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The influence of sex and obesity on gait biomechanics in people with severe knee osteoarthritis scheduled for arthroplasty

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ABSTRACT

Background: Sex and body mass may influence knee biomechanics associated with poor total knee arthroplasty (TKA) outcomes for knee osteoarthritis (OA). This study aimed to determine if gait differed between men and women, and overweight and class I obese patients with severe knee OA awaiting TKA.

Methods: 34 patients with severe knee OA (average age 70.0 (SD 7.2) years, body mass index 30.3 (4.1 kg/m^2)) were recruited from a TKA waiting list. Three-dimensional gait analysis was performed at self-selected walking speed. Comparisons were made between men and women, and overweight (body mass index (BMI) 25.0–29.9 kg/m^2) and class I obese (BMI 30.0–34.9 kg/m^2) participants. Biomechanical outcomes included absolute and body size-adjusted peak knee adduction moment (KAM), KAM impulse, peak knee flexion moment, as well as peak knee flexion and varus-valgus angles, peak varus-valgus thrust, and peak vertical ground reaction force (GRF).

Findings: Men had a higher absolute peak KAM, KAM impulse and peak GRF compared to women, and this sex-difference in frontal plane moments remained after adjusting for body size. However, when additionally adjusting for static knee alignment, differences disappeared. Knee biomechanics were similar between obesity groups after adjusting for the greater body weight of those with class I obesity.

Interpretation: Men had greater KAM and KAM impulse even after adjustment for body size; however adjustment for their more varus knees removed this difference. Obesity group did not influence knee joint kinematics or moments. This suggests sex- and obesity-differences in these variables may not be associated with TKA outcomes.

1. Introduction

Knee osteoarthritis (OA) is a leading cause of disability amongst older adults (Cross et al., 2014). It is a progressive disease and total knee arthroplasty (TKA) for end-stage OA is common (Australian Orthopaedic Association, 2015). Despite overall improvements in pain and quality of life (Silva et al., 2014), poor outcomes are common, with between 10 and 35% of patients reporting moderate to severe chronic post-surgical pain (Beswick et al., 2012) and up to 20% reporting dissatisfaction with surgery (Williams et al., 2013). Abnormal pre-operative gait biomechanics, such as altered frontal plane knee loading patterns (Astephen Wilson et al., 2010), greater sagittal plane knee joint loading (Smith et al., 2004; van Jonbergen et al., 2014), and decreased maximum knee flexion and knee flexion range of motion (Turcot et al., 2013), have all been associated with poor outcomes following TKA. Furthermore, female sex and obesity have been shown to adversely affect some gait biomechanical variables (Kumar et al., 2015; Messier et al., 1996) and TKA outcomes (Dowsey et al., 2010; Mehta et al., 2015). This is relevant because the majority of patients with OA are female (Pereira et al., 2011), and those proceeding to TKA are also predominantly female (68%), obese (60%), or both female and obese (44%) (Dowsey et al., 2010). Consequently, a more comprehensive understanding of the influence of sex and obesity on gait biomechanics in those with severe knee OA awaiting TKA is important in identifying

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factors that might influence poor post-surgical outcomes.

Limited research has examined differences in knee biomechanics during gait between sexes in people with knee OA. Women with mild to moderate knee OA are reported to walk with lower relative loading across the medial tibiofemoral joint compartment (shown by a lower peak size-normalized external knee adduction moment; KAM) (Kumar et al., 2015; Sims et al., 2009) and either similar (Phinyomark et al., 2016) or greater peak knee flexion (Kaufman et al., 2001), when compared to men. Regarding severe OA, it has been reported that women awaiting TKA had a lower knee joint flexion range of motion and lower normalized peak KAM than men (Astephen Wilson et al., 2015). Collectively, these few studies suggest that women with OA experience a lower normalized KAM, but less clear sagittal plane range of motion differences, compared to men. However, this may be counter-intuitive given a higher normalized KAM has been associated with worse knee OA symptoms and joint structural decline (Bennell et al., 2011; Miyazaki et al., 2002), which are also related to progression to arthroplasty (Conaghan et al., 2010). Thus, given the higher rate of female patients with OA, and proceeding to TKA, as well as the association between female sex and poor outcomes following TKA, further research is needed to clarify sex differences in knee biomechanics such as the KAM in those awaiting TKA.

In addition to sex, obesity may also influence gait patterns however few studies have examined this relationship in individuals with knee OA, possibly due to difficulties in 3D gait analysis of the obese. Of the limited research to date, obese individuals (defined as having a BMI ≥ 30 kg/m^2) with mild radiographic knee OA have been shown to walk with higher absolute peak vertical ground reaction force (Messier et al., 1996), lower normalized external knee flexion moments (KFM) (Kaufman et al., 2001), and a more extended knee (Messier et al., 1996) than non-obese individuals with similar severity of knee OA. Thus there may be differences between obese and non-obese knee OA patients in knee and other load-related biomechanical variables that have been associated with poor outcomes following TKA, including sagittal plane knee joint loading (Smith et al., 2004; van Jonbergen et al., 2014) and range of motion (Turcot et al., 2013). While this information is useful, a comparison between obese and overweight knee OA patients (rather than obese and non-obese) may be more relevant given most knee OA patients are either overweight or obese (Marks, 2007). Due to the paucity of studies comparing overweight and obese knee OA patients, further research examining differences in knee kinematics and kinetics between these groups is needed.

Furthermore, varus-valgus thrust identified during visual observation has been related to knee pain (Lo et al., 2012) and OA progression (Chang et al., 2004a), and also recently associated with knee kinematics relevant to knee OA (Chang et al., 2013). However, thrust quantified using 3-dimensional (3D) gait analysis has only been examined in severe OA in one study (Sosdian et al., 2016), and the effects of sex and obesity upon this parameter are unknown. Specifically, research has identified that knee OA patients with a varus thrust, quantified using 3D gait analysis, have a more varus static knee alignment, and walk with a greater knee varus angle, normalized peak KAM and KAM impulse, compared to knee OA patients with a valgus thrust. In addition, sex might also influence thrust as males without joint pathology have a more varus static alignment when compared to females (Bellemans et al., 2012), and static knee alignment (Chang et al., 2004b) and knee varus-valgus angles (Chang et al., 2013) have both been related to varus-valgus thrust. To date, the effects of obesity upon varus thrust in knee OA are unknown.

The purpose of this study was to examine sex- and obesity-related differences in knee biomechanics relevant to knee arthroplasty in a group of people with severe knee OA. It was hypothesised that female OA patients, and those with class I obesity, would walk with altered knee and other biomechanics compared to males and those classified as overweight.

2. Methods

2.1. Participants

Thirty-five patients with severe knee OA scheduled for primary elective TKA, and who met the inclusion and exclusion criteria and consented to participate, were recruited from surgical waiting lists of three orthopaedic surgeons at St Vincent's Hospital in Melbourne, Australia from March 2013 to February 2015. Participants were included if they were: (i) on the waiting list for a primary TKA for severe knee OA and ii) had a BMI of 25.0 to 29.99 kg/m^2 (overweight) or 30.0 to 34.99 kg/m^2 (class I obese) (World Health Organization criteria). Higher BMI was not included due to difficulties in performing gait analysis in the more severely obese. Exclusion criteria were: (i) TKA surgery planned for neoplastic disease; (ii) inability to provide informed consent; (iii) unable to perform gait analysis without a gait aid. All participants gave informed written consent and approval was obtained from the local institutional human research ethics committee.

2.2. Quantitative 3D gait analysis

Kinematic data (120 Hz) were acquired using a 12-camera Vicon MX motion capture system (Vicon, Oxford, UK) 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 direct kinematics and inverse dynamics model written in BodyBuilder (Vicon, Oxford, UK) was used to estimate lower limb joint kinematics and kinetics (Besier et al., 2003). The orientation and position of each lower limb segment was determined by attaching semi-rigid triads of 3 retro-reflective markers to the thigh and shank. Each body segment's technical coordinate system was defined using these markers, and their anatomical coordinate systems and joint centers were defined relative to the technical coordinate systems (Besier et al., 2003). Participants performed one functional knee flexion-extension movement trial that was used to define knee joint centers in Matlab (Mathworks, Natick, Massachusetts, USA) from the average helical axis (Besier et al., 2003). Harrington equations were used to define the hip joint centers, as a significant number of patients were not capable of performing functional movements required to determine hip joint centers by that method (Harrington et al., 2007; Kainz et al., 2015). Marker trajectories and ground reaction forces were low-pass filtered at 6 Hz using a 2nd order dual pass Butterworth filter. The Cardan angle sequence used for the knee joint angles was flexion/extension, varus-valgus, followed by internal/external rotation. Knee varus-valgus angular velocity was calculated by first-order finite differences. External knee joint moments were expressed in the distal segment (shank) coordinate system. Body segment mass and inertial parameters used for inverse dynamics were calculated using sex-specific equations for segment mass, center of mass location, and radii of gyration, based on total body mass and segment length (de Leva, 1996). Thrust was defined as the largest, most abrupt (determined using the peak knee angular velocity), frontal plane knee movement in either the varus or valgus direction during the loading phase (the first 30% of stance phase) (Sosdian et al., 2016).

Prior to data collection, one practice trial was completed. Participants completed a minimum of six trials walking barefoot at self-selected comfortable speed along a 10 m walkway without using any assistive devices. Walking speed was measured by two photoelectric beams positioned four meters apart. No attempt was made to ensure speed was consistent across trials or participants due to the high level of disability of the participants. As this was a between-group study investigating gait differences between men and women, and obese and non-obese individuals with severe OA, normalized walking speed was used. This non-dimensional number takes into account the leg length for each individual, particularly important for sex comparisons as men tend to have a longer leg length than women, and therefore a longer