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Mechanisms underpinning the peak knee flexion moment increase over 2-years following arthroscopic partial meniscectomy☆

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ABSTRACT

Background: Knee osteoarthritis is common in people who have undergone partial meniscectomy, and a higher external knee flexion moment during gait may be a potential contributor. Although the peak external knee flexion moment has been shown to increase from 3 months to 2 years following partial meniscectomy, mechanisms underpinning the increase in the peak knee flexion moment are unknown.
Methods: Sixty-six participants with partial meniscectomy completed three-dimensional gait (normal and fast pace) and quadriceps strength assessment at baseline (3 months following partial meniscectomy) and again 2 years later. Variables included external knee flexion moment, vertical ground reaction force, knee flexion kinematics, and quadriceps peak torque.
Findings: For normal pace walking, the main significant predictors of change in peak knee flexion moment were an increase in peak vertical ground reaction force ($R^2 = 0.55$), mostly due to an increase in walking speed, and increase in peak knee flexion angle ($R^2 = 0.19$). For fast pace walking, the main significant predictors of change in peak knee flexion moment were an in increase in peak vertical ground reaction force ($R^2 = 0.51$) and increase in knee flexion angle at initial contact ($R^2 = 0.17$). Change in peak vertical force was mostly due to an increase in walking speed.
Interpretation: Findings suggest that increases in vertical ground reaction force and peak knee flexion angle during stance are predominant contributors to the 2-year change in peak knee flexion moment. Future studies are necessary to refine our understanding of joint loading and its determinants following meniscectomy.

1. Introduction

People following Arthroscopic partial meniscectomy (APM) are at increased risk of developing knee osteoarthritis in both the tibiofemoral and patellofemoral compartments (Englund and Lohmander, 2005; Wang et al., 2012). Although knee osteoarthritis is considered in part a mechanical disease (Felson, 2013), the pathogenesis of this debilitating condition is not well understood in patients following APM. Higher joint loading inferred through external knee joint moments during gait has been associated with compromised cartilage health following APM (Hall et al., 2015) as well as in those with established osteoarthritis (OA) (Bennell et al., 2011; Chang et al., 2015; Chehab et al., 2014; Miyazaki et al., 2002). Although most literature highlights the role of the external knee adduction moment in structural change (Bennell et al., 2011; Chehab et al., 2014; Miyazaki et al., 2002), the external knee flexion moment (KFM) is increasingly being implicated as a factor in the pathogenesis of knee osteoarthritis (Chehab et al., 2014; Creaby, 2015; Hall et al., 2015; Teng et al., 2015).

Indeed, the peak KFM may be clinically relevant in people following APM. Three months following APM, we observed that a higher peak KFM during normal pace gait was associated with reduced patellar cartilage volume, over the subsequent 2 years (Hall et al., 2015). The peak KFM increased by approximately 13% over time, such that the peak KFM was 6–11% higher during walking in APM patients compared to healthy controls 2 years later (Hall et al., 2013). Furthermore, a higher KFM during gait has also recently been associated with medial tibial cartilage (Chehab et al., 2014) and patellofemoral joint (Teng et al., 2015) deterioration. Therefore, considering both an increase in KFM over time following APM and a potential link between higher KFM and subsequent adverse cartilage changes, the KFM may constitute a potential target for interventions aiming to preserve knee joint cartilage integrity. However, designing interventions to target the KFM requires an

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understanding of mechanisms responsible for the increase in peak KFM over time in individuals following APM.

The KFM during gait is predominately a product of the magnitude of the sagittal plane ground reaction force (GRF), which can be increased by a faster walking speed and greater body mass, and the sagittal plane moment arm (i.e. the perpendicular distance of the GRF vector to the knee joint centre). We have previously found a significant increase in peak vertical GRF (vGRF) over 2 years in the affected leg of patients who have undergone an APM compared to healthy controls (Hall et al., 2015). Knee flexion kinematics have not been longitudinally described in patients following APM. This is important to consider as an increase in knee flexion angle may partly explain the change in peak KFM by increasing the sagittal plane GRF moment arm (Creaby et al., 2013).

The KFM moment is supported predominantly by the quadriceps (Winter, 1984), and an increase in the KFM moment is likely to place a greater demand on quadriceps function. Indeed, a lower peak KFM moment is associated with reduced knee extension strength in patients with knee osteoarthritis (Farrokhi et al., 2015) and in those following anterior cruciate ligament reconstruction (Lewek et al., 2002). We have previously reported that the quadriceps were weaker in the APM leg compared to healthy controls at 3 months following surgery (Sturnieks et al., 2008) and that quadriceps strength significantly increased in these patients over 2 years (Hall et al., 2013), As such, an increase in peak KFM over time may reflect the improvement in quadriceps strength in these patients. Although improving quadriceps strength is typically encouraged following knee arthroscopy (Panisset and Prudhon, 2012), it has not been shown that an increase in quadriceps strength is indeed associated with the peak KFM increase in these patients.

The purpose of this study in people assessed 3 months following APM (baseline) and 2-years later (follow-up) was to explore potentially modifiable biomechanical characteristics that explain the change in peak KFM over time. We hypothesized that an increase in walking speed, greater knee flexion angle during stance, an increase in vertical GRF magnitude and increase in quadriceps strength would partially explain the 2-year increase in peak KFM observed in people following APM.

2. Methods

2.1. Participants

This is a further analysis of a 2-year prospective study (Hall et al., 2013). We recruited 82 participants aged between 30 and 50 years who had undergone an isolated medial APM 3 months prior. People were excluded if they had: evidence of 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 as assessed at arthroscopy; previous knee or lower limb surgery (other than the recent APM); history of knee pain (other than that leading to APM); post-operative complications; cardiac, circulatory or neuromuscular conditions; diabetes; stroke; multiple sclerosis; and/or contraindication to MRI. Participants provided written informed consent, and the local institutional Human Research Ethics Committee approved this study.

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 Massachusetts, 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). Hip and knee joint centres and knee joint flexion/extension axes were defined as per Besier et al. (2003). Five barefoot walking trials were performed at a self-selected normal pace described as 'natural and comfortable pace', and fast pace walking described as 'if you were in a hurry'. Walking speed was measured by two photoelectric timing gates placed 4 metres part, centred on the force plates. The peak KFM was expressed as an external moment applied to the distal segment and reported for the APM limb in this study. The peak KFM in the first half of stance was recorded, averaged over five trials, and normalised to the product of body weight and height (Nm / (BW × HT)%). The test–retest reliability for the entire KFM curve has been previously reported as 0.84 (coefficient of multiple determination, r^2) (Besier et al., 2003). The peak vertical GRF was extracted and normalised to body weight (N/BW). Knee kinematics including flexion at initial contact, peak knee flexion during stance, and flexion excursion from initial contact to peak knee flexion were used in subsequent analysis.

2.3. Strength assessment

Maximal isokinetic quadriceps muscle strength was assessed using a Kin-Com 125-AP dynamometer (Chattecx, Chattanooga, Tennessee, USA) at baseline and follow-up. On the APM limb only, participants performed two sub-maximal warm-up efforts for familiarisation and five repetitions of reciprocal maximal concentric–concentric contractions of quadriceps and hamstrings at 60°/s, followed by eccentric–eccentric contractions, with 40 s separating the two bouts. Verbal instructions were given to 'push as hard as you can'. The peak concentric and eccentric torques were recorded from five trials, and normalised to body mass (Nm/kg).

2.4. Statistical analysis

For descriptive purposes, Pearson correlations were performed between the change (from 3 months following surgery to 2 years later) in peak KFM and change in biomechanical variables considered to theoretically influence change in peak KFM including: walking speed, body mass, knee flexion at initial contact, peak knee flexion during stance, knee flexion angle excursion, peak vGRF and knee extensor strength. To determine if these parameters predicted change in peak KFM, a forward stepwise regression was performed with each of the aforementioned parameters entered as independent variables into the model (probability entry = 0.05 and probability of removal = 0.10), with change in peak KFM as the dependent variable.

In the event that change in vGRF was found to be a significant predictor of change in peak KFM, further analyses were performed to explore the mechanisms of change in vGRF magnitude. Pearson correlations were performed to describe the relationships between change in vGRF and i) change in walking speed, ii) change in body mass and iii) change in knee flexion angle kinematics. To ascertain if these parameters were associated with change in vGRF, a forward stepwise regression was again performed with each of the aforementioned variables entered as independent variables into the model (probability entry = 0.05 and probability of removal = 0.10), but with change in vGRF as the dependent variable.

Stepwise regression models were assessed to ensure the following assumptions were satisfied including: i) approximate linear relationship between predictor variables and dependent variable; ii) normality of residuals; iii) homoscedastic variance and iv) multicollinearity was assessed using collinearity statistics where a variance inflation factor (VIF) < 4 was considerable acceptable (Peat and Barton, 2008). Outputs of interest from regression models included: standardised coefficients (β) to provide relative strength of each predictor variable to the model; unstandardised coefficients (B) to describe relationship between change in predictor and change in outcome (i.e. change in peak KFM), and associated R-values to describe the amount of variance of the outcome explained by predictors. SPSS (SPSS Inc., Chicago, IL, USA) was used to perform statistical analyses with an alpha level of 0.05.