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Review Article

Patients with Patellofemoral Pain Exhibiting Decrease Vertical Ground Reaction Force Compared to Healthy Individuals during Weight Bearing Tasks: A Systematic Reviews and Meta-Analysis

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Abstract

Background: Vertical ground reaction force (VGRF) can lead to the development knee osteoarthritis. This review systematic and meta-analysis aimed to investigate the VGRF in patellofemoral pain patients (PFP) during weight bearing tasks.

Methods: Search strategy was conducted in databases: Science Direct, Scopus, PubMed and Google Scholar from Sep 2020 to Jun 2021. The VGRF components we measured were passive impact (Fz_1)/peak and propulsion/active peak (Fz_2). The quality of the studies was evaluated with Down and Black index and it was divided into three groups: low quality (LQ), medium quality (MQ) and high quality (HQ). The standardized mean difference between PFP and healthy individuals was used to calculate the effect size.

Results: Nine articles were selected for systematic review and meta-analysis of which 5 studies was HQ, 3 studies were MQ and 1 study was LQ were classified. PFP compared to healthy individuals with moderate and small effect size have reduced impact and propulsion respectively.

Conclusion: The in PFP, VGRF is influenced psychological, behavioral and biomechanical factors. Therefore, psychosomatic therapeutic approaches may have a long time effectiveness on the rehabilitation of PFP.

Keywords: Kinetic; Vertical loading; Patellofemoral pain; Movement

Introduction

Patellofemoral pain (PFP) is one of the most common overuse injuries of the lower limbs that being a burden on healthcare costs (1,2). The prevalence of PFP in the general and athlete population was reported to be 22.7% and 40%, respectively (3,4). Overall, the prevalence of PFP is twice as high in females into men's (5,6). The nature PFP is defined as pain around or behind the patella that is exacerbate by weight bearing tasks that load the patellofemoral joint (7,8). Of note, PFP is one of the most important factors that could lead to knee osteoarthritis in the future, that possible lead to reducing physical activity (9,10).

Alterations in kinetics and kinematics knee remain controversial in PFP patients (11,12). However, the role of faulty kinetics in the development of PFP has not been fully examined (2). Kinetic variables have more information because they identify and represent causes rather than the effect of movement (13). Ground reaction forces is among the most important kinetic variables that could affect movement (14). In this regard, repeated unipodal weight bearing tasks at higher physiological loading than usual is both damaging to lower limb joints and produce pain (10). The vertical ground reaction force (VGRF) components have been used as index for estimation overload level on the musculoskeletal system during the weight-bearing (10,15). The most important calculated VGRF components are impact peak (Fz1) and propulsive peak (Fz2) (16).

There are several factors involved in increase or decrease VGRF including the range of motion of the lower limbs and the muscles contraction (17). The relationship was found between knee flexion and GRF. Reducing knee flexion led to greater VGRF (18). In this regard, the changes of VGRF components in PFP patients than healthy individuals have been explained by altered biomechanical factors (19). The PFP patients with the goal decrease patellofemoral joint reaction force (PFJRF) and knee pain may reduce knee flexion (20). PFJRF is an equal force and in the opposite direction of the resultant of two quadriceps muscle tendon and patellar tendon forces, that with increasing each, the PFJRF increases (9,21). As a result, these parameters should be minimized to reduce PFJRF (21). Although knee flexion is a compensatory strategy logical for reducing pain, but this mechanism reduces the active shock absorption and possible lead to degenerative changes of the knee joint (18). Despite, altered of VGRF components may underlie the development of PFP, but reported conflicting findings. For example, patients with PFP showed an increase in Fz2 during climbing stairs (15); vis-a-vis patients with PFP showed a reducing in Fz2 during climbing stairs (10). Therefore, further research is needed to understand these contradictory findings related to VGRF (22). Results from studies in this field is effectives to guide development of interventions targeting impact absorption as part of rehabilitation (22). Since, VGRF components are related to PFP and osteoarthritis developments, investigated of VGRF components would assist in the development of optimal rehabilitation strategies (10,23). On the other hand, since most studies evaluated only one dynamic movement task, it is unknown if other weight bearing activities would yield the same results? (10).

Therefore, we aimed to investigate VGRF in PFP patients compared with healthy individuals during weight bearing tasks.

Methods

A systematic review with meta-analysis was conducted by following the PRISMA 2009 checklist.

Search criteria

The research question was determined using the PICOS framework. Articles were subject when they preparing results of clinical studies (S) that measuring VGRF components (O) in PFP patients (P) compared with healthy individuals (C). The intervention (I) were not determined. The three main groups of keywords MeSH terms and other keywords were used in this review (Table 1). The search strategy was conducted by researchers from Sep 2020 to Jun 2021. Search strategy was conducted in databases: Science Direct, Scopus, MEDLINE and PubMed without publication date limit. Google Scholar functioned as a complement search engine.

In the search strategy, MeSH keywords alone were not sufficient, because studies are listed in PubMed long before being indexed with MeSH terms. Therefore, the only use of the terms MeSH leads to the lack of access to all previous studies (24). Within each keyword category, the synonyms were combined by “OR” and categories were connected by “AND”. In all stages differences among the reviewers were resolved with a consensus session.

Table 1: Search strategy and keywords

Category	*Keywords*
Biomechanical	Biomechanical phenomena (MeSH), Kinetics (MeSH), Kinematics (MeSH), vertical loading, peak vertical ground reaction forces, ground reaction force parameters
Task	Running (MeSH), Gait (MeSH), Locomotion (MeSH), Ambulation (MeSH), Walking (MeSH), Squatting (MeSH), Weight-Bearing (MeSH)
Knee	Anterior Knee Pain Syndrome (MeSH), Patellofemoral Syndrome (MeSH), Pain Syndrome (MeSH), Patellofemoral (MeSH) / patellofemoral pain

Eligibility criteria

Inclusion criteria included case-control studies of human participants who compared VGRF components between PFP patients and healthy individuals. Weight-bearing tasks were determined as any functional movements that needed to support by the lower limbs and similar conditions in daily life and/or sport activities. Moreover, the data's Fz1 (weight acceptance phase or force maximum within first 50% of stance phase) and Fz2 (push-off phase or force maximum within the second 50% of stance phase) must be clearly defined or determinable (25,26).

Letters, conference proceedings, case reports, cadaveric studies, no comparison of PFP with healthy individuals, abstracts, reviews, clinical trial, prospective and non-English language articles were excluded.

Study selection

We independently assessed eligibility criteria. Frist, title and abstracts were checked. Studies that considered the eligibility criteria were acquired as full manuscripts and checked. References and abstracts of studies were saved based on the letters of the alphabet by software Mendeley version 1.19.8 and then repetitive references were deleted. After removing duplicates, we screened the titles and abstracts of the identified articles according to eligibility criteria.

Quality assessment of included studies

We independently evaluated the methodological quality. The modified Black and Downs index was used to assessment the quality of studies that included 15 questions which the following subgroups: reporting (items 1, 2, 3, 5, 6, 7, and 10), external validity (items 11 and 12), internal validity (items 16, 18, and 20), and internal validity confounding (items 21, 22, and 25) were evaluated (9,27,28). The items were scored as 0 ("no"), 1 ("yes") or UD or ("unable to determine"), except item 5 for the principal confounders, scored as 0 ("no"), 1 ("partially"), 2 ("yes"). Studies with quality scores of 75% or greater were classified as high quality, those with 60–74% as moderate quality, and those 60% or less as low quality (29).

Data extraction and analyses

We independently extracted the demographic information (author name and year of publication, purpose, task and results). Outcome measuring was: Fz1 and Fz2. Where data was not reported, contacted was to authors via email. If no result is obtained, Web Plot Digitizer with high reliability (Pearson's r = 0.999) and validity (r = 0.989) designed to extract data from graphs, was used (30). If a study reported data from several functional task, the number of tasks included in the primary analysis was divided by the number of tasks reported, and each task was considered as an independent study to data analysis (31).

All statistical analyses were conducted using REVMAN software version 1.19.8 (Cochrane Collaboration, Oxford, UK). A random effects model with forest plots was used to assessment and compare Fz1 and Fz2 between PFP and healthy groups. Continuous outcomes model to calculation of standardized mean differences (SMD) with 95% Confidence Intervals (CI) was used. The SMD was interpreted using Cohen's d: <0.5 = small; 0.5–0.8= moderate and >0.8=

large (32). Heterogeneity between studies was assessed using I^2 statistics. The I^2 statistic was determine: 25% = low, 50% = medium, and 75% = high heterogeneity (33). The level of statistical significance ($p < 0.05$) was calculated by Z test.
Quality rating were used to determine levels of evidence (34):

- Strong evidence: consistent findings among multiple studies including at least 3 high-quality studies.
- Moderate evidence: consistent findings amongst multiple studies, including at least 3 moderate/high-quality studies or 2 high-quality studies.
- Limited evidence: pooled findings amongst multiple low/moderate quality studies, or 1 high-quality study.
- Very limited evidence: findings from one low/moderate quality study.
- Conflicting evidence: one/some studies show significant effects and one/some studies show no significant effects while the CIs of the pooled effect size lead one to accept the null hypothesis.

Results

Study characteristics

The initial search identified 918 studies, which 31 were deleted due to duplication. Then, we screened the remaining 887 studies based on the title and abstract of the studies, which resulted in the elimination of 824 studies that were inconsistent with the purpose and eligibility criteria. Overall, 63 studies remained for full text evaluation, which 54 were omitted because they did not of the eligibility criteria. Thirty-four studies due to lack of healthy control group or comparison with other pathologies, 11 studies due to non-reporting of VGRF values, 7 studies due to phases uncertainty Fz1 and Fz2, 1 study was prospective and 1 study that had applied various interventions in the evaluation were removed from the review process. Finally, 9 studies were selected for systematic review and meta-analysis (Fig. 1) (8,9,12,17,20,31-34).

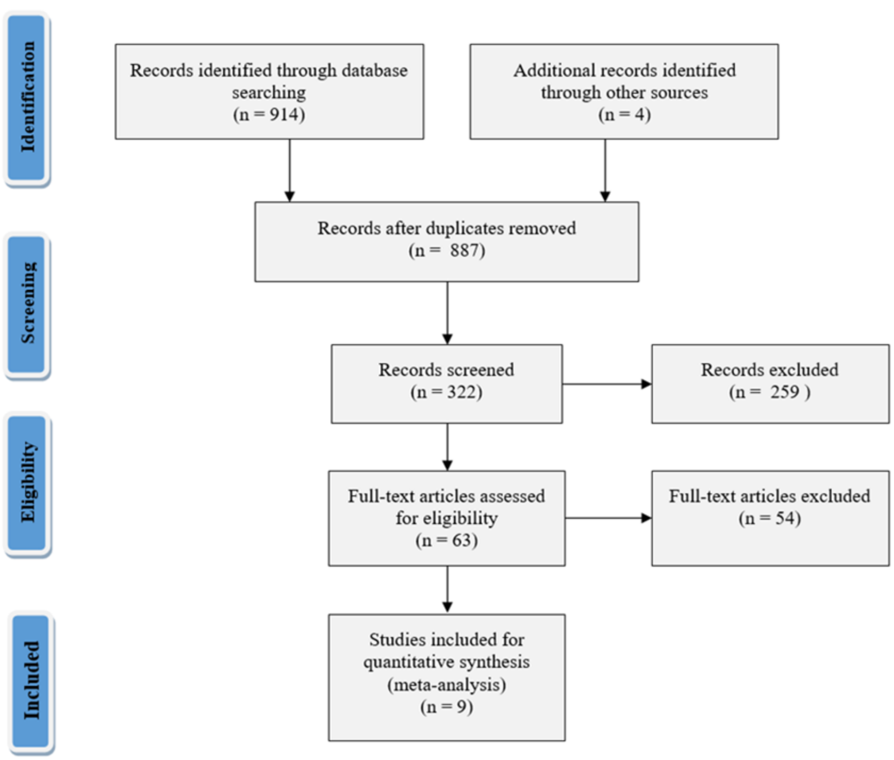

Fig. 1: PRISMA flowchart for meta-analysis

Quality assessment of studies

The average score of methodological quality of studies was 66.5% (range 33%-80%), which indicates the medium quality of studies. Fifty five percent of studies (n = 5) had high methodological quality (8,17,31-33), 33% of studies (n=3) were as medium quality (11,23,38) and 11% of studies (n=1) were as low quality (15) (Table 2).

The strength of the quality studies was report particular the expression of the objectives and outcome measures. All studies showed poor external reliability scores. In fact, none of the studies had not identified the source of the population and how patients selected. Moreover, most studies on the internal reliability of the confounder were poor. Only 3 studies reported that patients from the same population were employed (10,20,23). In addition, only 2 studies reported that patients were employed from the same time period (11,37).

Table 2: Black and Downs checklist for methodological quality of studies

Authors and year of publication	*Reporting*							*External validity*		*Internal validity - bias*			*Internal validity - confounding*			*Total*	*Percent (%)*	*Quality*
	1	**2**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**16**	**18**	**20**	**21**	**22**	**25**			
Messier et al. 1990 (38)	1	1	0	0	0	1	1	1	0	1	1	1	0	0	1	9	60	M
Radin et al. 1991 (23)	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	9	60	M
Powers et al. 1999 (20)	1	1	1	0	0	1	1	1	1	0	1	1	1	0	1	11	73	H
Duffey et al. 2000 (37)	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0	12	80	H
Levinger et al. 2007 (36)	1	1	1	0	0	1	1	1	2	1	1	1	0	0	0	11	73	H
Paoloni et al. 2010 (11)	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	9	60	M
Saad et al. 2011 (15)	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	5	33	L
Silva et al. 2015 (10)	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	12	80	H
Esculier et al. 2015 (35)	1	1	1	0	0	1	1	1	2	1	1	1	1	0	0	12	80	H

Abbreviations: H: high, M: medium, L: low

Characteristics of studies

Table 3 shows the demographic information of studies. There are 495 people (mean age: 28.39 yr; body weight: 64.05 kg; height: 164.05 cm) in 9 study. Overall, 228 people were healthy individuals (mean age: 28.71 yr; body mass: 62.96 kg; height: 168.31 cm) and 267 PFPS patients (mean age: 28.06 yr; body weight: 65.15 kg; height: 166.64 cm). Eleven percent of studies (n = 1) when climbing stairs (11); 11% (n = 1) up and down stairs (15); 33% running (n = 3) (35,37,38) and 44% during walking (n = 4) (11,20,23,36) measuring of VGRF components. Fz2 was not analyzed in two studies (20,35).

First peak (Fz1)

Nine studies (10,11,15,20,23,35–38) evaluated Fz1 during weight-bearing tasks (Fig. 2). Strong evidence suggests that PFP patients compared to healthy group with moderate effect size (SMD= -0.53; 95% CI= [- 0.82 to –0.23]) have Fz1 reduced in weight-bearing tasks (5 studies=HQ, 3 studies=MQ, 1 study = LQ; P=0.01, I_2 = 55 %).

Second peak (Fz2)

Seven studies (10,11,15,23,36–38) evaluated Fz2 during weight-bearing tasks (Fig. 2). Strong evidence suggests that PFP patients compared to healthy group with small effect size (SMD= -0.44; 95% CI= [- 0.74 to –0.15]) have Fz2 reduced in weight-bearing tasks (3 studies= HQ, 3 studies=MQ, 1 study=LQ; P=0.09, I_2 = 44).

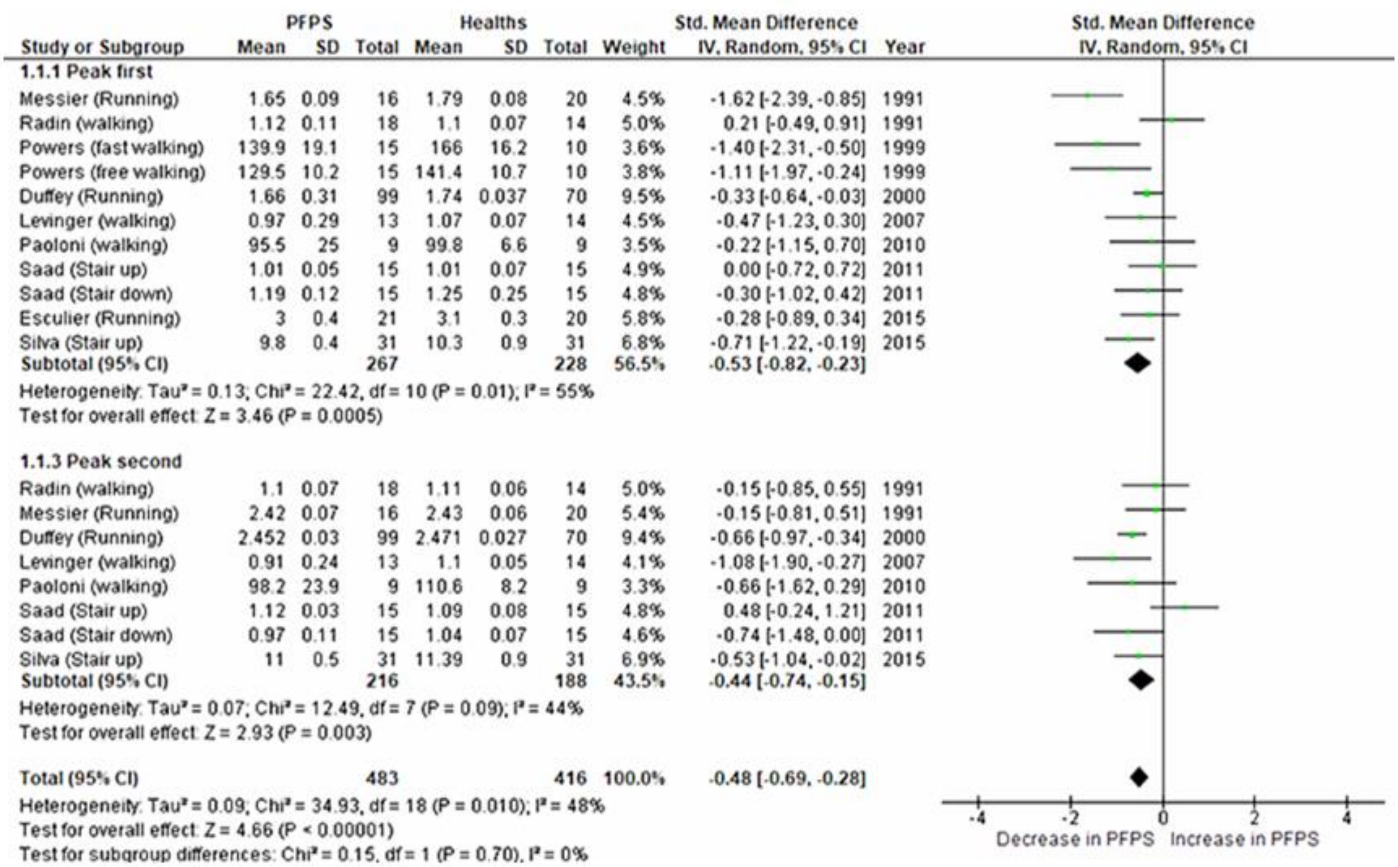

Fig. 2: The forest plot shows the vertical ground reaction force components

Table 3: Summary of demographic information of studies

Author/Year	*Purpose*	*Task*	*Results*
Messier et al. 1990 (38)	Relationships exist between selected biomechanical factors runners with PFP and healthy individuals	Running	The PFP group demonstrated that Fz1 were decreased and no significant difference was observed in the Fz2
Radin et al. 1991 (23)	The kinematic and kinetic examined the behavior of the legs of young adult with PFP patients	Walking	The Fz1 and Fz2 tended to decreased and increased in PFP patients, respectively
Powers et al. 1999 (20)	The determine if PFP patients demonstrate excessive lower limb loading	Walking	The Fz1 for the PFP group was decreased during both free and fast walking
Duffey et al. 2000 (37)	The examine differences between a non-injured and runners with PFP according to selected training, anthropometric, rear foot motion and GRF	Running	The PFP group demonstrated that Fz1 were decreased. No significant difference was observed in the Fz2 but was a tendency toward decreased in PFP group
Levinger et al. 2007 (36)	The measure rear foot and tibia motion and GRF in PFP patients compare to healthy individuals	Walking	There was no significant difference in the Fz1 and Fz2; but there is a tendency to decrease both peak forces in PFP patients.
Paoloni et al. 2010 (11)	The investigate Kinematic and kinetic features of normal level walking in PFP patients	Walking	There was no significant difference in the Fz1 but there is a tendency to force decrease in PFP patients
Saad et al. 2011 (15)	Evaluate the displacement area of the center of pressure, GRF in PFP patients compared to healthy individuals	Step up and step down	The PFP group show a Fz1 decrease in affected leg than not affected leg during the step-down activity, and Fz2 was increased in the step-up and decrease in the step down
Silva et al. 2015 (10)	The investigate differences in Fz1 and Fz2 between recreational female athletes with PFP and pain-free	Stair up	The PFP group demonstrated that Fz1 were decrease. No significant difference was observed in the Fz2
Esculier et al. 2015 (35)	The compare GRF during treadmill running in recreational runners with and without PFP	Running	Fz1 have a tendency toward decreased in PFP group

Abbreviations: PFP: patellofemoral pain, Fz1: impact/passive peak, Fz2: propulsive/active peak, GRF: Ground reaction force

Discussion

This systematic review and meta-analysis study suggests that PFP patients compared to healthy individuals had a reduced Fz1 and Fz2. The potential to change VGRF components in PFP patients can be examined from the perspective three: psychological, behavioral and biomechanical.

Psychological

Fz1 is related to the amount of loading one puts on the force plate that related to body mass and speed (39). The psychological factors are associated with pain and disability; they may affect protective movement patterns to reduce the load (10,40). Someone with high levels of kinesiophobia would have higher avoidance of knee joint loading (41). In other words, PFP patients used of Loading/Unloading compensation mechanism as a protective approach to avoid pain catastrophizing performed weight bearing tasks with caution when using the affected leg to reduce the stress; and shifting the body weight over to the healthy leg (6,10,12,42–44). Therefore, PFP patients not discharge so much weight on the affected leg at the start of the new cycle of movement (15). Furthermore, unloading and the protective mechanism of the affected knee may over time increased support and loading rate in the healthy limb, which increases the risk of knee osteoarthritis (18,42).

Behavioral

Aamong other factors that reduce VGRF in PFP patients can be explained by a slowing movement speed. Aliberti et al reported a "more cautious motor pattern" in PFP patients (40). In other words, slowing movement speed is due to psychological factors. Generally, slowing movement speed may be beneficial for PFP patients from two perspectives. Frist, slowing movement speed in PFP patients may be an attempt by patients to minimize the PFJRF (20). The PFJRF is force between the quadriceps muscles and patellar tendon that increases with quadriceps muscle force and knee flexion angle (9,21,46). Therefore, slowing movement speed of reduced the demand quadriceps during initial stance by decreasing the knee extensor moment (47). As a result, PFJRF decreases with reduce the extensor moment, which ultimately reduces pain. Second, slowing movement speed was suggested to maintain the capacity of the quadriceps muscles to absorb shock that reduce vertical impact and thus reduce PFJRF (11,48).

Biomechanical

Pronation in initial stance is a loading response function of the foot; therefore, abnormal eversion may be reverse the Fz1 (36). PFP patients exhibited an rear foot eversion at heel strike transient which can be the result of a compensatory mechanism to leave minor mechanical load to be attract at the knee; thus helping to control severity of pain (35). On the other hand, PFP patients have higher dorsiflexion which could possibly be a compensatory mechanism to reduce knee flexion during the stance phase and minimize the PFJRF (49). This mechanism is possible affect the foot from becoming a rigid and efficient lever during the propulsive phase at late stance. This mechanism may create insufficient propulsion, and inability to generate stable plantar force on the ground (36,48). As a result, Fz2 is reduced in PFP patients and they perform more compensatory and unconscious propulsion movements in healthy legs (38).

Overall, at the initial of the stance phase, when body acceleration and gravity are aligned, the vastus medialis and lateralis, gluteus medius and maximus play an important role in controlling Fz1 (10,50). In addition, in the terminal stance, which the acceleration of the body is opposite to the acceleration of gravity, the plantar flexor muscles of the ankle and the extensor muscles of the knee play an important role in maintaining Fz2 and accelerating the body (50). In this regard, the pattern of faulty activity and weakness of the gluteus medius the PFP patients are effective in reducing Fz1 (10) and quadriceps are effective in reducing Fz2.

The Field applications include: A) the focus clinicians on correcting altered psychosomatic parameters. B) The unloading habit to avoid pain and load symmetry in both legs should be corrected. C) Strength training is recommended for muscle weakness due to unloading. D) As this works as a global parameter, it could be used as an outcome to monitor the progress of this patients and the effectiveness of treatments or used as a tool to aid the characterization of PFP patients.

Limitations and suggestions

There are several limitations to the literature reviewed. First, due to the case-control nature of the studies, our results did not allow differentiation between cause and effect in relation to the VGRF components evaluated (18). Second was the low sample size (35). Third, VGRF is influenced other factors (for example, psychological) have not received much attention of other factors. Fourth, in some studies the patient population were only women, therefore, the results could not be generalized to all PFP patients (10). Fifth, analysis of Fz2 is poor. Therefore, we recommend that researchers in clinical trials in the long time evaluate the effect of interventions derived from the integration of psychological, behavioral and biomechanical approaches on the components of VGRF.

Conclusion

Decrease in Fz1 in PFP patients is influenced by psychological, behavioral factors and Fz2 influenced biomechanical factors. The reduction in load on the effected knee, action load on the knee healthy increases; therefore, the risk of developing knee osteoarthritis increases in the future. However, multifactorial therapeutic approaches with emphasis on psychosomatic can have a favorable long time therapeutic effectiveness for PFP.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Conflict of interest

The authors declare that there is no conflict of interest.

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