Clinical Biomechanics 24 (2009) 88–94

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Kinematic analyses during stair descent in young women with patellofemoral pain

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ARTICLE INFO

Article history:
Received 11 April 2008
Accepted 9 September 2008

Keywords:
Motor control
Knee
Model
Biomechanics
Three-dimensional

ABSTRACT

Background: Compensatory movement strategies may develop in response to pain to avoid stress on the affected area. Patellofemoral pain is characterised by intermittent periods of pain and the present study addresses whether long-term pain leads to compensatory movement strategies that remain even when the pain is absent.
Method: Lower extremity kinematics in three dimensions was studied in stair descent in 17 women with patellofemoral and in 17 matched controls. A two-dimensional geometric model was constructed to normalise kinematic data for subjects with varying anthropometrics when negotiating stairs of fixed proportions.
Results: There were minor differences in movement patterns between groups. Knee joint angular velocity in the stance leg at foot contact was lower and the movement trajectory tended to be jerkier in the patellofemoral group. The two-dimensional model showed greater plantar flexion in the swing leg in preparation for foot placement in the patellofemoral group.
Interpretation: The results indicate that an altered stair descent strategy in the patellofemoral group may remain also in the absence of pain. The biomechanical interpretation presumes that the strategy is aimed to reduce knee joint loading by less knee joint moment and lower impact force.
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1. Introduction

Musculoskeletal pain has the potential to influence motor activity. Increases as well as decreases in muscle activity have been shown, as well as more complex changes in posture and movement patterns (Sterling et al., 2001). Altered movement patterns have been studied mainly by the induction of experimental muscle pain (Sterling et al., 2001), but there are also studies on clinical pain showing that long-term pain may alter motor activity, and that such changes can remain even in the absence of pain (Hodges and Richardson, 1996, 1999; Stensdotter et al., 2008a).

The precise neurophysiologic bases for such changes are not well understood. However, reduced muscle activation may be a useful adaptation to pain that limits both the velocity and range of movement, protecting the affected body part from potential or further injury (Lund et al., 1991). Alternatively, an altered movement pattern may reflect a disruptive effect of pain on neuromuscular control, sometimes called "pain interference" (Moseley and Hodges, 2005). Pain processing appears to be of highest priority in the central nervous system (CNS), often causing interference with motor activities as well as mental processes (Crombez et al., 1996).

In patients with patellofemoral pain (PFP) there is evidence for altered movement patterns, for instance slower walking velocity (Powers et al., 1996) and decreased knee flexion during the stance phase of gait (Nadeau et al., 1997). PFP is a common problem in a physically active population, especially among young women (Thomee et al., 1995). Pain is usually described as retropatellar, and symptoms are of intermittent character, aggravated during activities requiring high levels of quadriceps activity such as running, squatting and stair walking (Brechter and Powers, 2002). The aetiology of PFP has not yet been clearly established, but it is commonly believed that symptoms are the result of an elevated patellofemoral joint stress, described as force per unit area (Goodfellow et al., 1976). A number of causative mechanisms has been postulated, such as a too rapid increase in the level of physical activity, anatomical malalignment of the lower extremity and/or patella (Thomee et al., 1999) or muscular imbalance between the different vasti of the quadriceps muscle (Cowan et al., 2001).

An increase in knee flexion angle or quadriceps muscle force during weight bearing activities will give rise to an elevated patellofemoral joint reaction force (Buff et al., 1988). Walking down stairs has been shown to increase the compressive forces in the patellofemoral joint up to eight times compared to level walking (Costigan et al., 2002). Consequently, stair walking is commonly reported to provoke knee pain in PFP patients. It is

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0268-0033/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2008.09.004

thus reasonable to expect altered movement patterns that reduce loading of the patellofemoral joint in such activities. Stair walking is accordingly often used to reveal abnormal movement patterns indicative of PFP or to reproduce the patients' symptoms in clinical examination (Salsich et al., 2001). Some clinical observations have been confirmed by research, like a slower cadence during stair descent and a reduction in the peak knee extensor moment during both ascent and descent (Brechter and Powers, 2002; Salsich et al., 2001). The findings on knee flexion during stair ambulation are conflicting. To our knowledge, six previous studies have examined knee flexion in persons with PFP during stair descent. Two reported reduced knee flexion (Crossley et al., 2004; Greenwald et al., 1996), whereas four studies reported no significant differences in knee joint flexion during stair descent (Brechter and Powers, 2002; Crossley et al., 2005; Powers et al., 1997; Salsich et al., 2001).

When walking down stairs, the controlled lowering of the body from one step to the next is achieved through eccentric contractions of muscles controlling the hip, knee and ankle joints. Normal muscle activity and joint kinematics during stair walking have been carefully described by McFadyen and Winter (1988). The stance phase at stair descent can be divided into sub-phases described as *weight acceptance*, *forward continuance* and *controlled lowering*. *Weight acceptance* occurs from foot placement of the swing leg on to the lower tread to toe-off of the stance leg from the upper tread. The eccentric work in what is now the stance leg, is during this phase is normally dominated by m. triceps surae and m. quadriceps, implying energy absorption mainly at the ankle and knee joints. During the following *forward continuance* phase, the eccentric quadriceps work in the stance leg shifts for a brief period to concentric muscle activity, to extend the knee and make the body rise slightly when moving forward. From approximately mid-stance the *controlled lowering* phase starts, dominated by eccentric work of the quadriceps muscles and m. triceps surae contributing to the controlled forward translation of the body. The gluteus medius muscle in the stance leg contributes with a power burst at the controlled lowering phase as well (McFadyen and Winter, 1988).

The knee joint is most extended at the beginning of weight acceptance, i.e., at the time of initial foot placement, but yet normally remains in approximately 20 deg flexion (McFadyen and Winter, 1988), continuously increasing during the stance phase and into swing phase, after toe-off, to enable the forward lifting of the leg off the present step. The ankle joint describes an alternating movement between plantar and dorsal flexion, with the maximum plantar flexed position in the swing leg at foot placement, and the maximum dorsal flexed position in the stance leg late in the controlled lowering phase, coinciding with foot placement of the other foot. The hip joint normally never extends beyond 0 deg in stair descent. The maximal extended position is reached in the weight acceptance phase. The hip angle in the stance leg then changes only slowly towards flexion throughout the forward continuance and controlled lowering phases, to be most flexed during the swing phase. The hip joint kinematics in the frontal plane during stair walking has not been described to our knowledge.

The "smoothness" of knee angular motion during stair descent has been investigated by analyses of knee angular velocity graphs. Anderson and Herrington (2003) reported a "break phenomena", described as a perturbation in the velocity graph, to occur in persons with PFP. An alternative way to measure the smoothness of a movement, first known from studies on reaching, is to estimate the number of *movement units* (MUs), (von Hofsten and Rönnqvist, 1993). In concept, a MUs consists of one acceleration and one deceleration phase. Jerky movement is characterised by high numbers of alternating accelerations and decelerations. The concept of MUs has, to our knowledge, not been applied to studies on lower extremity kinematics.

The objective of the present study was to address whether lower extremity kinematics are altered in young women with PFP during stair descent. Specifically, we wanted to investigate the possible existence of altered movement strategies as a result of long-term pain, in a period when the persons were not significantly bothered with pain. The hypotheses were that individuals with PFP have adapted a pattern of reduced knee flexion, and that this is compensated by greater angular displacements in the hip and ankle joints. We also hypothesized a slower cadence among PFP subjects, a lower angular velocity of knee flexion movement, as well as reduced smoothness in the movement, estimated by the number of MUs during the forward continuance and controlled lowering phases.

2. Methods

2.1. Subjects

Seventeen women (age 27.7 (6.6) years, height 167 (8) cm, and weight 63 (9) kg; means and (SD)) clinically diagnosed with PFP were recruited through community based health clinics. Eleven of the PFP subjects had bilateral knee pain, six had unilateral pain. As we were interested in altered patterns of motor behaviour after long-term pain, we included only subjects with a history of pain $\geqslant$ 1 year. The subject were to be pain free on the test day, why we rated pain on a scale from 1 to 3, where 1 = *no pain*, 2 = *moderate pain* and 3 = *severe pain*. All participants rated a score of one when entering the test on the test day. Participants were excluded if they: (i) had a traumatic knee injury; (ii) suffered a diagnosed alternative knee or neuromuscular pathology; (iii) had previous surgery to the lower extremities; or (iv) were athletes performing on elite level. As controls 17 women were recruited (age 26.0 (4.6) years, height 167 (4) cm, and weight 61 (4) kg; means and (SD)) from students and staff, and who had no present or previous knee pain or injury. Controls were matched to PFP subjects according to age, weight, height, and leg preference. Prior to participation, all subjects received verbal and written information about the project and signed a consent form according to the declaration of Helsinki. The project was approved by the regional ethical review board.

To describe the study population, the subjects with PFP completed a self administered questionnaire: knee injury and osteoarthritis outcome score (KOOS; Roos et al., 1998). The scale ranges from 0 to 100, where 0 indicates extreme symptoms and 100 indicates no symptoms. The mean (SD) scores in the five sub-categories were: pain = 51.2 (3), other symptoms (such as swelling and stiffness) = 24.4 (2), function in daily living = 52.6 (3), function in sport and recreation = 51.5 (2), knee related quality of life = 47.0 (2).

2.2. Procedure: stairs and stair walking

The participants performed the stair walking task barefoot and with arms folded across the chest. Starting from a standardised position with feet within marked squares on top of a free-standing stair module without rails they descended three steps down to the floor level (step height = 16.0 cm, width = 29.0 cm, Fig. 1). They were instructed to stand relaxed until hearing a sound signal, upon which starting to descend at a self-selected pace along a central line down the stairs and to stop with the feet side by side when having reached the floor. Each participant completed five consecutive trials taking the first step with the right leg, and then another five trials starting with the left leg.

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