asymptomatic controls.

2. Methods

2.1. Study design

This study provides six-month data from an ongoing two year longitudinal cohort study investigating change in selected biomechanical parameters post-TKA surgery in people with severe knee OA. A nested cross-sectional comparison of the TKA cohort at six months post-surgery with asymptomatic people was also conducted. A six month follow up was chosen as the interim time point because most improvement in physical function [40–43], and knee flexion range of motion [14] is achieved, and plateaus, by this time point.

2.2. Participants

Patients scheduled for TKA were recruited from surgical waiting lists of five orthopaedic surgeons at St Vincent's Hospital in Melbourne, Australia from March 2013 to July 2015.

Inclusion criteria were: (i) primary TKA for knee OA. Exclusion criteria were: (i) inability to provide informed consent; (ii) unable to undertake gait analysis without a gait aid; (iii) coronal alignment > 3° of neutral as measured by the computer navigation system during surgery, and iv) body mass index (BMI) > 36 kg/m^2 due to difficulties with 3D gait analysis in the severely obese.

Asymptomatic participants aged ≥50 years were recruited from the community Exclusion criteria were: i) history of surgery to the hip and/or knee; ii) BMI > 36 kg/m^{2,} iii) pain in the hip or knee within the past six months, or iv) unable to provide informed consent. Approval for the study was obtained from the local institutional Human Research Ethics Committees. All participants gave informed written consent.

2.3. Surgical and post-operative procedures

All patients received a fully cemented non-constrained cruciate retaining prosthesis with patellar resurfacing (Press Fit Condylar Sigma, Depuy, Johnson & Johnson, Warsaw, IN). Further detail regarding the TKA procedures can be found in the Supplementary material. Use of in-patient rehabilitation was recorded and dichotomised as yes/no.

2.4. Quantitative gait analysis

Kinematic data (120 Hz) were acquired using a Vicon motion capture system (Vicon, Oxford, UK) with 12 MX cameras while ground reaction force data (1200 Hz) were captured in synchrony using two OR6-6-2000 force plates (Advanced Mechanical Technology, Watertown, MA, USA). The eight-segment lower limb University of Western Australia model was used to estimate lower limb joint kinematics and kinetics [44]. One functional knee flexion-extension movement trial was used to define knee joint centers in Matlab (Mathworks, Natick, Massachusetts, USA) [44]. Harrington equations were used to define the hip joint centers as many patients were unable to perform functional movements required to determine hip joint centers [45,46]. Marker data were low-pass filtered at 6 Hz using a 2nd order dual pass Butterworth filter. External knee joint moments were calculated using inverse dynamics and were expressed in the distal segment (shank) coordinate system. Moments were adjusted for the body size (body weight x height) in our statistical analysis (see below).

Participants walked barefoot at a self-selected comfortable speed along a 10 m walkway without assistive devices. Walking speed was measured by two photoelectric beams positioned four meters apart. Speed consistency across the trials was not enforced due to the severe disability demonstrated by the TKA participants. Foot-strike and toe-off were detected using ground reaction force data and used to delineate stance phase.

2.5. Primary variables of interest

Knee kinematic and kinetic variables of interest included: peak knee varus-valgus angle, varus-valgus thrust excursion (as described previously [47]), peak knee flexion angle in stance, knee sagittal plane range of motion, peak KAM, KAM impulse and peak KFM (Table 1).

2.6. Descriptive measures

Mean age, BMI, and sex ratios were calculated. In the TKA cohort, the Western Ontario and McMaster Universities Osteoarthritis Index

Table 1
Biomechanical variables of interest from 3-D motion analysis.

Variable	Definition
Varus-valgus thrust excursion [°]	The varus or valgus movement with the greatest angular excursion within the first 30% of stance (positive values indicate varus thrust, and negative valgus thrust)
Peak knee varus-valgus angle [°]	Maximum knee varus-valgus angle in the first 16% of stance phase (positive values indicate varus, and negative valgus)
Peak knee adduction moment (KAM) [Nm]	Peak external knee adduction moment in the first half of stance
KAM impulse [Nm.s]	Positive area under the knee adduction moment-time graph for the entire stance phase
Maximum knee flexion stance [°]	Maximum knee flexion angle during the loading phase
Knee flexion excursion (range of motion) [°]	Difference between maximum knee flexion angle and maximum knee extension angle in overall stance
Peak knee flexion moment [Nm]	Peak knee flexion moment in stance phase