Clinical Biomechanics 30 (2015) 383–390

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Individuals with isolated patellofemoral joint osteoarthritis exhibit higher mechanical loading at the knee during the second half of the stance phase

Hsiang-Ling Teng [a,*], Toran D. MacLeod [a,b,1], Deepak Kumar [a,2], Thomas M. Link [a,3], Sharmila Majumdar [a,2], Richard B. Souza [a,c,3]

[a] *Department of Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, CA, USA*
[b] *Department of Physical Therapy, California State University, Sacramento, CA, USA*
[c] *Department of Physical Therapy and Rehabilitation Science, University of California San Francisco, San Francisco, CA, USA*

ARTICLE INFO

Article history:
Received 25 August 2014
Accepted 11 February 2015

Keywords:
Patellofemoral joint
Osteoarthritis
Gait
Stress
Kinetics

ABSTRACT

Background: Patellofemoral joint osteoarthritis is a highly prevalent disease and an important source of pain and disability. Nonetheless, biomechanical risk factors associated with this disease remain unclear. The purpose of this study was to compare biomechanical factors that are associated with patellofemoral joint loading during walking between individuals with isolated patellofemoral joint osteoarthritis and no osteoarthritis.
Methods: MR images of the knee were obtained using a 3D fast-spin echo sequence to identify patellofemoral joint cartilage lesions. Thirty-five subjects with isolated patellofemoral joint osteoarthritis (29 females) and 35 control subjects (21 females) walked at a self-selected speed and as fast as possible. Peak knee flexion moment, flexion moment impulse and peak patellofemoral joint stress during the first and second halves of the stance phase were compared between groups.
Findings: When compared to the controls, individuals with patellofemoral joint osteoarthritis demonstrated significantly higher peak knee flexion moment ($P = .03$, $\text{Eta}^2 = .07$), higher knee flexion moment impulse ($P = .03$, $\text{Eta}^2 = .07$) and higher peak patellofemoral joint stress ($P = .01$, $\text{Eta}^2 = .10$) during the second half of the stance phase. No significant group difference was observed during the first half of the stance phase.
Interpretation: Findings of this study suggest that increased mechanical loading (i.e. knee flexion moment, impulse and patellofemoral joint stress) during the second half of the stance phase is associated with patellofemoral joint osteoarthritis. Prevention and rehabilitation programs for patellofemoral joint osteoarthritis may focus on reducing the loading on the patellofemoral joint, specifically during late stance.

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1. Introduction

Patellofemoral joint (PFJ) osteoarthritis (OA) is a highly prevalent knee disease. Based on the findings of radiographic (Duncan et al., 2006) and magnetic resonance (MR) imaging (Stefanik et al., 2013) studies, 64% of adults over 50 years have PFJ OA with one third of them having isolated PFJ OA. This suggests that the prevalence of PFJ OA is as high, if not higher than, tibiofemoral joint OA (Duncan et al., 2006; McAlindon et al., 1992; Stefanik et al., 2013). Moreover, PFJ OA has been found to be an important source of pain and dysfunction in the knee joint (Duncan et al., 2009; Hunter et al., 2003; Kornaat et al., 2006). While a large body of literature has been established with regard to biomechanical risk factors associated with tibiofemoral joint OA, there is a substantial paucity of data on the biomechanical characteristics of individuals with PFJ OA.

Articular cartilage lesions are a hallmark sign of OA and can result from mechanical overload (Arokoski et al., 2000; Bennell et al., 2011; Mankin, 1982). Several biomechanical factors can provide direct or indirect estimations of mechanical loading of the articular cartilage of PFJ during functional activities. For example, PFJ stress represents the compressive (joint reaction) force applied to the PFJ per unit area. An increased PFJ stress indicates a higher mechanical loading on the PFJ. Additionally, increased knee flexion moments can result in higher PFJ reaction forces at a given knee angle and thus, may lead to increased PFJ stress (Besier et al., 2005; Teng and Powers, 2014). Taken together, biomechanical factors, such as PFJ stress, knee flexion moment, and

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[*] Corresponding author at: Department of Radiology and Biomedical Imaging, University of California San Francisco, 185 Berry Street, Suite 350, San Francisco, CA 94107, USA.

E-mail addresses: Hsiang-Ling.Teng@ucsf.edu (H.-L. Teng), toran.macleod@csus.edu (T.D. MacLeod), deepak.kumar@ucsf.edu (D. Kumar), Thomas.Link@ucsf.edu (T.M. Link), Sharmila.Majumdar@ucsf.edu (S. Majumdar), Richard.Souza@ucsf.edu (R.B. Souza).

[1] 6000 J Street, CSU Sacramento, Sacramento, CA 95819, USA.
[2] 1700 4th Street, Suite 203, Byers Hall, UCSF Mission Bay, San Francisco, CA 94158, USA.
[3] 185 Berry St, Suite 350, UCSF China Basin, San Francisco, CA 94107, USA.

http://dx.doi.org/10.1016/j.clinbiomech.2015.02.008
0268-0033/Published by Elsevier Ltd.

knee flexion moment impulse, may be potential risk factors associated with PFJ OA.

A few recent studies investigated PFJ loading during functional activities in individuals with and without PFJ OA (Crossley et al., 2012; Farrokhi et al., 2015; Fok et al., 2013). Farrokhi et al. (2015) reported a higher knee flexion moment during single-leg stance of gait in individuals with combined tibiofemoral joint and PFJ OA compared to individuals with isolated tibiofemoral joint OA. On the contrary, Crossley et al. (2012) reported that people with isolated PFJ OA walked with similar vasti muscle forces and Fok et al. (2013) reported that individuals with isolated PFJ OA or combined PFJ and tibiofemoral joint OA ascended and descended stairs with lower knee flexion moments and PFJ reaction forces when compared to asymptomatic controls. The conflicting results may be due to the differences in methodology and subject selection among these studies and highlight the need of further research in this area. It is important to note that neither of these previous studies evaluated PFJ OA based on the presence of cartilage lesions seen on MR imaging, but rather on indirect signs of cartilage wear, such as joint space narrowing on radiographs which is a later stage finding. Since OA is characterized by articular cartilage lesions, these previous studies may not be sensitive enough to identify risk factors associated with PFJ OA especially those with early stage disease. Moreover, in order to better identify biomechanical risk factors associated with PFJ OA, it would be important to exclude individuals with tibiofemoral joint OA since they have been reported to demonstrate altered knee flexion moment during walking (Chehab et al., 2014).

The purpose of this study was therefore to compare biomechanical factors that are associated with PFJ loading (i.e. knee flexion moment, knee flexion moment impulse and PFJ stress) during walking between individuals with no OA and isolated PFJ OA (as defined by articular cartilage lesions on MR imaging). Because increased PFJ loading may lead to mechanical damages on PFJ cartilage, which is used to define OA in this study, we hypothesized that individuals with PFJ OA would exhibit higher knee flexion moment, knee flexion moment impulse and PFJ stress during walking.

2. Methods

2.1. Subjects

A total of 112 subjects above 35 years with and without knee OA symptoms were recruited from the community as a part of a longitudinal study on knee OA. The exclusion criteria were (1) history of lower extremity or spine surgery, (2) self-reported inflammatory arthritis, (3) any conditions that limit the ability to walk (without assistant device) and (4) contraindications to MR imaging. For the purpose of OA classification, all subjects underwent knee MR imaging using a 3.0-Tesla GE MR 750w Scanner (General Electric, Milwaukee, WI, USA) and an 8-channel transmit-receive knee coil (Invivo, Orlando, FL, USA). A high-resolution 3D fast spin-echo CUBE sequence (repetition time/echo time = 1500/26.69 ms, field of view = 16 cm, matrix = 384 × 384, slice thickness = 0.5 mm, echo train length = 32, bandwidth = 37.5 kHz, number of excitations = 0.5, acquisition time = 10.5 min) was acquired to evaluate cartilage health.

Articular cartilage lesions of the PFJ (patella, trochlea) and tibiofemoral joint (medial and lateral tibia, medial and lateral femoral condyle) were graded by an experienced board certified radiologist using the modified Whole Organ Magnetic Resonance Imaging Score (WORMS) (Alizai et al., 2014; Peterfy et al., 2004; Souza et al., 2013; Stehling et al., 2010). Cartilage lesions were graded as follows: 0 = normal thickness, 1 = normal thickness, increased signal intensity, 2 = partial thickness focal lesion less than 1 cm of greatest width, 2.5 = full thickness focal lesion less than 1 cm of greatest width, 3 = multiple areas partial lesion less than 1 cm of greatest width, or grade 2 lesion wider than 1 cm but less than 75% of the region, 4 = diffuse partial thickness loss greater than 75% of the region, 5 = multiple areas of full thickness lesion greater than 1 cm but less than 75% of the region, and 6 = diffuse full thickness loss greater than 75% of the region (Peterfy et al., 2004). PFJ OA was defined if the patella or trochlea presented cartilage lesions in WORMS ≥ 2; TFJ OA was defined when the medial or lateral tibia, or medial or lateral femoral condyle presented cartilage lesions in WORMS ≥ 2 (Stefanik et al., 2013).

The 112 recruited subjects were then stratified into: no OA (n = 46), isolated PFJ OA (n = 35), isolated tibiofemoral joint OA (n = 9) and mixed PFJ and tibiofemoral joint OA (n = 22). To avoid potential influence of tibiofemoral joint OA on gait characteristics, 35 subjects with isolated PFJ OA and 35 age- and body mass index (BMI)-matched controls with no OA were included in this study. Prior to data collection, all subjects signed a written informed consent approved by the Committee of Human Research at the University of California, San Francisco. All participants completed the Knee injury and Osteoarthritis Outcome Score (KOOS) survey (100 = no symptom, 0 = maximum symptom) and the short-form International Physical Activity Questionnaire (IPAQ). In addition, all participants also completed the six-minute-walk, time-up-and-go, and stair-climbing tests to determine overall functional capacity.

2.2. Gait analysis

Three-dimensional lower extremity kinematics were recorded using a 10-camera motion capture system (VICON, Oxford Metrics, Oxford, UK) at a sampling rate of 250 Hz. Ground reaction force data were obtained using two embedded force platforms (AMTI, Watertown, MA, USA) at a sampling rate of 1000 Hz. Marker and ground reaction force data were collected and synchronized using motion capture software (Nexus, Oxford Metrics, Oxford, UK).

Prior to the walking test, retro-reflective (14 mm spheres) anatomical markers were placed on the following bony landmarks: L5/S1 junction, bilateral iliac crests, anterior superior iliac spines, greater trochanters, medial and lateral femoral epicondyles, medial and lateral malleoli, and 1st and 5th metatarsal heads. Additionally, tracking marker clusters mounted on semi-rigid plastic plates were placed bilaterally on the lateral surfaces of the subject's thighs, shanks, and heel counters of the shoes. A standing calibration trial was obtained to define the segment coordinate systems and joint axes. After the calibration trial, anatomical markers were removed, except for those on the L5–S1 junction, iliac crests, and anterior superior iliac spine, which served as tracking markers for the pelvis. The tracking markers remained on the subject throughout the entire data collection session.

Subjects were instructed to walk at two different speeds: 1) self-selected speed (purposeful walk, described to subjects as “you have some place to be, but you are not late”) (Free-Walk) and 2) as fast as possible (Fast-Walk). Five successful trials were obtained for each walking condition. A successful trial was defined when the foot of the tested limb fell within borders of either of the force platforms from initial contact to toe-off and the speed was within ±5% of the first successful trial.

2.3. Data process

Kinematic and kinetic data were computed using Visual3D (C-Motion, Germantown, MD, USA) and MATLAB software (Mathworks Inc., Natick, MA, USA). Marker trajectory data were low-pass filtered using a 4th-order Butterworth filter with a cutoff frequency at 6 Hz. Joint axes were defined by the anatomical markers placed during the standing calibration trial. Hip joint center was defined as one-fourth the distance between the markers on bilateral greater trochanters. Knee joint center was defined as the midpoint of the distance between the markers on the medial and lateral epicondyles of the femur in a plane defined by the hip joint center, knee joint center, and the marker placed on the greater trochanter. Ankle joint center was defined as the midpoint of the distance between the markers on the medial and lateral

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