Clinical Biomechanics 35 (2016) 56–61

Contents lists available at ScienceDirect

Clinical Biomechanics

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

# Proximal mechanics during stair ascent are more discriminate of females with patellofemoral pain than distal mechanics

Danilo de Oliveira Silva [a], Christian John Barton [b,c], Marcella Ferraz Pazzinatto [a], Ronaldo Valdir Briani [a], Fábio Mícolis de Azevedo [a,*]

[a] Physical Therapy Department, School of Science and Technology, University of São Paulo State, Presidente Prudente, Brazil
[b] Lower Extremity Gait Studies, La Trobe University, Australia
[c] Centre for Sports and Exercise Medicine, Queen Mary University of London, London, UK

ARTICLE INFO

*Article history:*
Received 3 January 2016
Accepted 12 April 2016

*Keywords:*
Patellofemoral pain
Kinematics
Biomechanics
Stair ascent
Hip
Knee

ABSTRACT

*Background:* Several hypotheses have been proposed to explain the pathomechanisms underlying patellofemoral pain (PFP). Concurrent evaluation of lower limb mechanics in the same PFP population is needed to determine which may be more important to target during rehabilitation. This study aimed to investigate possible differences in rearfoot eversion, hip adduction, and knee flexion during stair ascent; the relationship between these variables; and the discriminatory capability of each in identifying females with PFP.

*Method:* Thirty-six females with PFP and 31 asymptomatic controls underwent three-dimensional kinematic analyses during stair ascent. Between-group comparisons were made for peak rearfoot eversion, hip adduction, and knee flexion. Pearson's correlation coefficients were calculated to evaluate relationships among these parameters. Receiver operating characteristic curves were applied to identify the discriminatory capability of each.

*Findings:* Females with PFP ascended stairs with reduced peak knee flexion, greater peak hip adduction and peak rearfoot eversion. Peak hip adduction (>10.6°; sensitivity = 67%, specificity = 77%) discriminated females with PFP more effectively than rearfoot eversion (>5.0°; sensitivity = 58%, specificity = 67%). Reduced peak hip adduction was found to be associated with reduced peak knee flexion ($r = 0.54$, $p = 0.002$) in females with PFP.

*Interpretation:* These findings indicate that proximal, local, and distal kinematics should be considered in PFP management, but proximally targeted interventions may be most important. The relationship of reduced knee flexion with reduced hip adduction also indicates a possible compensatory strategy to reduce patellofemoral joint stress, and this may need to be addressed during rehabilitation.



## 1. Introduction

Patellofemoral pain (PFP) is defined as an idiopathic anterior knee pain and is a common condition presenting to orthopedic and sports medicine practices (Witvrouw et al., 2014). The estimated prevalence of PFP among females aged 18–35 years is 13% (Roush and Bay, 2012). Moreover, the prevalence of PFP in females is 2.23 times more than males (Boling et al., 2010). Key symptoms include peri- and retro-patellar pain, but etiology remains debated with many biomechanical alterations reported in the literature (Lankhorst et al., 2013), highlighting the multifactorial nature of PFP. The consensus statement from the most recent international PFP retreat led by area experts grouped possible biomechanical factors into 3 mechanistic categories: proximal, distal, and local factors (Witvrouw et al., 2014).

The source of symptoms in PFP is highly debated and remains unclear (Witvrouw et al., 2014), although increased patellofemoral joint (PFJ) stress is frequently identified in people with PFP (Brechter and Powers, 2002; Heino Brechter and Powers, 2002). Several theoretical hypotheses have been proposed in an attempt to explain the pathomechanisms underlying PFP development (Barton et al., 2012). Distally, excessive rearfoot eversion is thought to lead to greater PFJ stress due to joint coupling more proximally (Powers, 2003; Tiberio, 1987). Specifically, during the stance phase of gait, an everted rearfoot may result in excessive internal rotation of the tibia due to joint coupling. Consequently, greater hip internal rotation and subsequent hip adduction may result to maintain normal sagittal plane mechanics of the knee, thereby increasing PFJ stress (Tiberio, 1987).

Proximally, weakness or delayed onset of hip abductor and hip external rotator muscles is thought to potentially contribute to excessive hip adduction during weight-bearing activities in individuals with PFP (Powers, 2003; Robinson, 2007). Importantly, greater hip adduction during running in females has been reported to be a risk factor for PFP

* Corresponding author at: Fábio Mícolis de Azevedo, Rua Roberto Simonsen, 305, Presidente Prudente, SP 19060-900, Brazil.
*E-mail address:* micolis@fct.unesp.br (F.M. de Azevedo).

http://dx.doi.org/10.1016/j.clinbiomech.2016.04.009
0268-0033/

development (Noehren et al., 2013). McKenzie et al., 2010 previously reported greater hip adduction during stair ascent and descent in individuals with PFP. However, distal mechanics were not evaluated, which could play an important role in the altered hip mechanics observed (Tiberio, 1987). Additionally, we recently reported greater rearfoot eversion range of motion during stair ascent in a cohort of females with PFP but did not evaluate peak ankles which are more commonly considered in clinical practice. Additionally, we did not concurrently evaluate hip kinematics (De Oliveira Silva et al., 2015a). Concurrent evaluation of proximal and distal mechanics during stair ascent in the same PFP population is needed to determine which may be more important to target during rehabilitation (Barton et al., 2009).

An important consideration when interpreting findings from cross-sectional research evaluating kinematics in individuals with PFP is the likely presence of kinesiophobia or fear of movement which may develop to limit stress on the PFJ (Domenech et al., 2013). In regard to stair ascent, which patients with PFP commonly report pain with, Crossley et al., 2004 reported reduced peak knee flexion in individuals with PFP. This compensatory strategy may reduce PFJ stress due to sagittal plane joint loading but may also alter frontal plane kinematics such as hip adduction and rearfoot eversion (Crossley et al., 2004).

To the best of our knowledge there is no study that has investigated distal (excessive rearfoot eversion) and proximal (increased hip adduction) kinematics alongside a well-known local kinematic protection mechanism (reduced knee flexion) in individuals with PFP during stair ascent. Furthermore, previous studies evaluating these variables separately have only reported between-group differences for peak hip adduction and rearfoot eversion, without any attempt to identify their ability to discriminate or identify individuals with PFP.

This study aimed to investigate (i) possible differences in peak rearfoot eversion, hip adduction, and knee flexion during stair ascent; (ii) the relationship between these variables; and (iii) the discriminatory capability of each in identifying individuals with PFP. It was hypothesized that compared to controls, those with PFP will demonstrate greater rearfoot eversion, hip adduction, and decreased knee flexion. It was also hypothesized that the hip will discriminate those with PFP better than local and distal factors evaluated.

## 2. Methods

### 2.1. Participants

Thirty-six females with PFP and thirty-one pain-free females were recruited. Mean (SD) age, height, mass, and physical activity level are presented in Table 1. Physical activity was evaluated with the self-administered International Physical Activity Questionnaire long form (Craig et al., 2003). Participants were recruited from gyms, parks, and universities between January and September 2014. The study was approved by the Local Ethics Committee (number: 306.729). Each participant gave written informed consent prior to participation. Power calculations for this study were performed using preliminary data (8 individuals) from our laboratory for peak knee flexion, hip adduction, and rearfoot eversion. The kinematic parameter (peak rearfoot eversion) with the highest standard deviation and the smallest difference between groups was used. Sample size was determined based on predicted power to detect a difference of 1.9° (3.3°SD) between the groups with an alpha of 0.05 and 80% power. A minimum sample size of 31 subjects per group was indicated. Diagnosis of PFP was completed following consensus from two experienced clinicians (>5 years' experience) and based on definitions used in previous PFP studies (Briani et al., 2015; De Oliveira Silva et al., 2015a,b,c). The inclusion criteria were (1) anterior knee pain during at least 2 of the following activities: prolonged sitting, squatting, kneeling, running, climbing stairs, and jumping; (2) pain during patellar palpation; (3) symptoms of insidious onset and duration of at least 1 month; (4) worst pain level in the previous month of up to 3 cm on a 10 cm visual analog scale (VAS); and (5) 3 or more positive clinical signs in the following tests: Clarke's sign (Nijs et al., 2006), McConnell test (Watson et al., 1999), Noble compression (Magee, 2008), and Waldron test (Nijs et al., 2006). Prospective participants were required to fulfill all 5 requirements to be included in the PFP group. To be included in the CG participants could not present any signs or symptoms of PFP or other musculoskeletal conditions. Exclusion criteria for both groups were events of patellar subluxation or dislocation, lower limb inflammatory process, lower limb surgery, patellar tendon or meniscus tears, bursitis, ligament tears, or the presence of neurological diseases. Those who had received oral steroids, opiate treatment, acupuncture, physiotherapy, or any other treatment for pain during the preceding 6 months were also excluded from this study.

**Table 1**
Demographics.*

| Variable | Control group Mean (SD) | PFP group Mean (SD) | p-value |
|---|---|---|---|
| Age | 22.07 (3.67) | 21.9 (2.72) | 0.428 |
| Mass (kg) | 62.3 (7.3) | 65.72 (10.76) | 0.098 |
| Height (m) | 1.65 (0.04) | 1.65 (0.05) | 0.736 |
| Worst pain level in the previous month (VAS) | 0.00 (0.00) | 5.32 (1.37) | 0.000* |
| Pain level during stair ascent task (VAS) | 0.00 (0.00) | 2.22 (2.21) | 0.000* |
| Cadence (steps/min) | 83.01(7.87) | 75.09(3.72) | 0.035* |
| Physical activity (MET·min·wk.$^{-1}$) | 3829.62 (655.56) | 4525.93 (382.88) | 0.631 |

* Statistically significant ($p < 0.05$) values. VAS = visual analogue scale.

### 2.2. Kinematic analysis

Data collection included lower limb kinematic evaluation of each participant's symptomatic limb (unilateral symptoms) or most symptomatic limb (bilateral symptoms) during stair ascent. For the CG, the dominant limb was evaluated. This activity was chosen as it frequently reproduces symptoms and abnormal movement patterns indicative of PFP (De Oliveira Silva et al., 2015a,b). Motion analysis was collected using a three-dimensional motion analysis system (Vicon Motion Systems Inc.; Denver EUA) combined with 4 cameras (type Bonita®B10) operating at a sampling frequency of 100 Hz with a resolution of 1 megapixel. Ground reaction forces were collected using a force plate (AMTI, OR6, Watertown, MA, USA) at a sampling frequency of 2000 Hz.

Kinematic analysis was completed using the Oxford Foot Model (OFM) combined with plug-in gait (PIG-SACR), which was previously reported as a valid and reliable approach (Barton et al., 2011, 2012; De Oliveira Silva et al., 2015a; Kadaba et al., 1990). Retroreflective markers (9.5 mm) were placed in accordance with the models by the same investigator on specific anatomical landmarks (Fig. 1).

Prior to data collection, we established an acceptable error of 0.08 mm when the motion-system calibration was performed. A relaxed standing calibration trial was then captured, after which the participants performed three practice stair ascent trials to allow familiarization with the instrumentation and environment; it is important to state that the subjects were not able to use handrails. A seven-step staircase, each step being 18 cm high and 28 cm deep, with a 2 m walkway in front of and behind the staircase, was used, with the fourth step being evaluated (Fig. 2). These dimensions are in accordance to the Brazilian Regulatory Standards for construction of stairs 9077/2001 (Brazilian Association of Technical Standards). Once participants felt they were comfortable, and the investigator deemed they were climbing the stairs with consistent velocity, kinematic data collection commenced. Each participant was asked to climb the staircase at their natural comfortable speed. Five successful trials were collected for each participant; the mean value of these five trials was used. To ensure a natural stair climbing pattern, participants were not aware of the force plate which was hidden within the fourth step; only the investigator knew of its