Clinical Biomechanics 38 (2016) 13–21

Contents lists available at ScienceDirect

Clinical Biomechanics

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

# Determination of patellofemoral pain sub-groups and development of a method for predicting treatment outcome using running gait kinematics

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ARTICLE INFO

*Article history:*
Received 14 December 2015
Accepted 6 August 2016

*Keywords:*
Patellofemoral pain
Running
Kinematics
Exercise therapy
Principal component analysis
Linear discriminant analysis

ABSTRACT

*Background:* Not all patients with patellofemoral pain exhibit successful outcomes following exercise therapy. Thus, the ability to identify patellofemoral pain subgroups related to treatment response is important for the development of optimal therapeutic strategies to improve rehabilitation outcomes. The purpose of this study was to use baseline running gait kinematic and clinical outcome variables to classify patellofemoral pain patients on treatment response retrospectively.
*Methods:* Forty-one individuals with patellofemoral pain that underwent a 6-week exercise intervention program were sub-grouped as treatment Responders ($n = 28$) and Non-responders ($n = 13$) based on self-reported measures of pain and function. Baseline three-dimensional running kinematics, and self-reported measures underwent a linear discriminant analysis of the principal components of the variables to retrospectively classify participants based on treatment response. The significance of the discriminant function was verified with a Wilk's lambda test ($\alpha = 0.05$).
*Findings:* The model selected 2 gait principal components and had a 78.1% classification accuracy. Overall, Non-responders exhibited greater ankle dorsiflexion, knee abduction and hip flexion during the swing phase and greater ankle inversion during the stance phase, compared to Responders.
*Interpretation:* This is the first study to investigate an objective method to use baseline kinematic and self-report outcome variables to classify on patellofemoral pain treatment outcome. This study represents a significant first step towards a method to help clinicians make evidence-informed decisions regarding optimal treatment strategies for patients with patellofemoral pain.



## 1. Introduction

Patellofemoral pain (PFP) is the most common injury among runners (Lopes et al., 2012; Taunton, 2002) and though exercise interventions have been shown to be effective (Witvrouw et al., 2014), between 15% and 40% of treated patients do not have successful rehabilitation outcomes (Collins et al., 2009; Crossley et al., 2002; Ferber et al., 2015). Investigations on the natural history of PFP indicate that the onset commonly starts during adolescence, with an alarming rate of unsolved or recurrent pain even after 10 years in a general population and among athletes (Blønd and Hansen, 1998; Stathopulu and Baildam, 2003). Therefore, the ability to both identify patient sub-groups at baseline and identify optimal individualized therapeutic strategies are needed to improve rehabilitation outcomes, as stated in the consensus statement from the 3rd International Patellofemoral Pain Research Retreat (Witvrouw et al., 2014).

The first-line treatment for PFP is considered to be a conservative approach, and the inclusion of quadriceps, gluteal and core exercise components has been recommended (Barton et al., 2015). Although exercise intervention has been shown to result in high treatment success rates, there remains a sub-group of patients who do not respond well to this approach (Ferber et al., 2015). It has been suggested that one of the factors influencing the differential response to exercise therapy are differences in gait biomechanics within patients with PFP (Witvrouw et al., 2014). Several studies have reported altered gait kinematic patterns in physically active individuals with PFP during the stance phase of walking and running gait, especially in the frontal and transverse planes, with greater hip adduction and internal rotation, knee abduction and external rotation, and rearfoot eversion (Bazett-Jones et al., 2013; Duffey et al., 2000; Noehren et al., 2013; Powers, 2003). In addition, some studies have indicated the presence of kinematic sub-groups that present distinct movement patterns during running (Dierks et al., 2011, 2008; Noehren et al., 2012). For example, Dierks et al. (2011) identified three distinct PFP sub-groups and suggested that different kinematic patterns could exist to explain the mechanical etiology of PFP. Noehren et al. (2012) also identified two

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http://dx.doi.org/10.1016/j.clinbiomech.2016.08.003

distinct kinematic patterns wherein at heel strike all PFP runners exhibited increased hip internal rotation compared to controls, but half of the PFP runners then demonstrated external hip rotation, whereas the other half oscillated between external and internal hip rotation. Thus, the existence of kinematic sub-groups in PFP runners has been documented, but the clinical significance of these sub-groups has not been established. These sub-groups could be indicative of differences in etiological factors, and possibly linked to differences in their response to exercise treatment. However, to our knowledge, no study has investigated this relationship.

Previous studies have identified factors that predict response to treatment in patients with PFP. For example, a moderate predictive strength was reported for subjective clinical variables such as self-reported pain and function scales (Collins et al., 2013; Lack et al., 2014). To our knowledge, only one investigation has included gait kinematics as an objective functional measure to predict treatment efficacy, but these authors restricted the analysis to discrete dynamic foot and ankle peak joint angles as predictors of a patient's response to foot orthoses (Barton et al., 2011). Therefore, further research is necessary to explore predictive treatment models using comprehensive gait information.

Gait kinematic and self-report variables were recently combined to identify responders to treatment in a population of knee OA patients (Kobsar et al., 2015). These authors reported that a combination of clinical variables and gait kinematics, representing an objective functional classifier, successfully identified responders to treatment. Interestingly, these authors reported that the knee OA patients who exhibited the lowest response to treatment actually exhibited gait kinematics that were more similar to pain-free controls. This approach could also be promising for identifying responders to exercise treatment in PFP individuals.

Therefore, the purpose of this study was to use baseline 3-dimensional (3D) running gait kinematic data and self-reported pain and function measures to classify recreationally active individuals experiencing PFP with respect to whether they were Responders or Non-responders to a 6-week rehabilitation protocol. An approach similar to Kobsar et al. (2015) was proposed whereby complex multidimensional gait kinematics are transformed using principal component analysis (PCA), important features are selected using cross-validation training, and the final classification model is created using a linear discriminant analysis (LDA). We hypothesized that a combination of baseline kinematic and clinical variables would provide a classification model that successfully identifies those who respond and those who do not respond to treatment. A secondary aim of this study was to explore the features selected by the treatment-response classification algorithm to provide clinical context to the data and compare the PFP sub-groups to a set of pain-free control subjects.

## 2. Methods

### 2.1. Subjects

For this investigation, a retrospective research design was used such that a data set comprised of subjects from two previous investigations were used for a secondary analysis. The main data came from a multicenter randomized controlled trial (RCT) (Ferber et al., 2015), consisting of 41 recreationally active patients with PFP (12 males and 29 females). Additionally, data from a growing research database were also used and an additional 26 PFP patients, matched for age (mean 30.7; SD 9.2 years), body mass index (mean 22.44; SD 2.77 kg/m$^2$), sex (12 males and 14 females) and running speed (mean 2.68; SD 0.12 m/s), that did not participate in the RCT intervention protocol, were included in the sample for the data reduction step to help improve the robustness of the gait kinematic model (Fig. 1). The inclusion and exclusion criteria are listed in Table 1. A set of kinematic data from 31 pain-free control participants (14 males and 17 females) were also included to be used as reference to compare to the PFP patients. These control subjects were also matched for age, sex and running speed.

### 2.2. Protocol

Demographic, clinical measures, and gait kinematic data were collected at baseline at the University of Calgary (Alberta, Canada). All participants read and signed an informed consent for participating in the study that was previously approved by the university's Conjoint Health Research Ethics Board. The PFP patients involved in the RCT study were randomly assigned, using a random-number generator, to one of two 6-week treatment protocols: either hip- and core-focused, or knee-focused strengthening.

Details about the treatment protocols were described in the previously mentioned RCT investigation (Ferber et al., 2015), however a brief description follows. The hip- and core-focused protocol started with non-weight-bearing exercises focusing on the activation of hip musculature, and progressed to weight-bearing exercises, including core-strengthening and balance exercises, with emphasis on stabilizing the core musculature before initiating any movement. The knee-focused protocol involved quadriceps strengthening exercises that also progressed from non-weight-bearing to weight-bearing modalities.

### 2.3. Clinical assessment

The self-reported clinical variables, used as inputs to the classification model included: (a) baseline pain, assessed by a visual analog scale (VAS), a 10 cm line addressing the worst pain in the previous week, with a score of 0 being *no pain* and 10, indicating the *most pain*, and (b) baseline physical function, quantified by the Anterior Knee Pain Scale (AKPS), a questionnaire with 13 weighted questions regarding knee function with a score of 100 denoting *no disability*, and

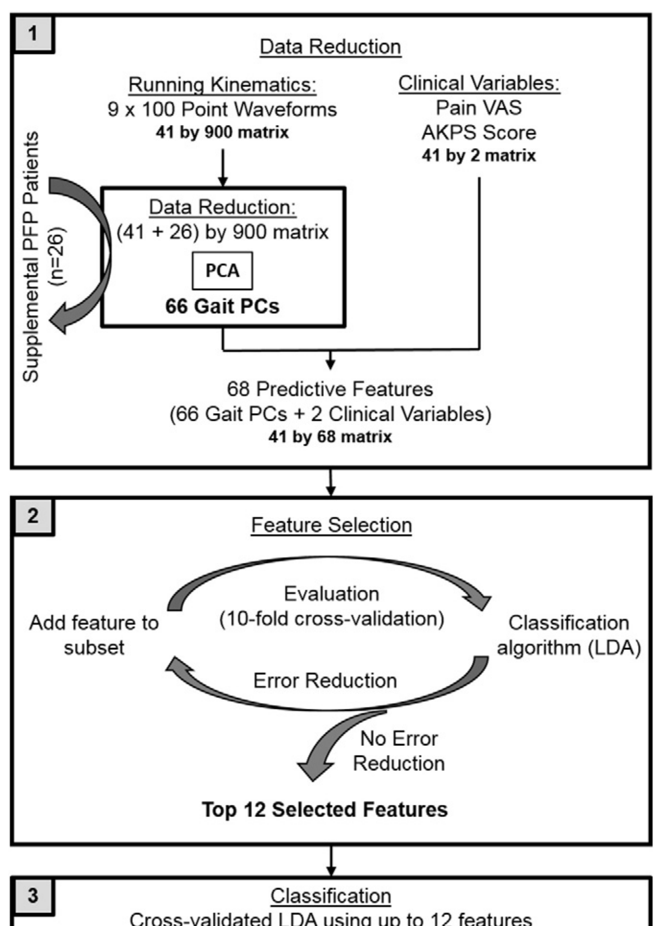


**Fig. 1.** Steps for the classification of PFP patients: (1) data reduction; (2) feature selection; and (3) classification.