Medial contact and smaller plantar loads characterize individuals with Patellofemoral Pain Syndrome during stair descent

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ABSTRACT

Objectives: To investigate plantar pressure distribution in individuals with and without Patellofemoral Pain Syndrome during the support phase of stair descent.

Design: Observational case–control study.

Participants: 30 young adults with Patellofemoral Pain Syndrome and 44 matched controls.

Main outcome measures: Contact area, peak pressure and pressure–time integral (Novel Pedar-X system) were evaluated in six plantar areas (medial, central and lateral rearfoot; midfoot; medial and lateral forefoot) during stair descent.

Results: Contact area was greater in the Patellofemoral Pain Syndrome Group at medial rearfoot (p < 0.019) and midfoot (p < 0.001). Subjects with Patellofemoral Pain Syndrome presented smaller peak pressures (p < 0.001).

Conclusion: The pattern of plantar pressure distribution during stair descent in Patellofemoral Pain Syndrome subjects was different from controls. This seems to be related to greater medial rearfoot and midfoot support. Smaller plantar loads found in Patellofemoral Pain Syndrome subjects during stair descent reveal a more cautious motor pattern in a challenging task.

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1. Introduction

Patellofemoral Pain Syndrome (PFPS) is one of the most common musculoskeletal dysfunctions of the knee joint, affecting 25–30% of the general population, mainly physically active young women (LaBella, 2004; Tauton, Ryan, Clement, McKenzie, Lloyd-Smith, et al., 2002). Despite its high incidence, the etiology of its multifactorial origin remains unclear.

PFPS is believed to be related to the reduction of the contact area in the patellofemoral joint, which occurs due to alterations in the dynamic alignment of the tibiofemoral joint (Salsich & Perman, 2007). There is a theory that excessive and/or prolonged pronation of the rearfoot leads to excessive medial rotation of the tibia in a closed kinetic chain (Tibério, 1987). This medial rotation of the tibia could induce a compensatory medial rotation of the femur to maintain the relative lateral rotation of the tibial plateau in relation to the femoral condyles associated with knee extension during the midstance phase of gait. When the femur medially rotates, the compression between the lateral joint surface of the patella and the lateral femoral condyle rises, consequently increasing patellofemoral joint stress (Gross & Foxworth, 2003; LaBotz, 2004; Powers, 2003).

Kinematic studies that have investigated the relationship between PFPS and greater or prolonged foot pronation as well as greater or prolonged rearfoot evasion have produced controversial findings. Some authors have observed a delayed time of peak rearfoot evasion and a larger rearfoot evasion angle at the heel strike transient during gait (Levinger & Gilleard, 2005; Levinger & Gilleard, 2007) as well as greater pronation during a lateral stepdown task in subjects with PFPS (Earl, Hertel, & Denegar, 2005) while others did not confirm a correlation of greater pronation and PFPS (Messier, Davis, Curl, Lowery, & Pack, 1991; Powers, Chen, Reischl, & Perry, 2002). One of the limitations of these latter studies was that rearfoot motion could not be differentiated from forefoot motion. As total foot pronation comprises two events – rearfoot evasion during weight acceptance and midfoot/forefoot loading during early midstance – modeling the foot as a rigid segment may lose information about its flexibility during motor tasks (Powers et al., 2002). Alternatively, an indirect way of evaluating the kinetic
chain results of foot rollover during ground contact as well as the forces produced during locomotor tasks is the assessment of plantar pressure distribution.

A prospective study (Willems, De Clercq, Delbaere, Vanderstraeten, De Cock, et al., 2006) of 400 volunteers found that subjects who developed lower extremity injuries presented alterations in plantar pressure distribution, with greater pressure on the medial portions of the plantar surface associated with greater rearfoot pronation during running. Thijs et al. (Thijs, Van Tiggelen, Roosen, De Clercq & Wittvrouw, 2007) evaluated plantar pressure during soldiers’ barefoot gait and observed a relationship between PFPS and lateralized support of the feet, suggesting that subjects who developed PFPS had a heel strike in a less pronated position and rollover on the lateral side of the foot. The results of plantar pressure distribution and its relationship with lower-limb injuries and pain demonstrated that there is no consensus in the literature and that more investigation is needed. Moreover, evaluation of plantar pressure distribution can increase the scientific basis for PFPS rehabilitation by elucidating foot-floor interaction as a consequence of motor strategies of lower limbs adopted during locomotor tasks.

The studies cited earlier were carried out while subjects were running and walking (Levinger & Gillean, 2005; Levinger & Gilleard, 2007; Messier et al., 1991; Powers et al., 2002). Evaluation of motor tasks that are more challenging in terms of mechanical and muscular demands, such as managing stairs, may further contribute to the understanding of compensatory mechanisms generated by subjects with PFPS that are not observed during walking (Sacco, Konno, Rojas, Arnone, Passaro, et al., 2006).

The purpose of this study was to investigate the plantar pressure distribution in individuals with and without Patellofemoral Pain Syndrome during the support phase of stair descent. Our hypothesis was that subjects with PFPS should have medially-directed support when compared to control subjects: in other words, higher pressure and greater contact area on the medial border of the plantar surface during stair descent.

2. Methods

2.1. Subjects

Seventy-four adults (18–45 years) volunteered for the study and were divided into two groups: Patellofemoral Pain Syndrome Group (PFPS) (n = 30; mean ± SD, 30 ± 7 years of age; 165 ± 9 cm; 63 ± 11 kg) and Control Group (CG) (n = 44; mean ± SD, 30 ± 8 years; 165 ± 8 cm; 60 ± 11 kg). Groups were matched for age (p = 0.698), height (p = 0.935), and body mass (p = 0.734). All participants gave their written informed consent, which was approved by the Local Ethics Committee (protocol n.1237/05).

The PFPS group included 26 female and 4 male subjects with pain in the patellofemoral joint region for at least two months (mean ± SD, 4 ± 3 years, range 0.5–10). Their pain arose in at least one of the following situations: resisted contraction of the quadriceps, squatting, prolonged sitting, descending or ascending stairs. They were excluded if they had undergone any previous knee surgery, if they had a history of patellar dislocation or if they had any other limitations that would influence gait.

To better characterize the knee function of PFPS and CG subjects, the Lysholm Functional Knee Scale was individually evaluated. The average (median) Lysholm score was 68 (range, 40–85) for PFPS and 98 (range 85–100) for CG (Natri, Kannus, & Jarvinen, 1998).

The control group consisted of 39 female and 5 male subjects who had no history or diagnosis of knee pathology or trauma, no knee pain with any of the activities mentioned and no limitations that would influence gait.

Overall exclusion criteria for both groups were a discrepancy of 1 cm. (Eng & Pierrynowski, 1994) or greater in lower leg length and major foot deformities. The arch index (Cavanagh, Rodgers, & Libishi, 1987) was evaluated in order to exclude major arch alterations (planus, equinus planus and extra cavus feet) that could interfere in gait mechanics.

The intensity of knee pain in individuals with PFPS was measured with a Visual Analogue Pain Scale (VAS) in order to characterize the pain intensity. VAS is reliable, valid and responsive in assessing pain in persons with PFPS (Crossley, Bennell, Cowan, & Green, 2004). The intensity of pain in the PFPS group was 1.6 ± 2.3 cm [range 0–7.9], and the control subjects presented a knee pain intensity equal to 0.0 cm.

As PFPS is common in physically active individuals, it is important to note that both groups were similar in terms of physical activity undertaken (GC = 51.1%, PFPS = 41.4%; p = 0.508). Both groups were also similar in how many years they had been physically active (GC = 5 ± 5 years [range 1–20]; PFPS = 3 ± 4 years [range 1–20]; p = 0.817), as well as the frequency (GC = 3 ± 1 days/week [range 1–6]; PFPS = 3 ± 1 days/week [range 1–6]; p = 0.177) and duration (GC = 85 ± 38 min [range 30–270]; PFPS = 67 ± 2 min [range 45–120], p = 0.419) of the physical activity practiced (Shephard, 2003). Fifty percent of the PFPS group practiced sports activities (swimming and cycling), 32% fitness (conditioning and strength program) and 18% walking. Forty-three percent of the CG practiced sports activities (running, cycling and swimming), 33% fitness (conditioning and strength program) and 24% walking.

2.2. Measurement procedures

Evaluation of plantar pressure distribution was performed using the Pedar-X System (Novel, Germany) at a sampling rate of 100 Hz. The individuals were instructed to descend the five steps of a stair without using the handrail for support, placing a single foot on each step, while wearing only Pedar-X insoles inside anti-skid socks, as described in the literature (Burnfield, Few, Mohamed, & Perry, 2004). The insoles were 2.5 mm thick and contained a matrix of 99 capacitive pressure sensors with a spatial resolution of 1.6–2.2 cm². Prior to the tests, the insoles were calibrated according to the manufacturer’s instructions; before data acquisition, the zero setting procedure was performed as recommended by Novel (Hipao, Guan, & Weatherly, 2002).

Cadence during stair descent was controlled by a metronome at 96 steps/min in order to minimize cadence interference in pressure variables (Herrington & Pearson, 2006). The stair was composed of 5 steps of these dimensions: 16 cm height, 32 cm length and 60 cm width. Only the three central steps were considered valid for analysis, and a mean of approximately 9 steps per subject was used for statistical purposes.

The three variables evaluated were contact area (cm²), defined as the sum of the area of all loaded sensors in a determinate plantar region; peak pressure (kPa), defined as the highest pressure experienced by one sensor in the plantar region selected; and pressure–time integral (kPa.s), defined as the area under the peak pressure–time graphic in the selected plantar region. These three variables were evaluated in six plantar areas that were adjusted proportionally to the length and width of each subject’s foot with the Novel Multiprojects software. The plantar surface was first divided into three larger areas: rearfoot (30% of foot length), midfoot (30% of foot length), and forefoot (40% of foot length), following the scheme established by Cavanagh and Ulbrecht (1994). The rearfoot and forefoot were subdivided into medial rearfoot (30% of rearfoot width), central rearfoot (40% of rearfoot width) and lateral rearfoot (30% of rearfoot width); medial forefoot (55% of forefoot width) and lateral forefoot (45% of forefoot width) (Fig. 1).
greater at the medial rearfoot and midfoot in the PFPS. The peak pressure did not show any significant effect between groups and areas ($F = 1.166; p = 0.324$). However, there was a significant effect of group ($F = 3.342; p = 0.039$), and PFPS subjects showed smaller peak pressures (Fig. 2).

4. Discussion

The purpose of this study was to investigate the plantar pressure distribution in individuals with and without Patellofemoral Pain Syndrome during the support phase of stair descent. The main findings showed that while descending steps, subjects with PFPS presented a larger contact area at the medial rearfoot and midfoot as well as smaller peak pressures all over the foot, regardless of foot region.

The larger contact area in plantar regions corresponding to the medial rearfoot and midfoot in individuals with PFPS bears out the initial hypothesis of the study, which suggests more medially-directed support in these subjects. This result may also be attributed to a greater eversion of the rearfoot at ground contact. A reduction of the contact area at the midfoot was observed in the gait of subjects wearing shoes, which restricted medial-lateral movement compared to barefoot; this suggests an association of the contact area to the extent of foot pronation (Molloy et al., 2008).

The results found in the present study may corroborate this association in subjects with PFPS. The greater medial contact area at the rearfoot in PFPS subjects appears to be in agreement with studies that observed a relationship with a greater rearfoot eversion angle during gait (Levinger & Gilleard, 2005).

However, in a prospective study, Thijs et al. evaluated plantar pressure in the gait of soldiers and found laterally-directed support at initial contact as well as during the rollover in midstance in subjects who had developed PFPS (Thijs et al., 2007). According to these authors, the individuals evaluated underwent frequent high-intensity exercise with very short recovery periods, and any generalization of these results must be made cautiously to other individuals whose physical activity does not have the same characteristics. The present study evaluated a task of greater mechanical and muscular demands compared to the task evaluated in the Thijs et al. study (Thijs et al., 2007), which would reveal compensatory mechanisms that are not observed in less demanding tasks such as gait.

Subjects with PFPS presented smaller peak pressures when descending stairs, indicating that these individuals perform this motor task more cautiously with smaller loads than asymptomatic individuals. This finding is in agreement with a study (Powers, Heino, Rao, & Perry, 1999) that verified smaller ground reaction forces during walking in subjects with PFPS, and also with Brechter and Powers (Brechter & Powers, 2002), who observed smaller knee extensor moments in PFPS subjects when they were descending stairs. According to these authors, this strategy is related to an effort to minimize the reaction force in the patellofemoral joint by reducing overloads and thus trying to reduce knee pain, as can be confirmed in our results on plantar pressure.

Despite smaller peak pressures found in subjects with PFPS, the pressure–time integral was similar between groups. As the pressure–time integral is characterized by the peak pressure impulse, this similarity suggests that contact time may be greater in the PFPS, even though this increase was not shown to be significant and the cadence was controlled between groups. It is important to note that the cadence of the stair descent was controlled in the present study, which minimizes the possibility that smaller peak pressure observed in subjects with PFPS could be due to a reduced cadence.

2.3. Statistical data analysis

The sample size was calculated based on the primary outcome (the pressure variables) with an expected proportion of PFPS development of 30%, a power of 80% and a $\alpha$ of 5% (Breslow & Day, 1980; Tauton et al., 2002). Statistical inferential analysis was performed with Statistica v.7 software (Statsoft Inc.). For statistical purposes, pressure data of only one foot per subject was analyzed and compared. In the control group, the foot was randomly chosen for analysis. In the PFPS group, the foot chosen corresponded to the painful knee in subjects with unilateral pain and to the most painful region.

Plantar pressure variables followed a normal distribution (Shapiro–Wilk’s Test) and variances were homogeneous (Levene’s Test). Groups and areas were compared using 3 two-way ANOVAs ($2 \times 6$), considering the plantar areas (6) as repeated measures, followed by a Newman–Keuls post-hoc test. The level of significance was set at $\alpha = 5$.

3. Results

Table 1 shows the descriptive and statistical analysis for contact area and pressure–time integral in each plantar area for both groups. There was a significant effect of group and plantar areas for the contact area ($F = 3.343; p = 0.042$), which was significantly greater at the medial rearfoot and midfoot in the PFPS. The pressure–time integral did not present any statistical difference between groups and areas ($F = 1.166; p = 0.324$).

Fig. 1. Six plantar areas masked to the size of the Pedar insole. The areas consisted of the following: MR medial rearfoot, CR central rearfoot, LR lateral rearfoot, M midfoot, MF medial forefoot, LF lateral forefoot.
in performing the task when compared to the velocities of asymptomatic individuals.

According to a recent systematic review, there is some evidence to suggest that altered spatiotemporal gait characteristics as a reduced cadence may be present in individuals with PFPS. Consequently, it is very important to consider spatiotemporal gait characteristics during methodological designs of case–control studies that evaluate PFPS since reduced cadence has been reported to reduce joint motion, reversing possible differences between groups (Barton, Levinger, Menz, & Webster, 2009).

The fact that subjects with PFPS present medially-directed support during descent of stairs indicates that activities that require greater knee flexion and greater quadriceps action and therefore exacerbate the symptoms may reveal dynamic misalignments and plantar pressure alterations that, although still present, are far more subtle in less challenging tasks, such as walking, that have already been investigated (Levinger & Gilleard, 2005; Levinger & Gilleard, 2007).

It is important to mention that plantar pressure data provide an indirect way of evaluating the kinetic chain results of foot roll over during ground contact. Besides that, it should be mentioned that biological significance of differences found between groups in contact area should be viewed with caution due to the overlap in terms of standard deviation and confidence intervals found in these results. Studies that evaluate the rearfoot kinematics associated with plantar pressure distribution may confirm the results of this study. On the other hand, modeling the foot as a rigid segment – which is the most common procedure during kinematic evaluation – may lose information about its flexibility during motor tasks. In this sense, plantar pressure distribution may enrich information about the flexibility of foot excursion when associated with kinematic analysis.

The specific pattern of plantar pressure distribution found in this study during stair descent suggests a more medially-directed support at the rearfoot ground contact, probably as a consequence of greater rearfoot eversion – that has already been related to the occurrence of this knee dysfunction during gait (Levinger & Gilleard, 2005) – as well as a more cautious motor strategy to deal with this challenging task. A more medially-directed support at the rearfoot ground contact could be related to excessive medial rotation of the tibia and compensatory medial rotation of the femur, increasing the lateral pull of patella and consequently the force of adoption by subjects with PFPS focusing on foot dynamic misalignment and reduction of symptoms would restore plantar pressure distribution patterns during stair descent.

5. Conclusion

Subjects with PFPS show a larger contact area in the medial regions of the foot during stair descent, suggesting a more medially-directed support at ground contact. Individuals with PFPS present smaller plantar loads in a task that is more challenging than walking or running in terms of muscular and mechanical demands. This strategy reveals a more cautious motor pattern adopted by subjects with Patellofemoral Pain Syndrome when performing a challenging task.

Conflict of interest statement

All authors state that they do not keep any commercial, financial or personal relationships which may lead to a conflict of interests that could inappropriately influence (bias) their work. The study sponsors had no involvement in the study design, in the collection, analysis and interpretation of data; in the writing of the manuscript; or in the decision to submit the manuscript for publication.
Ethical statement

This study was approved by Research Ethical Committee, Clinical Hospital of the Scholl of Medicine, University of São Paulo (No. 1237/05).

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