



Kinematic and kinetic features of normal level walking in patellofemoral pain syndrome: More than a sagittal plane alteration

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ARTICLE INFO

Article history:

Accepted 10 February 2010

Keywords:

Patellofemoral pain syndrome

Gait analysis

Kinetic

Kinematic

ABSTRACT

Patients with patellofemoral pain syndrome (PFPS) often report discomfort and pain during walking. To date, most of the studies conducted to determine gait alterations in PFPS patients have focused on sagittal plane alterations. Physiological and biomechanical factors, however, suggest that frontal and transverse plane alterations may be involved in PFPS. We therefore decided to conduct a kinematic and kinetic evaluation on all three planes in 9 PFPS subjects and 9 healthy sex- and age-matched controls. General gait characteristics were similar in patients and controls, with the exception of swing velocity, which was lower in PFPS patients. Patients also displayed an increased knee abductor and external rotator moments in loading response, and reduced knee extensor moment both in loading response and in terminal stance. We speculate that these findings may be linked both to a pain-avoiding gait pattern and to alterations in the timing of activation of different components of the quadriceps muscle, which is typical of PFPS. The relevance for clinicians is this gait pattern may represent a biomechanical risk factor for future knee osteoarthritis. We therefore recommend that treatments aimed at PFPS should also attempt to restore a correct walking pattern.

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1. Introduction

Patellofemoral pain syndrome (PFPS) is a term used for a variety of pathologies or anatomical abnormalities leading to a type of anterior knee pain (Witvrouw et al., 2005) that typically occurs with activity and is exacerbated by stair climbing and prolonged sitting. Alterations in knee kinetics and kinematics remain controversial in people affected by PFPS. Reduced knee flexion during loading response phase (LR) of walking has been found in some studies (Dillon et al., 1983; Nadeau et al., 1997), though not in others (Heino Brechter and Powers, 2002; Powers et al., 1996, 1997, 1999). Moreover, women with PFPS exhibit different lower extremity mechanics in a variety of activities with progressive knee loading when compared with controls (Willson and Davis, 2008). From a kinetic point of view, PFPS patients generally display a reduced knee extensor moment during the LR (Besier et al., 2009; Heino Brechter and Powers, 2002), and a reduced peak vertical ground reaction force (GRF) (Powers et al., 1999). Heino Brechter and Powers (2002) found no difference in

the patellofemoral joint (PFJ) forces between subjects with and without PFPS. They did, however, establish that the contact area between the femur and patella was reduced in subjects in the PFPS group, who consequently displayed increased PFJ stress. The study of the kinematics and kinetics involved in the frontal and transversal planes has not been considered a major goal of biomechanical research in the field of PFPS, largely because measurement of the sagittal plane alone may yield an indirect evaluation of patella functioning. Determination of kinetic and kinematic changes that occur in the knee joint in both the frontal and transversal planes may, however, be relevant to the biomechanical analysis in the clinical setting. Indeed, it has recently been suggested that increased knee abductor and knee external rotator moments during the stance phase of stair climbing and locomotion up an incline may be considered as biomechanical markers in the assessment of mechanisms involved in the development of knee osteoarthritis (OA) in the elderly (Karamanidis and Arampatzis, 2009). It is also suggested that kinematic and kinetic changes in the transversal plane at the knee joint play a specific role in the initiation of local degenerative cartilage alterations by shifting the mechanical load within the load-bearing regions of the knee (Andriacchi et al., 2004). This fact supports the numerous reports of an increased incidence of knee OA in patients who have experienced abnormal joint motion and

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mechanical load, such as those with anterior cruciate ligament injury or generalized joint laxity (Andriacchi et al., 2004).

We hypothesized that PFPS subjects may display abnormal knee joint moments in the frontal and transversal planes during gait due to a neuromuscular dysfunction that normally occurs in such patients. Subjects with PFSP, in fact, display a dysfunction of PFJ neuromotor control as a result of an imbalance in the timing of vastus medialis obliquus (VMO) and vastus lateralis (VL) activity (Cowan et al., 2001; Witvrouw et al., 1996), there being a significant delay in the electromyographic onset of the VMO when compared with that of the VL (Cowan et al., 2001). This fact may lead to abnormal patellar tracking within the trochlear groove. It should be considered, furthermore, that the quadriceps muscle, whose function is altered in PFPS subjects, provides the most knee stability on the frontal plane (Shelburne et al., 2006) and may influence tibial rotation (Li et al., 1999).

We therefore designed an explanatory (Bender and Lange, 2001), cross-sectional trial to investigate the kinetic and kinematic features on the transversal, frontal and sagittal planes of the walking pattern in PFPS subjects by means of instrumental gait analysis and to compare these features with those of a control group of healthy subjects.

2. Methods

2.1. Subjects

The experimental group (EG) was composed of 9 patients (2 men, 7 women) affected by PFPS (mean disease duration: 9.5 ± 1.5 months). In order to be included, patients had to report anterior or retropatellar knee pain in at least two of the following activities: prolonged sitting, climbing stairs, squatting, running, kneeling, and hopping or jumping. In addition, they had to have pain upon palpation of the patella, to have a pain level of 3 cm or more on a 10-cm visual analogue scale (VAS) while stepping down from a 25-cm step or during a double leg squat, to have had symptoms for at least 1 month, to have an average pain level of 3 cm or more on a 10-cm VAS, and to have had an insidious onset of symptoms unrelated to a traumatic incident. Participants were excluded if they had the following: a recent history (within 6 months) of knee surgery or of patellar dislocation or subluxation; clinical evidence of a meniscal lesion, ligamentous instability, traction apophysitis around the patellofemoral complex, patellar tendon pathology, chondral damage or osteoarthritis; pain referred to the spine. A total of 9 age- and sex-matched healthy subjects (2 men, 7 women) were also enrolled to form the control group (CG). The study protocol was approved by the local ethics committee and the participants' informed consent was obtained.

2.2. Instrumental evaluation

Gait analysis was performed using the ELITE system (BTS, Milano, Italy), with 8 infrared video cameras (TVC, BTS, Milano, Italy) for the acquisition of the kinematic variables. Two Kistler platforms (Kistler Instruments, Winterthur, Switzerland) were used to acquire the GRF. Kinematic and kinetic data were acquired and digitized with a sampling rate of 100 Hz. Anthropometric data were collected for each subject and retroreflective spherical markers were placed over prominent bone landmarks to determine the joint centers and segment axis (Davis et al., 1991). Subjects were then instructed to walk at a self-selected speed along a level surface approximately 10 m in length; three valid trials were acquired for each subject and the mean value was considered for time/distance, kinematic and kinetic data throughout the analysis. A valid trial was defined as one in which subjects struck the force platforms without adjusting their stride length. The affected side was analyzed in the EG, while either the right or left side was randomly used for the analysis in the CG.

Mean velocity (m/s) was assessed to ensure that any kinetic and/or kinematic differences between groups were not due to differences in gait speed. Swing velocity (distance travelled in the swing/swing duration) was also assessed.

Three-dimensional marker trajectories during walking were obtained by means of a frame-by-frame tracking system (Tracklab, BTS, Milano, Italy) and joint angular excursion, defined as a rotation of the distal segment relative to the proximal segment in our biomechanical model (Vaughan et al., 1999), was calculated; joint excursion data were normalized to the stride duration and reduced to 100 samples over the gait cycle. The following parameters were considered for the kinematic evaluation: (i) knee flexion angle at heel contact (HC), (ii) knee flexion range of movement (ROM) during the LR (defined as the first sub-phase from initial contact until contralateral toe-off, i.e., 0–12% of the gait cycle)

(Vaughan et al., 1999), (iii) hip and knee abduction peak during the LR and (iv) hip and knee rotation ROM during the whole gait cycle.

Net internal joint moments were calculated by means of an inverse dynamics approach. Joint moments were normalized to the subject's body weight. We considered the following parameters for the kinetic analysis: (i) in the LR, we assessed the hip and knee extensor, abductor and external rotator moment peaks and (ii) in the terminal stance sub-phase (TS), we assessed the hip flexor, abductor and internal rotator moment peaks, as well as the knee extensor, abductor and internal rotator moment peaks. We also considered the peak values of the vertical GRF curve.

2.3. Statistical analysis

Statistical analysis was performed using the SAS8.2 (SAS Institute Inc., Cary, NC, USA). Data normality was verified by means of the Shapiro–Wilk test. The mean value $\pm$ standard deviation of each parameter was calculated in both the EG and CG. The unpaired *t*-test or Mann–Whitney test was used to evaluate the significance of differences between the EG and CG. A *p* value of less than 0.01 was considered statistically significant.

3. Results

No significant differences were observed between PFPS subjects and controls in mean age [EG: 28.1 ± 8.1 (range 19–45) years; CG 28.3 ± 5.9 (range 21–38) years], in mean height [EG: 1.71 ± 0.09 (range 1.60–1.82) m; CG: 1.70 ± 0.09 (range 1.60–1.86) m] or in mean body weight [EG: 64.4 ± 9.5 (range 55–80) kg; CG: 64.2 ± 10.8 (range 53–83) kg]. The mean velocity did not differ significantly between groups [EG 1.1 ± 0.15 m/s; CG 1.15 ± 0.16 m/s; $p=0.5$]. Patients in the EG, however, displayed a significantly slower swing phase velocity than those in the CG [EG 2.44 ± 0.28 m/s; CG 2.95 ± 0.46 m/s; $p=0.01$]. The kinematic results are summarized in Table 1. A greater degree of adduction was observed during the LR in the knee of PFPS patients than in that of controls. The kinetic results are provided in Table 2. During the LR, patients in the EG exhibited an increase in knee external rotator moment associated with a marked reduction in the knee extensor moment, when compared with subjects in the CG. Increased hip and knee abductor moment was also noted in EG. In the TS, knee extensor moment was significantly lower in the EG than in the CG. Hip abductor moment in the TS was also significantly greater in the EG than in CG. The results of the GRF analysis are provided in Table 3. The vertical GRF peak at HC was significantly lower in the EG than in the CG (Fig. 1), whereas no differences were observed between the two groups in any of the other parameters analyzed.

4. Discussion

Subjects with PFJS generally have anterior knee pain that is exacerbated by knee loading activities. It has been hypothesized that the load exerted by walking upon the PFJ is not sufficient to reveal consistent biomechanical alterations, it being suggested that stair ambulation is a more appropriate means of eliciting such changes since the latter activity loads the PFJ to a greater degree (Costigan et al., 2002). Strategies that tend to minimize knee loading during gait have been widely described in PFPS patients with gait limitations (Nadeau et al., 1997; Powers et al., 1997). Moreover, as walking is the most important loading activity performed on a daily basis, any factors involved in gait that may explain joint pathology progression warrant investigation.

The results of our study confirm our initial hypothesis, i.e. that altered knee joint moments may be observed not only on the sagittal plane but also on the transversal and frontal planes. It is noteworthy that the present study shows, to the best of our

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