Osteoarthritis and Cartilage xxx (2016) 1–6

Osteoarthritis
and Cartilage

# Knee kinematics and kinetics are associated with early patellofemoral osteoarthritis following anterior cruciate ligament reconstruction

A.G. Culvenor [†] [‡] [††], L. Perraton [§], A. Guermazi [||], A.L. Bryant [§], T.S. Whitehead [¶], H.G. Morris [#], K.M. Crossley [‡] [*]

[†] Paracelsus Medical University, Institute of Anatomy Salzburg & Nuremberg, Salzburg, Austria
[‡] La Trobe University, La Trobe Sport and Exercise Medicine Research Centre, School of Allied Health, Bundoora, Australia
[§] The University of Melbourne, Department of Physiotherapy, School of Medicine, Dentistry and Health Sciences, Parkville, Australia
[||] Boston University School of Medicine, Department of Radiology, Boston, USA
[¶] OrthoSport Victoria, Epworth Richmond, Melbourne, Australia
[#] The Park Clinic, St Vincent's Private Hospital, Melbourne, Australia
[††] Australian Hip and Knee Institute, Melbourne, Australia

ARTICLE INFO

*Article history:*
Received 11 December 2015
Accepted 9 May 2016

*Keywords:*
Anterior cruciate ligament
Osteoarthritis
Magnetic resonance imaging
Biomechanics
Patellofemoral joint

## SUMMARY

*Objective:* Patellofemoral osteoarthritis (PFOA) commonly occurs following anterior cruciate ligament reconstruction (ACLR). Our study aimed to compare knee kinematics and kinetics during a hop-landing task between individuals with and without early PFOA post-ACLR.
*Design:* Forty-five individuals (mean ± SD 26 ± 5 years) 1–2 years post-ACLR underwent 3T isotropic MRI scans and 3D biomechanical assessment of a standardised forward hop task. Knee kinematics (initial contact, peak, excursion) in all three planes and sagittal plane kinetics (peak) were compared between 15 participants with early PFOA (MRI-defined patellofemoral cartilage lesion) and 30 participants with no PFOA (absence of patellofemoral cartilage lesion on MRI) using analysis of covariance (ANCOVA), adjusted for age, BMI, sex and the presence of early tibiofemoral OA.
*Results:* Compared to participants without PFOA, those with early PFOA exhibited smaller peak knee flexion angles (mean difference, 95% confidence interval [CI]: $-5.2^{\circ}$, $-9.9$ to $-0.4$; $P = 0.035$) and moments ($-4.2$ Nm/kg.m, $-7.8$ to $-0.6$; $P = 0.024$), and greater knee internal rotation excursion ($5.3^{\circ}$, 2.0 to 8.6; $P = 0.002$).
*Conclusions:* Individuals with early PFOA within the first 2-years following ACLR exhibit distinct kinematic and kinetic features during a high-load landing task. These findings provide new information regarding common post-ACLR biomechanical patterns and PFOA. Since management strategies, such as altering knee load, are more effective during the early stages of disease, this knowledge will help to inform clinical management of early PFOA post-ACLR.

## Introduction

Patellofemoral osteoarthritis (PFOA) is common following anterior cruciate ligament reconstruction (ACLR); reportedly affecting approximately 50% of people a decade after ACLR[1]. While this prevalence is similar to reported rates of tibiofemoral osteoarthritis (TFOA), PFOA appears to be more strongly associated with knee symptoms and impaired knee function following ACLR[2]. The mechanisms underpinning the development of PFOA post-ACLR remain unclear, but the high-rates of PFOA appear to be independent of graft type[1].

Altered kinematics and kinetics are considered important drivers of OA post-ACLR[3]. Adaptations in tibiofemoral biomechanics that are apparent following ACLR[3] may partly explain the higher incidence of PFOA post-ACLR compared to uninjured populations. For example, increased tibial external rotation during gait in individuals with knee valgus was associated with radiographic

---

[*] Address correspondence and reprint requests to: K.M. Crossley, La Trobe Sport and Exercise Medicine Research Centre, School of Allied Health, La Trobe University, Melbourne 3086, Australia. Tel: 61-3-94793902; Fax: 61-3-94795768.
*E-mail addresses:* adam.culvenor@pmu.ac.at (A.G. Culvenor), lperraton@unimelb.edu.au (L. Perraton), ali.guermazi@bmc.org (A. Guermazi), albryant@unimelb.edu.au (A.L. Bryant), tswhitehead@osv.com.au (T.S. Whitehead), haydenmorris@me.com (H.G. Morris), k.crossley@latrobe.edu.au (K.M. Crossley).

http://dx.doi.org/10.1016/j.joca.2016.05.010
1063-4584/© 2016 Osteoarthritis Research Society International. Published by Elsevier Ltd. All rights reserved.

Please cite this article in press as: Culvenor AG, et al., Knee kinematics and kinetics are associated with early patellofemoral osteoarthritis following anterior cruciate ligament reconstruction, Osteoarthritis and Cartilage (2016), http://dx.doi.org/10.1016/j.joca.2016.05.010

PFOA 9-years after ACLR[4]. To our knowledge, our previous study is unique in its evaluation of the relationship between knee biomechanics and OA post-ACLR[4]. Another recent biomechanical study in older adults (without a history of ACL injury) observed lower knee flexion angles during gait in patients with more severe PFOA compared to less severe PFOA[5], suggesting that sagittal plane motion may also be implicated in PFOA. Other reports of higher sagittal plane patellofemoral stress during the second half of stance in patients with PFOA compared to controls[6], suggests a possible role of sagittal plane joint moments in PFOA.

Identifying potential mechanisms associated with early (i.e., pre-radiographic) OA (of which articular cartilage lesions are a hallmark sign)[7] is required to inform management strategies that may be implemented prior to the development of advanced (i.e., radiographic) disease. Biomechanical assessment of high-load tasks (such as hopping), which simulate sports related activity, may be more relevant than walking for this active, young population. Focussing on the patellofemoral joint enables associations to be drawn with the knee compartment that has gone under-recognised post-ACLR[1], yet is at high risk of OA and related symptoms[1]. Therefore, this study aimed to compare knee kinematics and kinetics during a hopping task between individuals with and without early PFOA post-ACLR. Based on our previous PFOA gait evaluations 9-years post-ACLR[4], and gait kinematics of those with non-traumatic PFOA[5], we hypothesised that, compared to those with no PFOA, individuals with early PFOA would exhibit greater peak tibial external rotation and lower peak knee flexion angles and moments.

## Patients and methods

### Participants

Participants were recruited from our cohort study ($n = 111$) investigating the prevalence of MRI-defined OA approximately 1-year following ACLR[7]. Ethical approval was granted from The University of Melbourne and University of Queensland, and participants provided written informed consent. All participants had a primary arthroscopic single-bundle ACLR with a hamstring-tendon autograft (4-strand semitendinosus/gracilis, tunnels placed in the anatomical footprint of the native ACL) performed by one of two high-volume (>150 ACLRs annually) experienced orthopaedic surgeons.

To be eligible for the original MRI evaluation, participants needed to be aged 18–50 years at the time of ACLR and be approximately 12 months post-ACLR at the time of MRI assessment (11–15 months)[7]. Exclusion criteria for the original MRI study were: (1) inability to read/speak English; (2) previous injury/surgery to ACLR knee; (3) subsequent injury/surgery to ALCR knee; (4) another condition influencing daily/sporting function; and (5) currently pregnant or breastfeeding[7].

Additional exclusion criteria for the biomechanics evaluation were: (1) current/history of injury/surgery to the contralateral knee; (2) concurrent Grade III collateral ligament/PCL injury or fracture; and (3) symptoms of knee instability (i.e., clicking, catching, giving-way) during any activity. Details of the surgical procedure, rehabilitation protocol and indications for concomitant meniscectomy have been published[2,7].

Participant age, sex, height, weight, limb dominance (preferred leg to kick a ball) and knee laxity (KT-1000) were recorded at the time of MRI. Participants also completed the Tegner Activity Scale, the modified Tampa Scale of Kinesiophobia[8] (TSK-11), and a clinical assessment of lower-extremity function – the maximum hop-for-distance test (maximum of three trials from a stationary start with hands held behind the back) during the same visit as for biomechanical assessment. The hop test results were presented as a limb symmetry index (LSI) (ACLR ÷ contralateral limb × 100).

### Procedure

All participants ($n = 111$) first underwent MRI examination as part of our recent study at a mean 14 ± 2 months post-ACLR[7]. To assess early PFOA unilateral MRI examinations of the affected knee were performed using a 3.0-Tesla system (Philips Achieva, The Netherlands) with a 16-channel knee coil (Invivo, Gainesville, Florida, USA). Early PFOA was defined as the presence of at least a partial-thickness patellar or femoral trochlear cartilage lesion on MRI, which is consistent with previous definitions of early PFOA[6,9]. Our imaging protocol consisted of a three-dimensional proton-density VISTA sequence acquired at 0.35 mm isotropically (TR/TE 1300 ms/27 ms, 150 $mm^2$ field of view). Patellofemoral cartilage lesions were graded by a musculoskeletal radiologist (AG) with 15-years of experience in semiquantitative MRI analysis of knee OA features and previously established reliability in semi-quantitative MRI evaluation of knee OA using the MRI OA Knee Score (MOAKS) (weighted $\kappa$ 0.54 to 1.00)[10]. Specifically, cartilage lesions were scored as partial- or full-thickness loss as per MOAKS criteria[10]. Early TFOA (defined as at least a partial thickness cartilage lesion affecting medial or lateral tibia or femoral condyle) was also assessed to enable evaluations of PFOA to be adjusted for TFOA presence. Weight-bearing anteroposterior and non-weight-bearing skyline radiographs were obtained in approximately 30° flexion[7]. From the assessment of radiographs with the Osteoarthritis Research Society International atlas[11], low frequency of radiographic knee OA (<5%) was observed[7].

Following MRI acquisition, and ≤2-years post-ACLR, three-dimensional kinematics and kinetics of the ACLR knee were recorded during a standardised forward hopping task using a 12-camera Vicon analysis system (VICON, Oxford Metrics, Oxford, UK) and an embedded force plate (AMTI, Watertown, MA, USA), respectively. For the standardised hop task (a completely separate task from the clinical hop-for-distance test), participants first walked forwards for three steps at a cadence of 100 beats per minute (audible metronome) to standardise centre of mass velocity prior to hopping. From the third step, participants hopped forward, with a balanced landing, to a mark on the floor that was at a distance representing 100% of their leg length (greater trochanter to floor in standing). A maximum of five practice trials were permitted to standardise any learning effect. No specific instructions on landing technique were provided. Five successful trials (i.e., no secondary hops upon landing, or large trunk/contralateral limb deviation >45° from vertical) with arms folded were recorded with participants barefoot. A 10 cm visual analogue scale (VAS) for pain during the hopping task was completed (0 cm = no pain, 10 cm = worse possible pain).

Prior to the hopping task, 19 reflective markers were placed at specific anatomic landmarks on the pelvis and lower-extremities[12] by a single investigator (LP). These landmarks included: anterior and posterior superior iliac spines, distal anterior thigh, proximal and distal lateral thigh, medial and lateral femoral condyle, proximal and distal anterior tibia, lateral tibia, medial and lateral malleoli, proximal and distal calcaneus, superior and lateral mid-foot, and forefoot (junction between second and third metatarsophalangeal joints). A static trial was collected to calibrate relevant anatomic landmarks and establish joint centres[12]. The knee flexion–extension axis was determined using dynamic optimisation and defined as the flexion–extension axis that results in minimal variance in the knee abduction-adduction angle (i.e., least amount of cross-talk)[13]. Kinematic (120 Hz) and kinetic data (2400 Hz) were time-synchronised using motion capture software

Please cite this article in press as: Culvenor AG, et al., Knee kinematics and kinetics are associated with early patellofemoral osteoarthritis following anterior cruciate ligament reconstruction, Osteoarthritis and Cartilage (2016), http://dx.doi.org/10.1016/j.joca.2016.05.010