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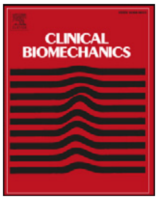

Mechanisms underpinning longitudinal increases in the knee adduction moment following arthroscopic partial meniscectomy

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ABSTRACT

Background: Knee osteoarthritis is common following arthroscopic partial meniscectomy and a higher external peak knee adduction moment is believed to be a contributor. The peak knee adduction moment has been shown to increase over 2 years (from 3-months post-arthroscopic partial meniscectomy). The aim of this study was to evaluate mechanisms underpinning the increase in peak knee adduction moment over 2 years observed in people 3-months following arthroscopic partial meniscectomy.

Methods: Sixty-six participants with medial arthroscopic partial meniscectomy were assessed at baseline and again 2 years later. Parameters were evaluated at time of peak knee adduction moment as participants walked barefoot at their self-selected normal and fast pace for both time points.

Findings: For normal pace walking, an increase in frontal plane ground reaction force-to-knee lever arm accounted for 30% of the increase in peak knee adduction moment ($B = 0.806$ [95% CI 0.501–1.110], $P < 0.001$). For fast pace walking, an increase in the frontal plane ground reaction force magnitude accounted for 21% of the increase in peak knee adduction moment ($B = 2.343$ [95% CI 1.219–3.468], $P < 0.001$); with an increase in tibia varus angle accounting for a further 15% ($B = 0.310$ [95% CI 0.145–0.474], $P < 0.001$).

Interpretation: Our data suggest that an increase in lever arm and increase in frontal plane ground reaction force magnitude are contributors to the increased knee adduction moment observed over time in people following arthroscopic partial meniscectomy.

1. Introduction

Knee osteoarthritis is considered a mechanical disease, whereby abnormal biomechanical loading is believed to cause a pathological response in susceptible joint tissues. The external knee adduction moment (KAM) is frequently used as an indicator of medial-to-lateral knee joint load distribution during gait (Birmingham et al., 2007; Zhao et al., 2007). People following arthroscopic partial meniscectomy (APM), are at risk of developing tibiofemoral knee osteoarthritis (Lohmander et al., 2007), and experience a higher peak KAM during gait than healthy controls (Hall et al., 2013; Sturnieks et al., 2008). Importantly, evidence suggests the KAM is a risk factor for structural disease in people with established knee osteoarthritis (Bennell et al., 2011a; Miyazaki et al., 2002). Furthermore, we have found that in people 3-months post-APM, the peak KAM increased during gait by approximately 9% over the subsequent 2 years (Hall et al., 2013). Therefore, given the association between structural change and high KAM, and its increase over time following APM, the peak KAM is a logical target for interventions aiming to reduce knee joint load and ultimately delay or prevent the development or progression of knee osteoarthritis often observed in this population. It is currently unknown why the peak KAM increases over time in people following APM.

The KAM is predominantly considered a product of the magnitude of the frontal plane ground reaction force (GRF) and the perpendicular distance of the GRF vector from the knee joint center to the GRF (knee-GRF lever arm). Studies have found associations between static frontal plane knee alignment and peak KAM magnitude (Andrews et al., 1996; Barrios et al., 2009), where increased varus malalignment is thought to increase the knee-GRF lever arm and consequently, the KAM during gait. Moreover, dynamic frontal plane alignment of the knee and the tibia has been shown to account for 46% and 61% of the variance in peak KAM, respectively (Barrios et al., 2012; Foroughi et al., 2010). Although dynamic frontal plane alignment has not yet been studied in

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people following APM, we and others have observed that individuals following medial APM adopt a greater static varus position over time (Hall et al., 2013; Yoon et al., 2013). Given that static frontal plane knee alignment measures are strongly correlated to dynamic frontal plane knee alignment (Hunt et al., 2008), these patients may increase dynamic frontal plane knee varus malalignment during gait over 2-years, that could partially explain an increased peak KAM over time.

It is also plausible that the magnitude, origin (center of pressure position) and/or orientation of the frontal plane GRF vector at the time of peak KAM may change over time, and thus partially explain the increased peak KAM. Muscles (including the quadriceps and hamstrings) assist in controlling the position, velocity and acceleration of the body center mass during gait (Pandy et al., 2010), which in turn influences the frontal plane GRF magnitude and orientation, and ultimately the KAM. Patients following APM exhibit changes in knee muscle activity patterns during functional tasks (Sturnieks et al., 2011; Thorlund et al., 2012), maximal knee muscle strength (Hall et al., 2013; Sturnieks et al., 2008), and proprioception (Al-Dadah et al., 2011; Malliou et al., 2012); each of these, alone or in combination, may contribute to alterations in vertical, anterior–posterior and medio-lateral accelerations of the center of mass.

Understanding the mechanisms that underpin the increase in peak KAM over time will assist with developing and refining therapeutic interventions aimed at reducing the peak KAM in people following APM. Therefore, the purpose of this study in people assessed 3 months following medial APM (baseline) and 2-years later (follow-up) was to evaluate how potentially modifiable frontal plane postures and movements are associated with an increase in peak KAM over time.

2. Methods

2.1. Participants

This is a further analysis of a 2-year longitudinal cohort study (Hall et al., 2013). Individuals between 30 and 50 years old with an isolated medial APM performed 3 months previously were recruited. These participants have been previously described (Hall et al., 2013). Exclusion criteria were any of the following: lateral meniscal resection; greater than one third of medial meniscus resected; >2 tibiofemoral cartilage lesions; a single tibiofemoral cartilage lesion > approximately 10 mm in diameter; previous knee or lower limb surgery (other than current APM); history of knee pain (other than that leading to APM); post-operative complications; cardiac, circulatory or neuromuscular conditions; diabetes; stroke; multiple sclerosis; contraindication to MRI. The University of Melbourne Human Research Ethics Committee approved the study, and written informed consent was provided by each participant.

2.2. Gait analysis

Kinematic data (120 Hz) were acquired using a Vicon motion capture system (Vicon, Oxford, UK) with eight M2/MX CMOS cameras (1280 × 1024) while kinetic data (1080 Hz) were captured in synchrony using two 0R6-6-2000 force plates and one BP-600-900 force plate (Advanced Mechanical Technology, Watertown, MA, USA). A custom seven-segment lower limb 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). Following the application of reflective markers, participants performed three functional hip and knee movement trials, that were used to define hip joint centers and knee joint flexion/extension axes in Matlab (Mathworks, Natick, Massachusetts, USA) (Besier et al., 2003). Participants then performed five barefoot walking trials at a self-selected normal and fast pace described as a 'natural and comfortable pace' and a pace 'you would walk in a hurry' respectively. The peak KAM in the first half of stance, was expressed as an external moment and applied to the distal segment. The peak KAM was measured from each trial, averaged, and normalized to body size (Nm/(BW × HT)%). The test–retest reliability for the external frontal plane moment curve during walking has previously been reported as 0.75 (curve coefficient of multiple determination, r^2) (Besier et al., 2003). Walking speed was measured by two photoelectric beams as participants walked along the 10-m walkway.

The variables of interest for this study are defined in Table 1. The knee-GRF lever arm, frontal plane GRF angle, knee varus–valgus angle, frontal plane tibia angle, frontal plane femur angle, center of pressure offset, lateral trunk lean, frontal plane knee–pelvis distance, and foot progression angle were determined using a custom-written Body Builder program (Vicon, Oxford, UK). For each walking pace, the variables that occurred at time of peak KAM were averaged over five trials. The changes in variables were determined by subtracting the baseline (3 months post-APM) from the follow-up scores (2 years post-APM), such that a negative score represented a reduction at follow-up.

2.3. Statistical analysis

Statistical analyses were performed using SPSS (SPSS Inc., Chicago, IL, USA) and an alpha level of 0.05. Analyses were performed separately for normal and fast pace walking. Using a similar approach to our previous work evaluating mechanisms underpinning change in peak KAM with lateral wedge orthotics (Hinman et al., 2012), we first evaluated change in variables (Table 1) using paired t-tests. For those variables that changed significantly, we examined their relationship with change in the peak KAM using Pearson correlations. Change variables that were significantly associated with change in peak KAM were then entered as independent variables into a stepwise regression model (probability of entry = 0.05 and probability of removal = 0.10), with change in peak KAM as the dependent variable.

Table 1
Biomechanical variables of interest.

Variable	Definition
Peak knee adduction moment (Nm/(BW × HT)%)	Peak external knee adduction moment during first half of stance
Knee-GRF lever arm ((mm/HT)%)	Perpendicular distance between the GRF vector and knee joint center in the laboratory frontal plane
GRF magnitude (BW)	Resultant magnitude of GRF in laboratory frontal plane
Hip external rotation angle (°)	Hip angle in transverse plane
Knee flexion angle (°)	Knee angle in sagittal plane
Knee–pelvis-distance ((mm/HT)%)	Relative frontal plane distance between pelvis center and the knee joint center (Winter and Wells, 1981)
Hip–knee–ankle angle (°)	Angle determined from hip–knee–ankle centers in laboratory frontal plane, positive values indicated varus
Tibia angle (°)	Angle of knee–ankle center vector in laboratory frontal plane, positive values indicate varus
Femur angle (°)	Angle of hip–knee center vector in laboratory frontal plane, positive values indicate varus
Knee varus–valgus angle (°)	Varus–valgus angle calculated as first Euler–Cardan angular rotation of the shank with respect to thigh (equivalent to shank varus–valgus angle projected on thigh coordinate system), positive values indicate varus
Lateral trunk lean (°)	Angle of the trunk in laboratory frontal plane, positive values indicate lateral trunk lean
Center of pressure offset (mm)	Distance of the center of pressure from the long axis of the foot (ankle joint center to the 2nd metatarsal), negative values indicate lateral offset
Frontal plane GRF angle (°)	Angle of the GRF vector in laboratory frontal plane, positive values indicate varus leaning GRF
Foot progression angle (°)	Angle between long foot axis (ankle joint center to 2nd metatarsal) with respect to the pelvis, negative values indicate toe out

GRF = ground reaction force magnitude; BW = body weight; HT = height.