CURRENT CONCEPTS REVIEW

The Effect of Patellofemoral Pain Syndrome on Gait Parameters: A Literature Review

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Abstract

Patellofemoral pain syndrome (PFPS) is one of the most frequent causes of anterior knee pain in adolescents and adults. This disorder can have a big effect on patients' ability and quality of life and gait. This review included all articles published during 1990 to 2016. An extensive literature search was performed in databases of Science Direct, Google Scholar, PubMed and ISI Web of Knowledge using OR, AND, NOT between the selected keywords. Finally, 16 articles were selected from final evaluation. In PFPS subjects, there was lower gait velocity, decreased cadence, and reduced knee extensor moment in the loading response and terminal stance, delayed peak rear foot eversion during gait and greater hip adduction compared to healthy subjects, while for hip rotation, there was controversy in studies. Changes in the walking patterns of PFPS subjects may be associated with the strategy used for the reduction of patellofemoral joint reaction force and pain.

Keywords: Kinematic, Kinetics, Patellofemoral pain syndrome, Spatiotemporal

Introduction

Patellofemoral pain syndrome (PFPS) is one of the most frequent cause of anterior knee pain in adolescents and adults (1). PFPS is defined as pain behind or around the patella caused by stress in the patellofemoral joint that usually provoked by climbing stairs, squatting, and sitting with flexed knees for long periods of time. The prevalence of this disorder among young adults in military varies from 7% to 15% (2). This syndrome, constitutes 5% of all injuries and 25% of knee injuries (3, 4). The syndrome is more common among obese people and athletes and it is more prevalent in women rather than men (3, 5-10).

This syndrome can be caused by intrinsic and extrinsic risk factors. Intrinsic risk factors included patella alta, patella poor flexibility and disorder of femoral articular surface. Extrinsic factors can be trauma, muscle dysfunction, quadriceps weakness, atrophy and weakness of internal oblique muscle, tight lateral structures such as iliotibial band and vastus lateralis oblique, increase of Q angle and excessive subtalar pronation (11-13). This disorder can have a big effect on patients' ability and quality of life and gait (11, 14).

Subtalar joint is slightly supinated during normal gait at the heel strike. During the contact phase, the subtalar joint is located in pronation. From foot flatted to midstance, the subtalar joint is reversed and set to supination. But in the patellofemoral pain syndrome, subtalar joint is not reversed and pronation of the subtalar joint in the middle phase of stance continues. Therefore eternal rotation of tibia and knee extension in midstance become impaired. In addition, compensatory internal rotation of the femur occurs to facilitate extension of tibiofemoral joint (15 16).

PFPS can affect gait parameters. Previous studies showed reduction of cadence during gait with decreased gait velocity in patient with PFPS (17-21). Differences in gait characteristics between PFPS and healthy subjects have been demonstrated. Salsich *et al.* and Paoloni *et*

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al. found significant decrease in knee extensor moment in PFPS subjects when compared with healthy control group (19, 21). A study by Roach *et al*. conducted in 2014 showed that PFPS was associated with a less passive hip range of motion but there was no statistically significant difference between healthy and PFPS groups in rotational range of motion. In addition, there are many investigations showing greater hip adduction, significant reduction of the knee flexion angle, delayed peak rearfoot eversion and shorter step length in PFPS during gait (5, 17-27). Many papers have been published to investigate the effect of gait on PFPS. But the literature is lacking a comprehensive study related to the analysis of gait in subjects with PFPS. Thus, the aim of this article is to provide an extensive evaluation of gait in individuals with PFPS.

To achieve this goal, this article reviewed selected papers which participants showed Patellofemoral pain syndrome and kinematic parameters, kinetic parameters with measured spatio-temporal parameters of the patients.

Materials and Methods

Search strategy

The search strategy was based on Population Intervention Comparison Outcome (PICO) which included all articles published during 1990 to 2016 [Table 1]. The search was performed in the databases of Science Direct, Google Scholar, PubMed and ISI Web of Knowledge using OR, AND, and NOT between the selected keywords to find relevant articles. The keywords were gait parameters, gait variability, spatiotemporal kinetic, kinematic, walking speed, velocity, cadence, stride length, stride width, energy consumption, and cost of walking, Finally, 16 articles were selected from final evaluation. The search and evaluation procedure followed the method recommended by Preferred Reporting Items for Systematic Review and Meta Analyses (PRISMA), [Figure 1].

Inclusion and exclusion criteria

Table 2 demonstrates considered inclusion and exclusion criteria to select articles. This review contains articles, which evaluated gait parameters in PFPS individuals. Studies, which involved other groups, were excluded including patella chondromalacia, knee osteoarthritis, and knee pain with other reasons. Also, studies which considered other disorders in knee joint were excluded. This review contains articles that utilized the following criteria including patellofemoral pain syndrome, gait parameters and walking. Only studies reported in English language were used for analysis.

Results

The following section summarizes the results demonstrated by studies investigating the effects of patellofemoral pain syndrome on gait parameters [Table 3].

Research question No. 1: the effects of patellofemoral pain syndrome on kinematic parameters

Cadence

Only three studies noted a decreased in cadence during walking and stair ambulation for PFPS compared to healthy subjects. The mean of this variable has been shown to be 74.0 steps per minute, 101.3 steps per minute and 114.1 steps per minute (21, 23, 28). However, Power *et al*. reported that there was no significant difference in cadence in initial contact during free and fast walking

Table 1. Selected key words used in this study based PICO

Population	Intervention	Comparison	Outcome
Individuals with Patellafemoral pain syndrome	No	Healthy People	Step length, stride length, single-limb support time, double limb support time, swing time, stance time. Cadence, gait velocity, knee flexion angle, ground reaction forces (vertical GRF, medial GRF), knee transverse and frontal plane angles. Hip adduction, hip abductor moment, hip internal rotation, hip extension torque, knee extensor moment, knee external rotation moment, knee abductor moment, tibia internal rotation, support moment, hip, ankle support moment.

Table 2. Inclusion and exclusion criteria utilized to select articles

Inclusion Criteria	Exclusion criteria
• Patellafemoral pain syndrome	• Other pathological condition
• Kinetic parameters in PFPS in gait	• Subjects have other functional limitation or disable
• Kinematic parameters in PFPS in gait	• Gait parameters in knee osteoarthritis subjects
• Spatiotemporal parameters in PFPS in gait	• Gait parameters in chondromallishia subjects
• Compared PFPS and healthy subjects in gait parameters	• Knee pain with other reasons

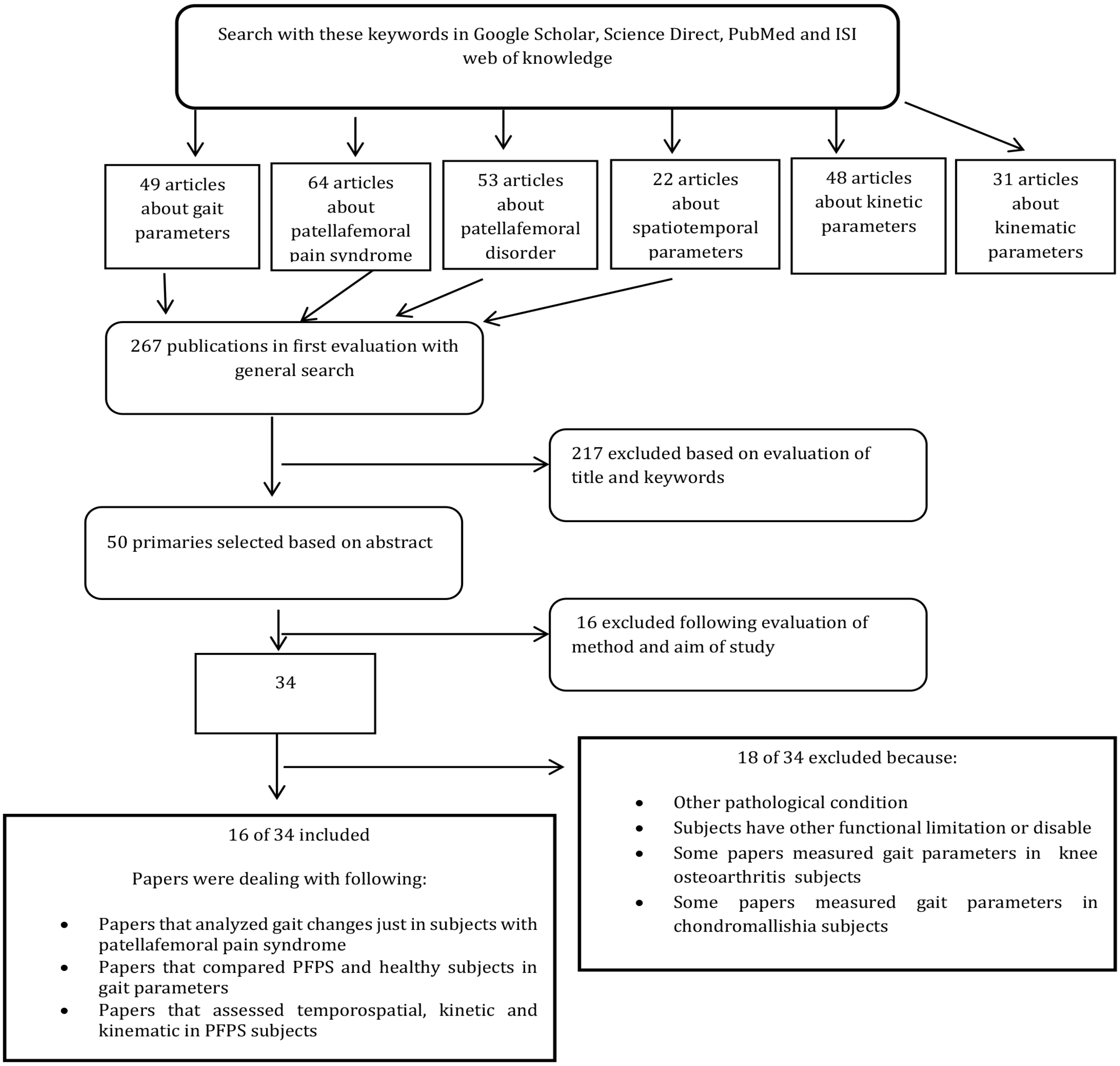

Figure 1. The procedure of article selection was followed using the PRISMA method.

(20). In a healthy subject the number of steps or cadence is 121 steps per minute (29). In most studies motion analysis was performed using a computer-aided video motion analysis system (Vicon).

Speed of walking

Typical walking speed is approximately 1.3 m/s during normal walking in healthy subjects. Three studies demonstrated that this can be reduced to 1.29 m/s, 0.94 m/s, or 1.2 m/s in PFPS subjects (20, 23, 28). One study revealed that there was a trend toward a reduction in gait velocity for the PFPS compared to the control group (1.37 m/s vs. 1.45 m/s, *P*=0.073) (17). However,another study reported that no significant difference on walking velocity between healthy and PFPS groups was observed (18). Paoloni reported that the mean velocity did not differ significantly between groups (1.17 m/s vs. 1.15 m/s, *P*=0.5). Patients with PFPS, however, displayed a significantly slower swing phase velocity than those in the normal people (2.44 m/s vs. 2.95 m/s, *P*= 0.01) (19). Motion analysis system was used in these studies.

Knee flexion angle

Two studies indicated that by using an inverse

Table 3. Studies investigating the effects of patellafemoral pain syndrome on gait parameters

Authors	Study design	Sample size	Outcome measures	Results
Willson *et al.* (2014)	Comparative study	10 PFPS F 13 H F	Step length	PFPS subjects displayed 14% increase of patellofemoral joint stress per mile in the long step length ($P < 0.001$) and decreased 7.5% in the short step length ($P < 0.001$). Therefore these individuals for a traverse a distance had a short step length despite the greater number of steps.
Noehren *et al.* (2012)	Comparative study	16 PFPS F 16 H	Hip adduction, hip internal rotation, pelvic drop, rearfoot eversion, tibia internal rotation, forefoot dorsiflexion and abduction	There was a Significantly greater hip internal rotation (9.8° (4.2)) in PFPS than the control group (5.2° (3.3)) ($P = 0.002$) and there was a greater peak hip adduction (20.0° (3.5)) than the control group (17.8° (2.6)) ($P = 0.046$). Although there was no difference in peak rearfoot eversion (−11.2° (4.0) vs. −9.4° (5.3), $P = 0.27$), forefoot dorsiflexion (7.2° (2.5) vs 7.5° (2.5), $P = 0.66$), or forefoot abduction (−12.5° (4.0) vs., −10.8° (3.2), $P = 0.16$). There was no significant differences in peak contra-lateral trunk lean ($P = 0.071$) and peak contra-lateral pelvic drop ($P = 0.304$) between groups.
Barton *et al* (2011)	Comparative Study	26 PFPS 20 H	Hip internal rotation peak rearfoot eversion rearfoot dorsiflexion gait velocity	There was less peak hip internal rotation ($P = 0.024$), earlier peak rearfoot eversion ($P = 0.010$) and greater rearfoot dorsiflexion range of motion relative to the laboratory ($P = 0.007$) in PFPS. Also the result showed reduced gait velocity ($P = 0.073$) in the PFPS group.
Aliberti *et al.* (2011)	Case-Control Study	22 PFPS 35 H	foot rollover pattern	PFPS participants showed a foot rollover pattern that is medially directed at the rearfoot during initial heel contact and laterally directed at the forefoot during propulsion
Barton *et al.* (2010)	Comparative study	20 PFPS 20 H	rear foot eversion	PFPS subjects during gait exhibit a significant rear foot eversion and delayed peak rearfoot eversion.
Paoloni, *et al.* (2010)	Comparative study	9 PFPS 9 H	Knee external rotation moment Knee abductor moment Knee extensor moment Hip abductor moment Vertical GRF swing velocity	Increased knee external rotation moment ($P = 0.007$), increased knee abductor moment peak ($P = 0.01$) in the loading response, reduction in the knee extensor moment during both loading response ($P = 0.005$) and terminal stance ($P = 0.003$), increased hip abductor moment during loading response and terminal stance ($P < 0.05$) and reduced vertical GRF at the heel contact ($P = 0.01$) were observed in PFPS subjects in comparison to a healthy group. Also there was no significant difference in vertical GRF at the loading response and terminal stance. In PFPS subjects swing velocity was lower in PFPS patients ($P = 0.01$) compared with healthy subjects.
Souza *et al.* (2009)	cross-sectional study	21 PFPS Female 20 H	Ground reaction forces Peak hip internal rotation Hip extension torque Peak hip adduction	PFPS individuals showed greater amount of peak hip internal rotation, ($P < 001$) and less hip extension torque when compared to the control group; ($P = .005$). Also, there was no significant difference for peak hip adduction between PFPS and healthy groups.
Willson *et al* (2008)	Case control study	20 PFPS F 20 H F	Ground reaction force Knee internal rotation Knee external rotation Hip internal rotation Hip adduction pelvic drop Foot externally rotated	When compared with healthy subjects, PFPS subjects produced 22% increase ground reaction force during single leg squats, 164% during running and 183% in single leg jumps. Also PFPS group had a 2.2 less knee internal rotation ($P = 0.05$), 4.3 greater knee external rotation ($P = 0.06$) and 3.5 greater contralateral pelvic drop than the control group across activities. Finding showed that PFPS subjects exhibited a decreased hip internal rotation ($P = 0.01$) and greater hip adduction ($P = 0.012$) during activities.
Bolgla *et al.* (2008)	Cross-sectional study	18 PFPS F 18 H F	Hip external rotator Hip abductor Hip and knee transverse and frontal plane angles	Hip external rotator 24% less ($P = 0.002$) and hip abductor torque 26% less ($P = 0.006$) in PFPS compared with healthy subjects. Average hip and knee transverse and frontal plane angles during stair descent were not different among the PFPS and healthy individuals ($P > 0.05$).
Dierks *et al.* (2008)	Research Support	20 PFPS 20 H	Hip adduction angle Hip abduction strength Hip abduction strength	PFPS subjects displayed significantly lower hip abduction strength ($P = 0.045$) but hip adduction angle for the PFPS was not statistically significant difference at the beginning of the run, however, it was significant at the end of the run.
Levinger *et al.* (2007)	Comparative Study	13 PFPS F 14 H F	Peak rearfoot eversion Peak dorsiflexion medial GRF vertical GRF Tibia transverse rotation	Peak medial GRF ($P = 0.03$), minimum vertical GRF trough ($P = 0.02$) and the second vertical GRF peak ($P = 0.01$) were significantly lower in the PFPS group. In PFPS peak rearfoot eversion ($P = 0.02$) significantly delayed but tibia transverse rotation was not different. However, there was prolonged rearfoot eversion during the stance phase of gait.

Continuous of Table 3.

Noehren *et al.* (2007)	Comparative study	13 PFPS F	Hip adduction Hip abduction moment Hip internal rotation Hip external rotation moment Time to peak rearfoot eversion	Compared with their healthy subjects, PFPS had greater hip adduction (*P* = 0.007) and greater hip external rotation moment (*P* = 0.07), but hip abduction moment was not greater (*P* = 0.896). Also individual with PFPS had a greater hip internal rotation through stance, although this was not significantly different (*P* = 0.47). The result indicated that There was no difference in the time to peak rearfoot eversion between groups.
Levinger *et al.* (2005)	Cross-sectional study	11 PFPS F 14 H F	Rearfoot eversion Rearfoot angle walking velocity	PFPS subjects at time of heel strike transient exhibit a rearfoot eversion. Also result demonstrated significantly delayed appearance of the peak heel strike transient (*P* = 0.04) and a reduction in its magnitude in the PFPS individuals (*P* = 0.03).There was a significant difference in the rearfoot angle in frontal plane between the control and PFPS group (*P* = 0.001) but no significant difference in the walking velocity between the groups showed (*P* = 0.22)
Salsich *et al.* (2001)	cross-sectional study	10 PFPS 10 H	Peak knee extensor moment Cadence Hip, ankle and support moment	There was a decreased cadence during stair descent in PFPS (74.0 steps/min) (*P* = 0.02) compared to healthy subjects (96.9 steps/min). In PFPS compare with healthy subjects peak knee extensor moments reduce during stair ascent (0.75 vs. 1.11 Nm/Kg *P* = 0.006) and descent (0.50 vs. 0.78 Nm/Kg *P* = 0.006). As well as no significantly difference for hip, ankle and support moment.
Power *et al* (1999)	Prospective comparative study	15 PFPS F 10 H	Vertical ground reaction forces velocity stride length cadence	Velocity of gait in PFPS lowers than the healthy subjects during free walking (77.8 m/min vs. 87.9 m/min; *P* = 0.04) and fast walking (99.0 m/min vs. 110.7 m/min; *P* = 0.05). There was a tendency toward decreased stride length in the PFPS but no significantly different in stride length between groups. There was no significant difference in cadence and knee flexion angle at initial contact between the two groups during free and fast walking. As well as, knee flexion angle at loading response during free walking was not significantly difference but for fast walking was significantly less than control group(*P* = 0.04). For fast walking knee flexion angle at loading response was significantly less than healthy group (*P* = 0.04). The Peak vertical ground reaction force of the PFPS subjects was significantly lower than the healthy subjects in free walking (129.5 % body weight (bw) vs. 141.4 % bw; *P*ˆ0.01) and fast walking (139.9 % bw vs. 166.0 % bw; *P*ˆ0.001).
Powers *et al* (1997)	Comparative study	19 PFPS F 19 H F	Walking speed Stride length Cadence Single-limb support time Double limb support time Swing time Stance time Ankle dorsiflexion	The result showed in walking, ascending and descending stairs, and ascending and descending ramps, The average walking speed of the PFPS was 81% of the average walking speed of the control group (56.5 m/min versus 69.7 m/min, *P* < 0.001), The average stride length of the PFPS was 88% of the average stride of the control group (1.22 m versus 1.38 m), *P* < 0.001). Cadence in PFPS subjects (114.1 steps/min) was 91% of the control group (125.2 steps/min) (*P*<.001). Also the results showed that no differences between groups for time spent during single-limb support, double limb support, swing, and stance. Individual with PFPS have a greater ankle dorsiflexion compared with the other group for fast walking (9.9" versus 7.0". *P* < 0.05), descending ramps (15.8" versus 1 l.gO, *P* < 0.01), and descending stair (27.6" versus 18.g0, *P*<.001).
Nadeau *et al.* (1997)		5 PFPS 5 H	Knee flexion angle Knee and hip moments support moment	The finding of the study was that in PFPS and at the beginning of the stance phase (15% of the gait cycle) the knee extensor moment was slightly lower (0.104 N.m/kg or 16%) and the hip extensor moment was slightly higher (0.064 N-m/kg or 56%) than the control group. Also knee flexion reduce at the beginning of the stance phase in PFPS individuals. As well as, There were no significant differences between the two groups of subjects for the support moment (*P* > 0.05).

PFPS: Patellafemoral Pain Syndrome, F: Female, H: Healthy

dynamic, knee flexion angle reduced in subjects with PFPS compared to healthy people (20, 23). One study reported that knee flexion angle in individuals with PFPS at loading response during free walking was not significantly different. But in fast walking this mean angle from 21.6 degrees in control group reduced to 16.9 degrees in PFPS (20). This reduction in another study conducted by Nedua *et al.* was showed as 10%, 20% and 70% of the cycle of gait (*P*>0.05)(21).

Research question No. 2: the effects of patellofemoral pain syndrome on spatio-temporal parameters

Stride length

The normal step length in healthy adults ranges from 0.56 m to 1.1 m, and a stride length varies from 1.32 m to 1.48 m (29). Four studies analyzed step length in PFPS subjects by using microprocessor-based Footswitch Stride Analyzer system and Vicon. A decrease of this parameter was reported in one study (1.22 m) and the similar study demonstrated that there was no significant difference in step length for slow and normal gait speed (1.32 m vs. 1.43 m, *P*=0.06) (28). But in faster speed, there was significant difference (1.46 m vs. 1.62 m, *P*=0.008) (20). Also Willson showed Patellofemoral joint stress per step was increased 31% in the long step length condition (*P*<0.001) and decreased 22.2% in the short step length condition (*P*<0.001). They noted despite the inverse relationship between step length and number of steps required to run a mile, patellofemoral joint stress per mile increased 14% in the long step length condition (*P*<0.001) and decreased 7.5% in the short step length condition (*P*<0.001) (26). One study demonstrated that there is no significant difference in stride length between PFPS and healthy subjects (*P*=0.97)(23).

Research question No. 3: the effects of patellofemoral pain syndrome on Kinetic parameters

Knee extensor moment

Knee extensor moment was analyzed using a motion analysis system (Vicon) with camera in three studies for PFPS subjects, and results were compared with normal subjects (19, 21, 23). Nadeau *et al.,* in gait evaluation of PFPS announced that all subjects had lower knee extensor moment (0.104) (23). Salsich *et al.,* showed reduction peak knee extensor moments in subjects with patellofemoral pain syndrome during stair ascent (*P*=0.006) and descent (*P*=0.006)(21). Paoloni *et al.* reported that knee extensor moment reduced during both loading response (0.027 vs. 0.377 *P*=0.005) and terminal stance (0.083 vs. 0.329 *P*=0.003) (19).

Knee abductor, external rotator moments and internal rotation

Only two studies evaluated knee abductor, external rotator and internal rotation in individuals with PFPS using a video motion analysis system. An increase in knee external rotation moment has been demonstrated in both studies (19, 25). One study reported an increased knee external rotation moment in PFPS when compared to normal subjects (0.071 compared to 0.042 baseline *P*=0.007)(19). Also Willson *et al.,* showed that subjects with PFPS demonstrated 4.3 degree greater knee external rotation than subjects without PFPS (*P*=0.06) (25). In PFPS subjects, knee abductor moment peak significantly increased in loading response (0.555 vs. 0.398 degree, *P*=0.01) and average knee internal rotation excursion was 2.2 degree less than the control group across activities (*P*=0.05) (19, 25).

Hip rotation

Six studies analyzed hip rotation in PFPS subjects compared to normal subjects using video motion analysis system. A significantly increase of this parameter was reported in two studies that the mean of this parameter was 9.8 vs. 5.2 degree, and 7.6 vs. 3.8 degree (24, 30). Nohern *et al.*, reported that the PFPS group had a greater hip internal rotation throughout stance, although this was not significantly different (4.5 versus 3.0 degree *P*=0.47) (32). However, two studies reported reduction of this parameter (17, 25). One study reported no difference was observed on hip internal rotation between PFPS and control group (32).

Hip and knee transverse, tibia transverse rotation and frontal plane

Only two studies examined these parameters using video motion analysis system. Bolgla *et al.,* noted no differences among groups (*P*>0.05) were found for average hip and knee transverse and frontal plane angles during stair descent (5). In another study, Levinger *et al*. reported that tibia transverse rotation was not shown to be different in PFPS subjects compared with healthy subjects (22).

Vertical ground reaction

Power *et al.* evaluated the effect of patellofemoral pain syndrome on gait in 15 female patients and 10 subjects as control group during gait. The finding indicated that the average vertical ground reaction force of the PFPS was significantly lower than the control group during free walking (129.5 vs. 141.4) and fast walking (139.9 vs. 166.0) (*P*=0.001) (20). By using the force plate, significantly lower peak medial ground reaction force (GRF) (*P*=0.03), minimum vertical GRF trough (*P*=0.02) and the second vertical GRF peak (*P*=0.01) were found in the PFPS group in another study (22). Willson *et al.* compared biomechanical evaluation of activity (run, jump and squat) of 20 female subjects with PFPS and 20 healthy female individuals using a 6-camera Vicon 3D motion analysis system. Their results showed there was no significant difference for vertical ground reaction force (*P*=0.50) between groups, and ground reaction force increased 22% during single leg squats, 164% during running and 183% during single leg jumps (25). Findings from the another study indicated that by employing Kistler platforms vertical GRF significantly reduced at the heel contact (40.7 vs. 56.7 *P*=0.01), however, no significant difference observed in vertical GRF at the loading response and terminal stance (19).

Support moment

Support moment was analyzed using a camera computer-aided video motion analysis (Vicon) in two studies in which both of them revealed similar results. Salish *et al.*, showed no significant difference for support moment between PFPS group and healthy subjects during stair ascent and descent. The mean value of there variables were 2.59 vs. 2.84 and 1.89 vs. 2.16 (*P*>0.05) (21). Nedua *et al.*, also reported the same findings for walking (23).

Foot eversion and dorsiflexion

Powers *et al.,* noted that the PFPS demonstrated greater ankle dorsiflexion compared with other groups for fast walking (*P*<0.05), descending stairs (*P*<0.001) and descending ramps (*P*<0.01) (28). Results of the study by

Levinger *et al.*, demonstrated significant delayed peak rear foot eversion (P=0.02) and earlier occurrence of peak dorsiflexion (P=0.02) for PFPS group. However, there was prolonged rear foot eversion during the stance phase of gait (22). In another study, Aliberti *et al.* evaluated the effect of PFPS on plantar pressure during gait. The results demonstrated that PFPS individual present larger contacts area on the medial and central hind foot during initial heel contact, at the medial and lateral fore foot in the midstance and at the lateral forefoot during propulsion. Subjects with PFPS had a medially direct contact in the rear foot during stair descent. In the midstance, the larger contact area at both medial and lateral forefoot suggested that PFPS individuals had a greater excursion of the foot during this phase both medially and laterally. Individuals with PFPS exhibited a foot rollover pattern that is medially directed at the rear foot during initial heel contact and laterally directed at the forefoot during propulsion (33). One study indicated earlier peak rear foot eversion (P=0.010) and greater rear foot dorsiflexion (P=0.007) in PFPS (17). However, Nohern *et al.*, reported that between PFPS and healthy subjects there was no difference in forefoot dorsiflexion (P=0.66), peak rear foot eversion (P=0.27) and forefoot abduction (P=0.16) (30). Motion analysis system was used in these studies.

Discussion

The aim of this review was to evaluate the effect of PFPS on gait parameters. People with PFPS had a significantly delayed peak rear foot eversion than the healthy subjects. The evidence in the literature demonstrated that PFPS subjects had an increased rearfoot eversion at heel strike transient during walking. In addition, in comparison to normal subjects there was increased contact area on the medial and central hind foot during initial heel contact. Also, contact area was larger on the medial and lateral fore foot in the midstance, and at the lateral forefoot during propulsion phase of gait. According to a study conducted by Aliberti *et al*. it was revealed that foot rollover pattern was medially directed at the rear foot during initial heel contact and laterally directed at the forefoot during propulsion in terminal stance in the PFPS subjects (33). Noehren *et al*. noted that there was no difference in the time to peak rear foot eversion between PFPS and healthy groups, but Levinger *et al.* indicated a delayed timing of peak rear foot eversion in PFPS subjects (22, 31).

The mean speed of walking in PFPS was lower compared to normal subjects. Patients with PFPS have reduced gait velocity for some reasons such as reduction of patellofemoral joint reaction force during walking, peak loading rate and peak vertical ground reaction force. Another reason for reduced gait velocity is reduced quadriceps muscle activity and subsequent loading on the patellafemoral joint and its possible effects on pain in walking which requires more evaluation. Individuals with PFPS were ambulating with lower speed than the healthy subjects; which was accomplished by a decrease in stride length (17, 19, 20, 23, 28). The results also showed decreased cadence during walking and stair ambulation for PFPS compared to healthy subjects that contributing to reduce knee moment (20, 21, 23, 28). PFPS-associated changes in kinematic gait parameters such as a reducing knee flexion angle, as well as change in knee and hip moments in the range of 10% and 20% gait cycle. Decrease knee joint flexion in PFPS compared to a control group is a positive function to reduce loading on the painful patellofemoral joint (20, 23).

It should be pointed out that patellofemoral joint stress increased 14% in the long step length and decreased 7.5% in the short step length. Therefore it has been proposed that short step length, maybe a compensatory strategy to decrease patellofemoral stress. Because of the direct relationship between gait speed and stride length, reduction in gait speed in the PFPS resulted in reduction of stride length, as well (20, 26, 28). Stride time in healthy subjects was approximately one second and results showed that there was no difference between groups (healthy and PFPS subjects) for time spent during single-limb support, double limb support, swing, and stance support time (20, 22).

Several authors have highlighted that subjects with PFPS exhibit reduced knee extensor moment during stair ascent and descent, loading response and terminal stance, compared to healthy people. Individual with PFPS had reduced knee extensor moment as a strategy to avoid symptom intensification and need to unload the knee joint to avoid pain (19, 21). The evidence in the literature demonstrated that PFPS increased knee abductor and external rotator moments and decrease knee internal rotation in gait and activity such as run, jump and squat. Perhaps, increased knee external rotation can be an explanation for the greater tibia external rotation among subjects with PFPS. Greater tibia external rotation in PFPS subjects can be related to greater toe out during running and jumping (18, 24).

About hip rotation during gait in PFPS subjects, there was controversy in papers. Noehren *et al*., Souza *et al*. and Nohern *et al*. demonstrated that PFPS exhibit greater peak hip internal rotation during gait compared to healthy subjects but Barton *et al.* and Willson *et al.* showed reduction in hip internal rotator during run, jump, squat and walking. Also, Dierks *et al*. reported no difference on hip internal rotation between PFPS and control group. The inconsistencies in reported hip internal rotation between studies may be explained by differences in study methodology factor such as differences in the inclusion criteria of the patients, the time point at which the discrete value was selected in the stance phase and normalizing joint angles to the standing angle. Willson and Davis normalized their hip internal rotation data to each subjects standing posture during a calibration trial and quantified kinematic variables at discrete points. Also, each subject's standing posture was considered as the zero position. Whereas Souza elected to report peak stance phase kinematics regardless of when they occurred and quantified the subjects' hip joint angle regardless of the standing posture. Other reasons for discrepancy between these studies may be relevant to differences in the inclusion criteria of the participants and variety of the kinematic models used by authors (17, 25). The authors indicated that hip adduction is greater in PFPS during gait and activities such as run, jump and squat (25, 30-32), however, Souza *et al*. found that there was no significant difference for peak hip adduction (24). The evidence in the literature demonstrated that subjects with PFPS during running and stair descent has a less hip external rotator, hip abductor torque and hip extension (5, 23). According to this study no significant differences between PFPS and healthy subjects in the average hip and knee transverse, tibia transverse rotation and frontal plane angles during gait and activity such as stair descent (5, 22).

Evidence in the literature demonstrated that the average vertical ground reaction force of the PFPS was significantly lower during walking. The decrease in vertical ground reaction force during walking can relatively be explained by the reduced velocity employed by the PFPS subjects and may be characterized by altered neuromotor control due to knee pathologies (19, 20, 22). Nadeau *et al*. and Salsich *et al*. have demonstrated that there is no significant difference for support moment between PFPS and healthy subjects. No difference in support moment and present difference in knee and hip moment may indicat that subjects with PFPS maintain overall lower limb support similar to normal subjects (21, 23).

Future studies should therefore include the following subjects:

- An investigation into energy consumption in PFPS.
- With respect to contradictions in the internal rotation of the hip, more studies in this context should be done to reach a more definitive conclusion.
- Future studies can also study the parameters of the gait in both men and women.

PFPS-associated changes in gait parameters produce a reduction in stride length and step length. Kinematic and kinetic alterations apparent in PFPS subjects, compared to healthy subjects, include lower gait velocity, slower swing velocity, decrease cadence, reduce knee extensor moment in the loading response and terminal stance, delayed peak rear foot eversion during gait, greater contralateral pelvic drop during run, jump and squat, greater hip adduction. Some of these changes in the walking patterns of PFPS subjects may be related to the strategy for the reduction of patellofemoral joint reaction force and pain.

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