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SYSTEMATIC REVIEW

HIP MUSCLE STRENGTH AND ENDURANCE IN FEMALES WITH PATELLOFEMORAL PAIN: A SYSTEMATIC REVIEW WITH META-ANALYSIS

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ABSTRACT

Purpose/Background: Patellofemoral pain (PFP) is a common knee conditions experienced by adolescents and young adults, seen particularly in women. Clinicians and researchers need to understand how proximal, local, or distal factors may influence the development of PFP and affect individuals once they have developed PFP. Proximal factors are the focus of recent studies and the purpose of this systematic review was to determine if females with PFP have hip muscle strength or endurance deficits when compared to their unaffected leg and to comparison groups.

Methods: A systematic review was conducted to identify relevant studies in the databases PubMed, PEDro, ScienceDirect and EBSCOhost up to June 2013. Data including study design, participants demographic data, and assessments of hip muscle strength or endurance were extracted from individual trials. The mean differences of hip muscles strength or endurance between females with PFP and healthy controls or unaffected side were extracted or calculated from individual trials and, when possible, a meta-analysis was performed.

Results: Ten cross-sectional studies were included in this review. Concerning isometric strength, pooled data reported deficit in hip abduction, extension, external rotation and flexion but no deficit in adduction and internal rotation when compared with healthy controls. When compared with the unaffected side, deficit in hip abduction was reported in two studies and deficit in extension and external rotation in one study. Studies with isokinetic strength evaluation reported deficit in abduction but contradictory results for extensors and rotators in females with PFPS. Finally, one study reported hip endurance deficit in extension and one found no significant differences in hip endurance compared to control subjects.

Conclusion: The results of this systematic review confirm that females with PFPS have deficit in hip muscle strength compared with healthy controls and the unaffected side but are contradictory concerning endurance.

Key Words: Endurance, Female, Hip, patellofemoral pain, strength

Level Of Evidence: 2a

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The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

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INTRODUCTION

Patellofemoral pain (PFP) is the most common knee condition experienced by active adolescents and young adults.[1] Boling et al[2] reported that females are significantly more likely to develop PFP than males while Roush et al[3] estimated a prevalence rate of 12-13% in females 18 to 35 years of age. Symptoms are characterized by anterior, retro or peripatellar pain during activities such as squatting, kneeling, prolonged sitting, ascending or descending stairs, running, hopping, and jumping.[4,5] Diagnosis of PFP is clinical in nature, and must exclude pain due to meniscal, cruciate or collateral ligament injuries, patellar tendinopathy, Osgood-Schlatter or Sinding-Larsen-Johansson syndrome, or other pathologic conditions.[6]

Researchers suggest that PFP is a multifactorial problem.[7] Potential impairments that have been associated with PFP include increased quadriceps angle,[8] hypermobile patella,[8] altered lower limb kinematics,[9] muscle dysfunction,[10,11,12] and decreased lower limb flexibility.[13,14]

During the last decade, numerous researchers have investigated the connection between and supported the influence of the hip on PFP.[9,10,11,12,15] Powers et al[16] reported that impaired muscular control of the hip can increase hip adduction or internal rotation and, therefore, increase the quadriceps angle (Q-angle) during dynamic movements. Huberti and al[17] showed that a 10-degree increase in the Q-angle can increase patellofemoral contact pressures by 45% at 20° of flexion of the knee. Repetition of this excessive movement may contribute to development of PFP.[18]

Based on these studies, authors have hypothesized that deficit of hip muscular strength or endurance may increase femoral movement during functional tasks and contribute to the development of PFP.[7,18] Additionally, Powers[19] suggested that females are more predisposed to hip neuromuscular deficits than males.[19] Prins et al[20] performed a systematic review of five studies[7,18,21,8,22] assessing hip strength in females with PFP. Because data were insufficiently reported and methodologies varied, the authors chose not to implement a meta-analysis. The authors reported hip muscle weakness in participants with PFP compared with healthy controls. All included studies tested maximum isometric strength assessed with hand held dynamometry. Additionally, specific research questions for their review were targeted on hip strength and not endurance.

Since the work presented by Prins et al,[20] several studies have been performed that evaluated hip muscle function in females with PFP, including strength and endurance evaluation using varied assessment techniques (isometric, isotonic, isokinetic).

Therefore, the purposes of this systematic review were:

- To determine if females with PFP have isometric and isokinetic hip muscle strength deficits when compared to their unaffected leg and to comparison groups.
- To determine if females with PFP have hip muscle endurance deficits when compared to their unaffected leg and to comparison groups.

A systematic review was conducted and when meta-analysis was possible, data from individual studies were pooled and analyzed.

METHODS

Search strategy

A systematic search strategy was utilized in order to identify relevant studies in the databases PubMed, PEDro, ScienceDirect and EBSCOhost up to June 2013. The following key words were combined: *patellofemoral pain syndrome, anterior knee pain, hip, muscle strength, muscle endurance, female***.** The search was applied without restrictions on language or year of publication. Study types searched excluded systematic reviews, meta-analyses, case series, and case reports. Furthermore, this strategy was supplemented by hand searching the references of all articles selected for the review.

Study Selection

Studies were selected using the following criteria: (1) studies had to assess hip muscle strength or endurance in females with PFP; (2) studies that included both males and females had to describe specific results for females; (3) studies had to include a healthy control group. Studies focusing on other knee pathologies were excluded.

The selection of studies was performed independently by two reviewers (JVC and CP) based on the title and the abstract. Articles not excluded by both reviewers were assessed in full-text and disagreement regarding inclusion was resolved by consensus.

Data Extraction and Synthesis

The first author extracted data including study design (type, author, date), participants (number, age, activity level, PFP definitions) and assessment of hip muscle strength or endurance (nature of contraction, body position, type of fixation and instrument used, number of trials, dynamometer placement, measurement units). When possible, the mean differences (MDs) of hip muscles strength or endurance between females with PFP and healthy controls or unaffected side, were extracted or calculated from individual trials, with matching 95% confidence intervals (CIs). If data were missing, information was requested from the authors. Nature of contraction (isometric, isotonic or isokinetic) and type of instrument used were also determined and recorded for data extraction or calculation.

When meta-analysis was possible, data from individual studies were pooled with the software package Review Manager 5 (Nordic Cochrane Center, Copenhagen, Denmark) to determine a weighted mean difference (WMD) or a weighted standardized mean difference (WSMD) with a 95% CI.[23]

Two statistical methods were used to analyze statistical heterogeneity, the chi-square test for heterogeneity and the I^2 test. When the chi-square test is significant, statistical heterogeneity is present.[24] The percentage of I^2 represents the percentage of total variation across studies due to heterogeneity and is interpreted as 25% indicating low heterogeneity, 50% medium heterogeneity, and 75% high heterogeneity.[25]

The meta-analysis was conducted using a random-effects model. If heterogeneity between studies was medium or high or if data were not sufficient for a meta-analysis, a descriptive analysis was performed.

Methodological Quality Assessment

The authors created a methodological quality assessment list with items from the Newcastle-Ottawa Scale, the Dutch Cochrane Centre website (http://dcc. cochrane.org/dutch-cochrane-centre), the Cardiff University Systematic Review Network (http:/www.cardiff.ac.uk/insrv/libraries/sure/sysnet), the Scottish Intercollegiate Guidelines Network (http:/www.sign.ac.uk) and work by Higgins et al[23] and Lankhorst et al[26].

Table 1 lists the resulting 10 questions that were used for assessing the methodological quality of the studies. Two reviewers (JVC and CP) assessed the included studies independently. Disagreements between reviewers were resolved through a consensus procedure. Each item was rated as "positive", "unclear" or "negative". Because calculating a summary score is explicitly discouraged by Higgins et al,[23] a total score was not calculated.

RESULTS

Flow of Study Selection

The database search identified 686 potentially relevant articles (Appendix A). After exclusion of 670 studies from titles and abstracts, 16 articles were retrieved for full-text review. On basis of the full-text review, the authors' excluded five articles because subgroups for females or healthy control groups were not included. Souza and Powers[27,28] and Bolgla et al[7,29] each published two articles with some similar data. Data were extracted from both of these articles, but only Souza and Powers[27] and Bolgla et al[7] were used for citations. One study was added to the review after screening of the reference sections of selected articles.[30] Ultimately, 10 studies were included in the systematic review.[7,18,21,22,27,30,31,32,33,34] Figure 1 describes the flow chart of the studies selection.

Characteristics of the Included Studies

Evaluation of studies: Table 2 reports methodological quality assessment list. Only two studies reported blinded application of evaluation[18,32] and five used a functional assessment scale reported as reliable, valid and responsive in population with PFP.[22,30,31,32,34] Moreover, studies often insufficiently described the place of recruitment, the activity level of participants, and experience and profession of the clinical investigator.

Participants: In total, 374 females were included in the studies. The number of participants ranged from

Table 1. *Methodological Quality Assessment Questions & Scoring.*

Methodological Quality Assessment Questions	Scored Positive if :
1. Did the study address an appropriate and clearly focused question?	Research question or hypothesis was that females with PFPS have decreased hip muscle force or endurance compared with healthy controls.
2. Was the study population clearly defined?	The place of recruitment, age and activity level were given.
3. Was patellofemoral pain syndrome clearly defined?	PFPS participants completed a reliable, valid scale responsive in this specific population. The intensity and history of symptoms was clearly documented.
4. Was the method of patellofemoral pain syndrome assessment reported?	The following information was described: - Localization and activities associated with symptoms of females with PFPS - Exclusion criteria - Experience and profession of the clinical investigator
5. Were the females with PFPS representative of the target population?	The participants were females, actives, between 18 and 35 years of age.
6. How comparable are the females with PFPS and healthy controls with respect to potential confounding factors?	Age and activity level are comparable between both groups. Strength or endurance were normalized to body weight.
7. Were the same exclusion criteria used for both females with PFPS and healthy controls?	The exclusion criteria were described and similar for both groups.
8. Was the method of hip muscle strength or endurance assessment reported?	Body position, type of fixation and instrument used, numbers of trials, order of testing sequences, verbal encouragement, dynamometer placement, measurement units and warm-up were documented.
9. Was the same method of assessment for both females with PFPS and healthy controls?	The same method of strength or endurance assessment was used for both groups.
10. Were the assessors blinded to the different groups?	Blinded application of strength or endurance assessments was performed.

Abbreviations: PFPS=patellofemoral pain syndrome.

20 [22,31] to 100.[32] Only one study[33] examined both males and females. In the others, all participants were female. The average age of participants ranged from 15.7 [21] to 27 years.[27] Activity level was not specified in five studies.[7,22,30,31,33] Table 3 provides the characteristics of participants.

Inclusion criteria for experimental groups: Participants complained of symptoms for a minimum of 4 to 12 weeks.[7,21,30,31,32,33,34] Depending on the studies, participants had to report anterior, retro, or peripatellar pain during at least two or three of the following provocative activities: squatting, kneeling, prolonged sitting, ascending or descending stairs, running, hopping, jumping, palpation or compression of medial or lateral patella facet, isometric quadriceps contraction.

Exclusion criteria for both groups: All studies excluded participants if they had previous knee surgery or signs of meniscal, cruciate or collateral ligament injuries, patellar dislocation, Osgood-Schlatter or Sinding-Larsen-Johansson syndrome, or other

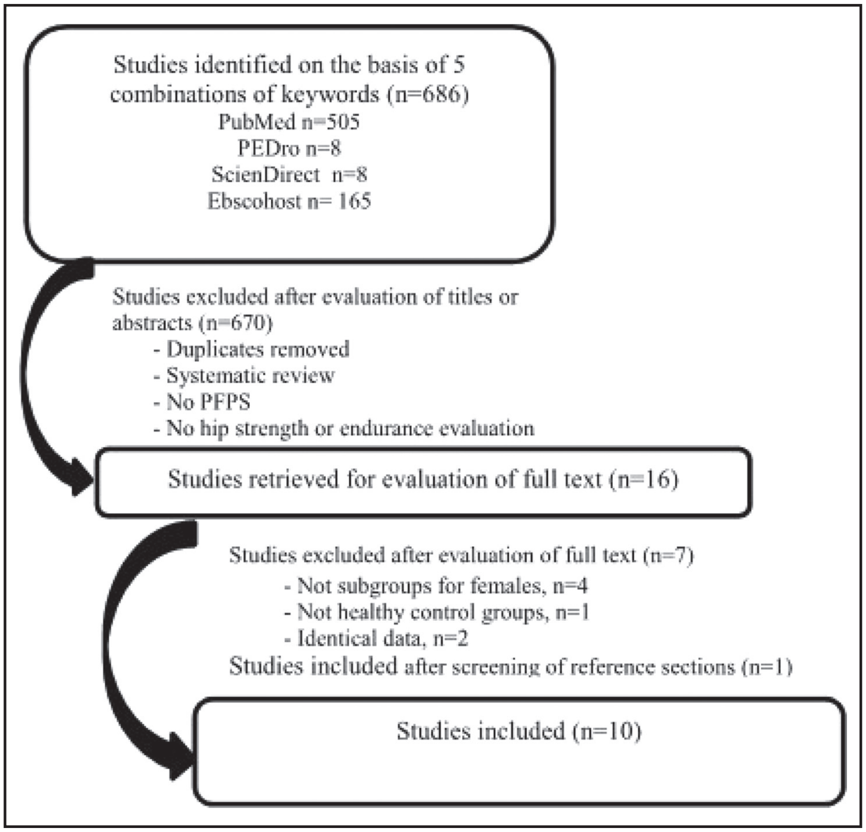

Figure 1. *Flow chart of study selection*

Table 2. *Summary of Methodological Quality Assessment of Included Papers.*

Study	Quality assessment list 1	2	3	4	5	6	7	8	9	10
Baldon et al[31]	+	-	+	+	?	+	+	+	+	-
Bolgla et al[7]	+	-	-	-	+	+	+	+	+	-
Cichanowski et al[18]	+	+	-	+	+	+	+	+	+	+
Ireland et al[21]	+	-	-	+	+	+	-	+	+	-
Magalhaes et al[32]	+	+	+	+	-	+	+	+	+	+
McMoreland et al[30]	+	+	+	-	?	+	+	+	+	-
Nakagawa et al[33]	+	-	-	+	?	-	+	+	+	-
Robinson and Nee[22]	+	-	+	+	-	?	+	+	+	-
Souza and Powers[27]	+	+	-	+	-	+	+	+	+	-
Willson and Davis[34]	+	-	+	+	+	+	+	+	+	-

pathologic conditions. Cichanowski et al[18] and Robinson and Nee[22] excluded participants with bilateral PFP from their experimental groups,. Additionally, in one study, females over 45 were excluded.[27] Table 4 describes the methods of evaluation of strength and endurance for included studies.

Hip muscles strength and endurance

Isometric muscle strength: Maximum isometric strength was tested in eight studies. [7,18,21,22,27,30,32,34] In all studies hip abductors and external rotators were evaluated. Four authors investigated hip extensors,[8,30,38,40] and three measured internal rotators.[8,30,31] Hip flexors and adductors were evaluated in two studies.[8,30] The pooled data demonstrated significantly lower strength in females with PFP than in healthy controls for abduction (WSMD, -0.75; 95% CI: -1.09, -0.41),[7,18,21,22,27,30,32] external rotation (WSMD, -0.88; 95% CI: -1.17, -0.60),[7,18,21,22,27,30,32,3] flexion (WSMD, -0.70; 95% CI: -1.14, -0.26)[18,32] and extension (WSMD, -0.90; 95% CI: -1.50, -0.30).[18,32,22,27] The pooled data were not significantly lower in females with PFP for

Table 4. *Methods of strength and endurance evaluations.*

	Evaluation	Body position	Stabilisation	Dynamometer position	Range of motion	Contractions	Modalities
Baldon et al[2]	Isokinetic muscle strength	Abd /Add: side lying ER/IR: sitting	Strapping	Abd/Add: femoral condyle ER/IR: malleolus	Abd/Add: 0° to 30° of abd ER: 0° to 30° of ER IR : 0° to 30° of IR	Eccentric	Average of 5 repetitions at 30°/s
Bolgla et al[3]	Isometric muscle strength	Abd: side lying ER: sitting	Strapping	Abd: femoral condyle ER: malleolus	N/A	Isometric	Average of 3 trials
Cichanowski et al[8]	Isometric muscle strength	Abd/Add: side lying ER/IR/Flex: sitting Ext.: prone	Manual	Abd/Add: femoral condyle ER/IR: malleolus Ext /Flex: thigh	N/A	Isometric	Best of 2 trials
Ireland et al[21]	Isometric muscle strength	Abd: side lying ER: sitting	Strapping	Abd: femoral condyle ER: malleolus	N/A	Isometric	Best of 3 trials
Magalhaes et al[30]	Isometric muscle strength	Abd/Add: side lying ER/IR/Flex: sitting Ext.: prone knee extended	Manual	Abd, IR: lateral malleolus Add, ER: medial malleolus Flex/Ext: thigh	N/A	Isometric	Average of 2 trials
McMoreland et al[31]	Isometric muscle strength	Abd: side lying ER/IR: sitting	Strapping	Abd: femoral condyle ER/IR: malleolus	N/A	Isometric	Average of 3 trials
	Muscle endurance	Abd: side lying ER/IR: sitting	Strapping	Abd: femoral condyle ER/IR: malleolus	75% of full active range of motion	Concentric	30 maximal repetitions at 30°/s
Nakagawa et al[33]	Isokinetic muscle strength	Abd: side lying ER: sitting	Strapping	Abd: femoral condyle ER: malleolus	Abd: 0°to 30° of abd ER: 5° of IR to 20° of ER	Eccentric	Average of 5 repetitions at 30°/s
Robinson and Nee[38]	Isometric muscle strength	Abd: side lying ER: sitting Ext.: prone knee flexed	Manual	Abd: malleolus ER: malleolus Ext: thigh	N/A	Isometric	Average of 3 trials
Souza and Powers[40]	Isometric muscle strength	Abd : side lying Ext.: prone knee flexed ER: sitting	Not reported	Abd: femoral condyle ER malleolus Ext thigh	N/A	Isometric	Average of 3 trials
	Isokinetic muscle strength	Ext.: prone knee flexed	Not reproted	Ext : thigh	Ext: 30° of flex to 10° of ext	Eccentric and concentric	Average of 10 repetitions at 10°/s
	Muscle endurance	Ext.: prone knee flexed	Not reported	Ext : thigh	Ext: 30° of flex to 10° of ext	Eccentric and concentric	25% of body weight, 2.5 s/repetition
Willson and Davis[46]	Isometric muscle strength	Abd: side lying ER: prone	Strapping.	Abd: femoral condyle ER: malleolus	N/A	Isometric	Average of 3 trials

Abbreviations. Abd=abduction; add=adduction, ER=external rotation; IR=internal rotation; flex=flexion; ext=extension; ant=anterior; post=posterior.

Table 3. *Characteristics of Participants.*

Study	Participants: *PFPS*	Participants: *Control*	Activity level
Baldon et al[31]	n= 10 Age (y) : 22.9 (SD : 5.2)	n= 10 Age (y): 23.9 (SD : 2.3)	Not mentioned
Bolgla et al[7]	n= 18 Age (y): 24.5 (SD : 3.2)	n= 18 Age (y): 23.9 (SD : 2.8)	Not mentioned
Cichanowski et al[18]	n= 13 Age (y): 19.3 (SD : 1,1)	n= 13 Age (y): 19.5 (SD : 1.3)	Female athletes
Ireland et al[21]	n= 15 Age (y): 15.7 (SD : 2.7)	n= 15 Age (y): 15.7 (SD : 2.7)	All subjects reported routine participation in either recreational or organized sports
Magalhaes et al[32]	n= 21 Age (y): 24.1 (SD : 6.3)	n= 50 Age (y): 24.6 (SD : 6.4)	Sedentary (did not perform sports activities any day of the week for at least the previous 6 months)
McMoreland et al[30]	n= 12 Age (y): 23 (SD : not mentioned)	n= 12 Age (y): 21 (SD : not mentioned)	Recreational sports > 30 minutes three times weekly
Nakagawa et al[33]	n= 20 Age (y): 22.3 (SD : 3.1)	n= 20 Age (y): 21.8 (SD : 2.6)	Not mentioned
Robinson and Nee[22]	n= 10 Age (y): 21.0 (range 12-34)	n= 10 Age(y): 26.6 (range 16-35)	Not mentioned
Souza and Powers[27]	n= 19 Age (y): 27 (SD : 6)	n= 19 Age (y) : 26 (SD : 4)	Active females
Willson and Davis[34]	n= 20 Age (y): 23.3 (SD : 3.1)	n= 20 Age (y): 23.7 (SD : 3,6)	Recreational sports that require running or jumping (5/10 on the Tegner activity scale)

Abbreviations: PFPS=patellofemoral pain syndrome; SD=standard deviation; y=years.

strength of adduction (WSMD, -0.35; 95% CI: -0.78, 0.08) [18,32] and internal rotation (WSMD, -0.36; 95% CI: -0.74, 0.03).[18,30,32] Additionally, Magalhaes et al[32] compared the average of both sides in participants with bilateral PFP to healthy controls and reported significant differences in abduction, extension, and external rotation. Willson and Davis[34] did not provide sufficient information to calculate MDs with matching 95% CIs, however, they reported a statistically significant decrease in abductor and external rotator strength in females with PFP.

When compared with the unaffected side, the pooled data showed a significant decrease in strength in abduction (WMD, -3.21; 95% CI: -5.20, -1.21) [18,32] and extension (WMD, -1.12; 95% CI: -5.14, 2.90) [18,32] but no significant differences between both sides for adduction (WMD, 0.15; 95% CI: -2.27, 2.58), [18,32] external rotation (WMD, -1.13; 95% CI: -2.84, 0.58), [18,32] internal rotation ((WMD, -1.17; 95% CI: -2.97, 0.64) [18,32] and flexion (WMD, -1.83; 95% CI: -4.40, 0.73). [18,32] Because of missing data and insufficient information to calculate MD with matching 95% CI, the data from Robinson et al[22] were not pooled but their study reported a decrease in abduction, external rotation, and extension when compared to the unaffected side. Figures 2-7 display forest plots of the differences in hip isometric strength between females with PFP and controls (A), and between both sides (B).

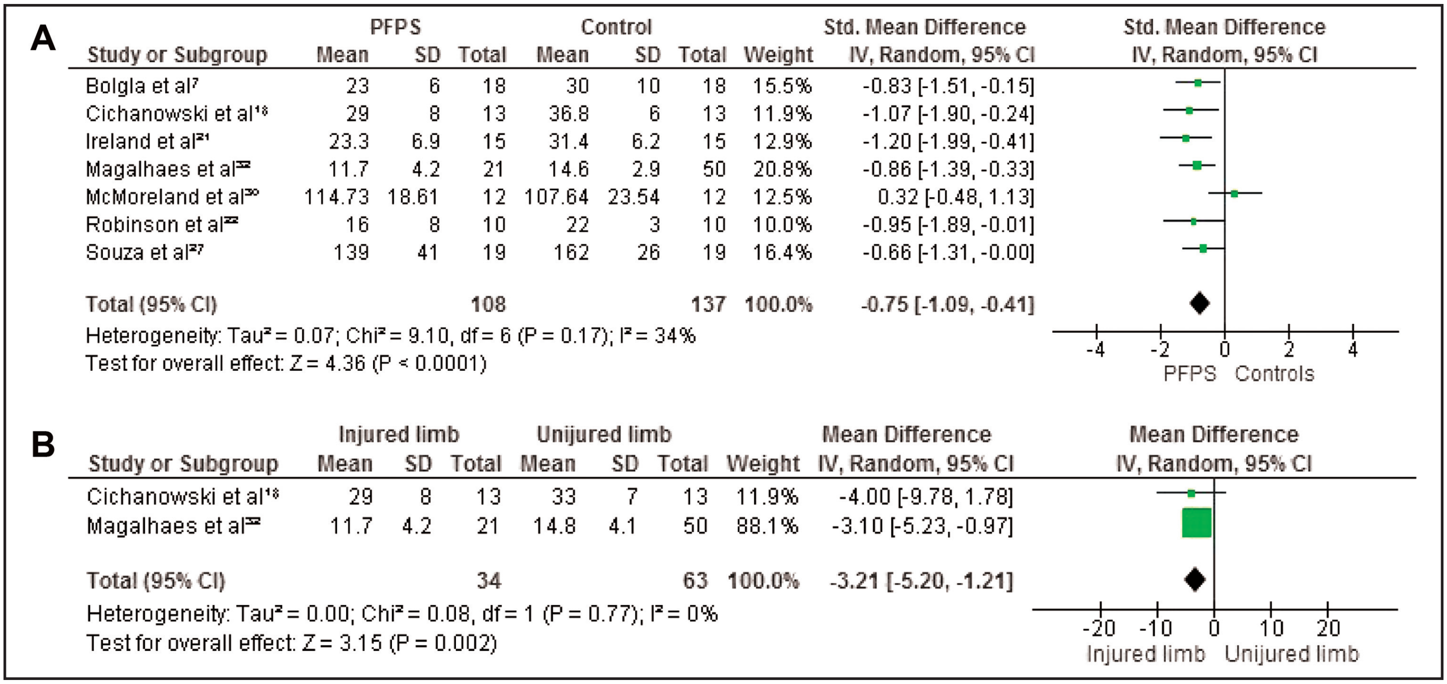

Figure 2. *Forest plot of the difference in hip abductors isometric strength between females with PFPS and controls (A) and between both sides (B)..*

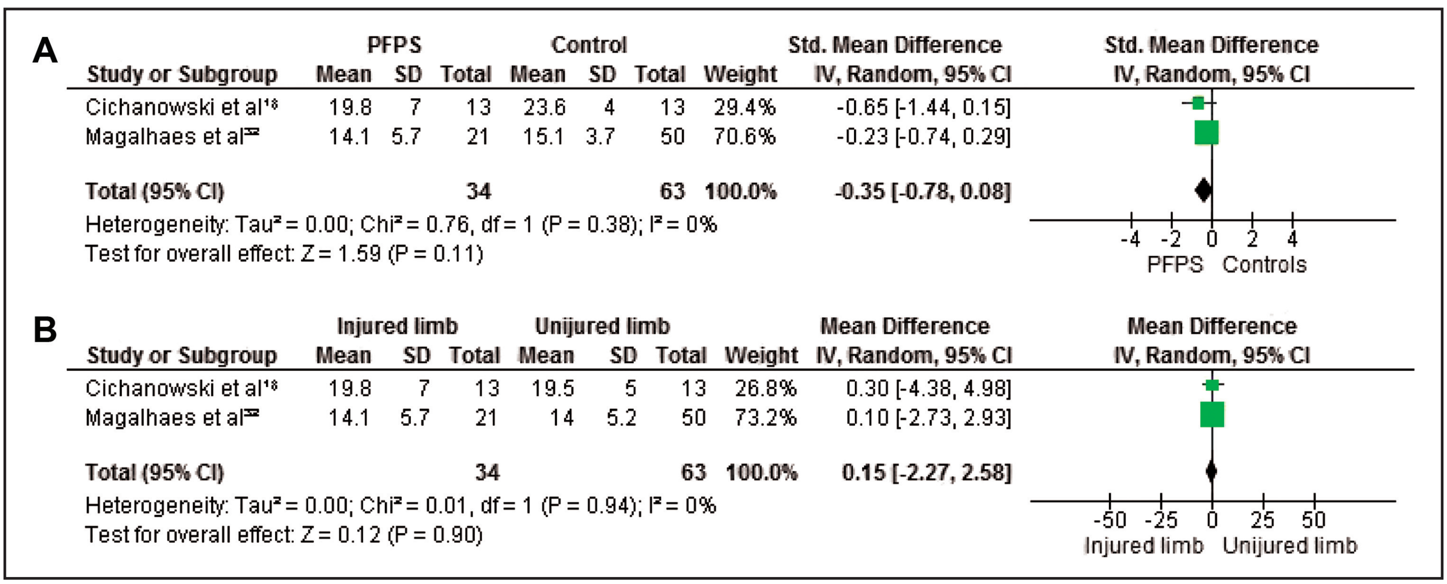

Figure 3. *Forest plot of the difference in hip adductors isometric strength between females with PFPS and controls (A) and between both sides (B).*

Isokinetic muscle strength: Peak torque during isokinetic evaluation was tested in three studies.[27,31,33] Due to high heterogeneity, data from these studies could not be pooled. Baldon et al[2] found eccentric peak torques significantly decreased in females with PFP for abduction (MD, -34.48; 95% CI: -41.81, -27.15), adduction (MD, -26.48; 95% CI: -37.69, -15.27), and internal rotation (MD, -9.21; 95% CI: -16.90, -1.52) when compared with healthy controls. Nakagawa et al[33] compared females with PFP to a control group and reported significantly decreased eccentric peak torques in females with PFP for abduction (MD, -17.00; 95% CI: -25.70, -8.30) and external rotation (MD, -9.00; 95% CI: -13.04, -4.96). Souza and

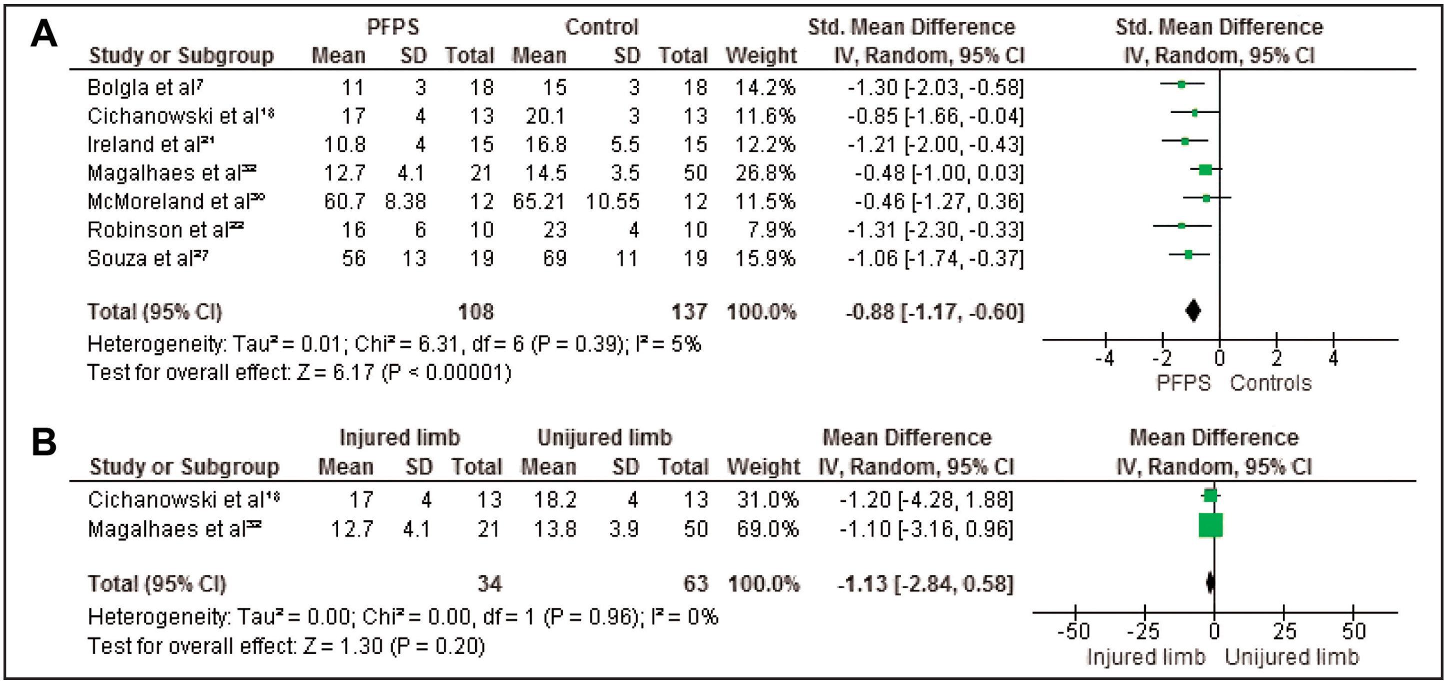

Figure 4. *Forest plot of the difference in hip external rotators isometric strength between females with PFPS and controls (A) and between both sides (B).*

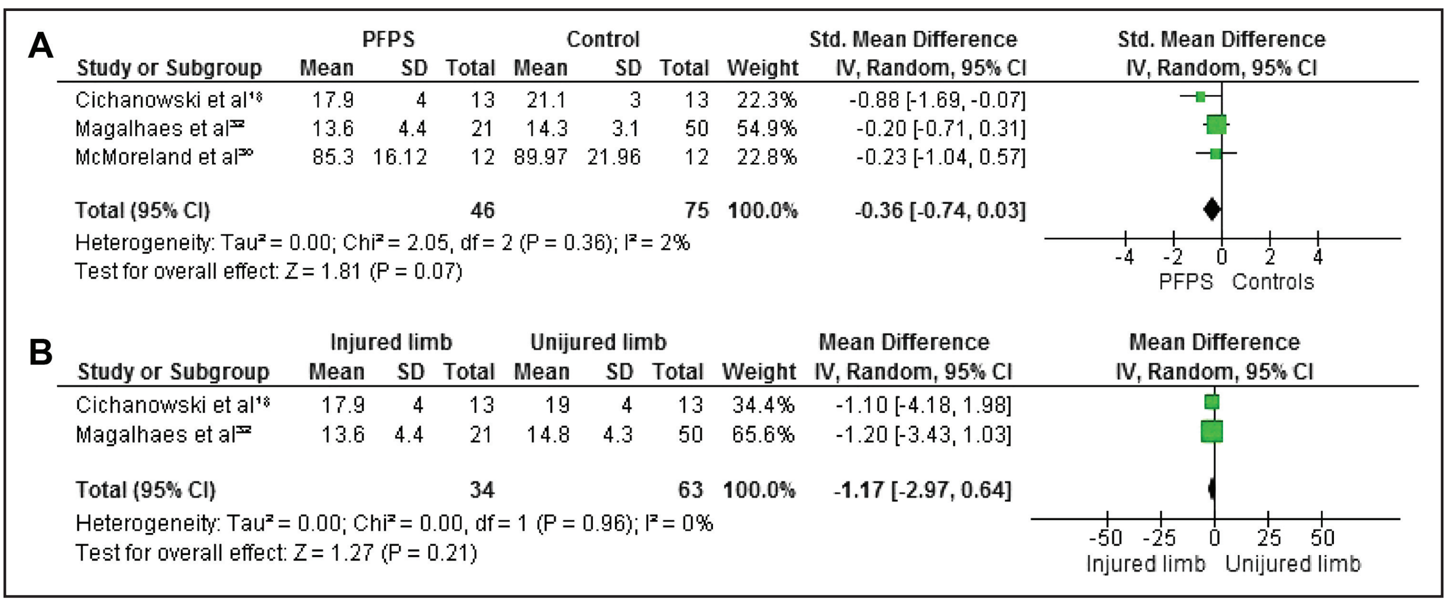

Figure 5. *Forest plot of the difference in hip internal rotators isometric strength between females with PFPS and controls (A) and between both sides (B).*

Powers[27] compared eccentric and concentric peak torques of the hip extensors between females with PFP and healthy controls and found concentric peak torques to be significantly lower in females with PFP (MD, -16.00; 95% CI: -30.28, -1.72) but no significant difference between groups for eccentric isokinetic strength measures (MD, -5.00; -24.52, 14.52).

Muscle endurance: Two studies assessed hip muscle endurance, using isokinetic dynamometer.[27,30] Souza and Powers[27] evaluated endurance of hip extensors. Subjects were instructed to contract against 25% of body weight and to perform as many repetitions as possible throughout the desired arc of motion. Each repetition was performed in 2.5 seconds. When suc-

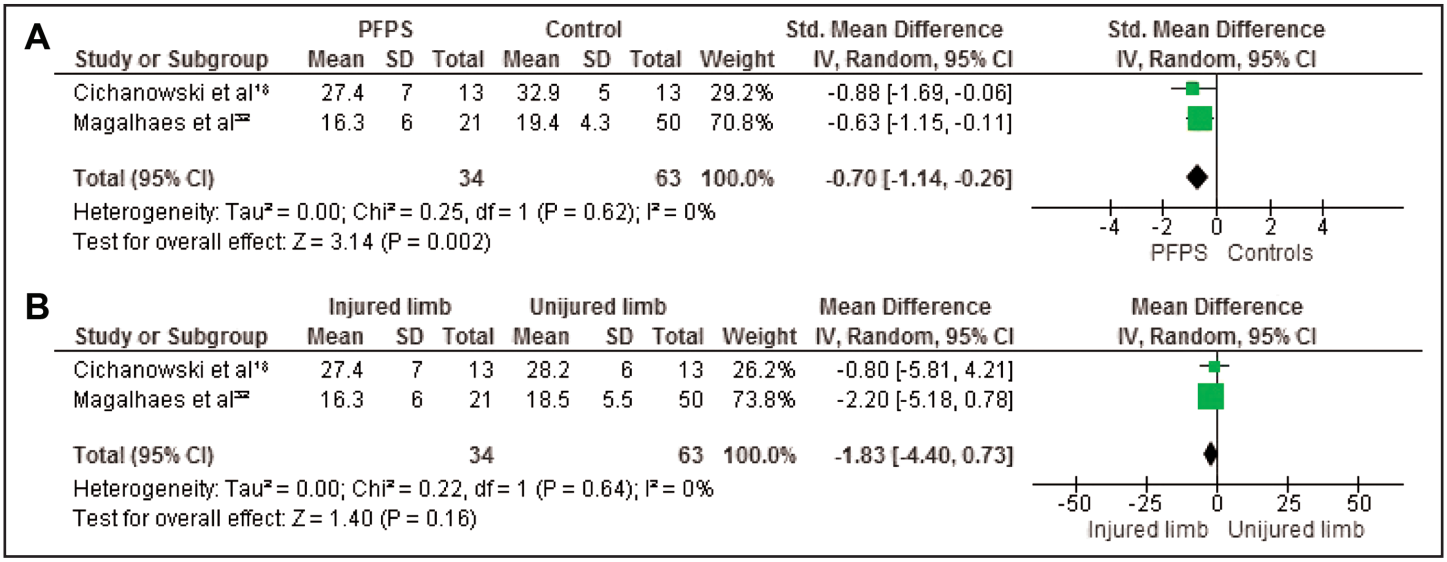

Figure 6. *Forest plot of the difference in hip flexors isometric strength between females with PFPS and controls (A) and between both sides (B).*

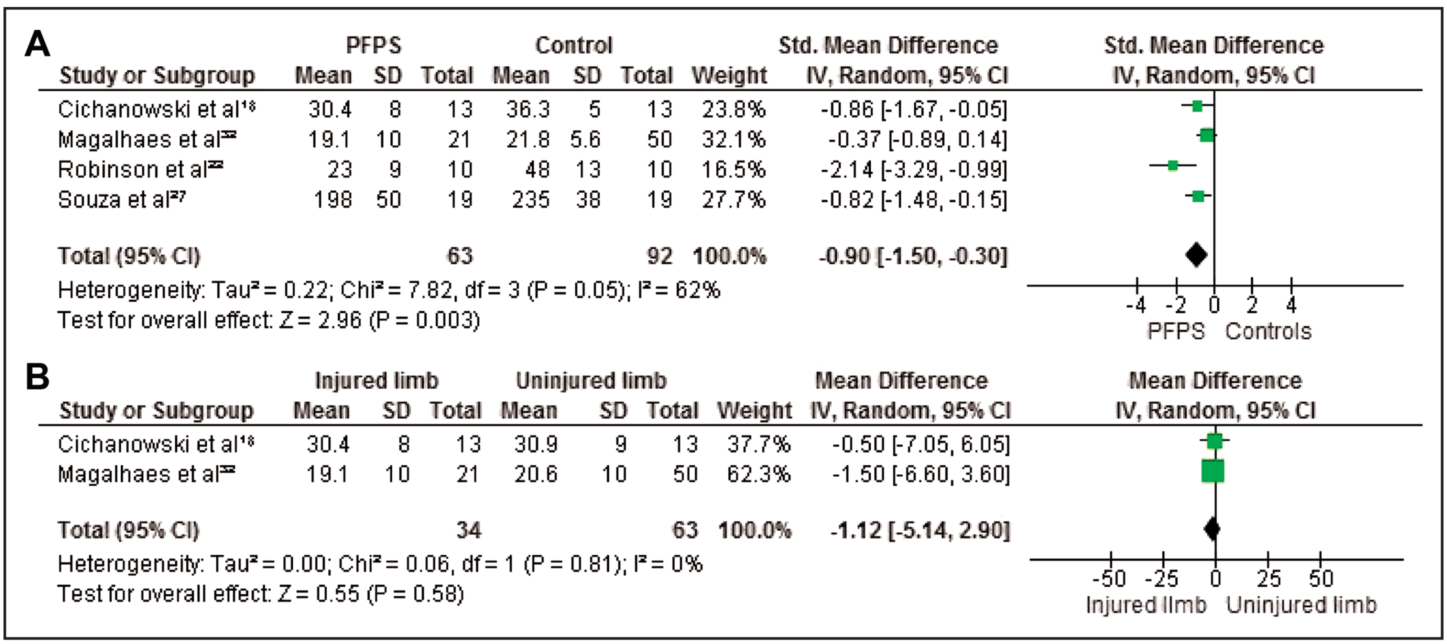

Figure 7. *Forest plot of the difference in hip extensors isometric strength between females with PFPS and controls (A) and between both sides (B).*

cessful repetition was not achieved (arc of motion or time allotted), the dynamometer power output would drop. A drop to < 75% torque output was considered a failed repetition and the test was terminated after two successive failed repetitions. The authors reported significantly fewer repetitions performed in females with PFP than in healthy controls (MD, -15.30; 95% CI: -20.17, -10.43). McMoreland et al[30] tested endurance of hip abductors and rotators between females with PFP and healthy controls. Total work (joules) produced during 30 maximal concentric repetitions at 30°/s was used to quantify muscle endurance. Their results showed no significant between-group difference for total work during tests. Appendix B reports all outcomes and mean differences of hip muscle strength and endurance for the included studies.

DISCUSSION

The aim of this systematic review was to determine if females with PFP have hip muscle strength and endurance deficits when compared to their unaffected leg and to comparison groups (normals). The results confirm that females with PFPS have strength deficits of several hip muscles in comparison with healthy controls and the unaffected side, but are contradictory concerning endurance.

Hip muscle endurance and PFP

Prins et al[20] suggested that deficit in hip muscle endurance may contribute to PFP and hypothesized that muscles of patients with PFP have greater deficits in endurance than strength. Only two studies investigated these questions. McMoreland et al[30] and Souza and Powers[27] evaluated muscle endurance of the hip in females with and without PFP. Souza and Powers[27] observed that females with PFP performed 49% less hip extension repetitions when compared with healthy controls. The authors suggested that these results may explain why symptoms in subjects with PFP increase during prolonged activities. These findings may also help to explain observations by Dierks et al[35] who described increased hip adduction in subjects with PFPS during prolonged running, especially at the end of the run. McMoreland et al[30] reported a moderate correlation between strength and endurance and suggested that clinicians should evaluate both measures separately, however, they found no significant differences in hip endurance compared to control subjects.[30] A possible explanation for these contradictory results may be differences in level of pain in the study population as compared to the controls. Indeed, the study of McMoreland et al[30] included females with mild patellofemoral pain while other studies included subjects ranging from mild to severe pain. The question concerning whether there is a lack of hip muscle endurance in patients with PFP remains unanswered.

Hip muscle strength and PFP

With regard to isometric strength of the hip, the results of studies indicated that a deficit in hip abduction, extension, external rotation, and flexion but no deficits in adduction and internal rotation when compared with healthy controls. However, differences in the number of studies pooled to evaluate each muscle group were observed. Seven studies were pooled for abduction and external rotation,[7,18,21,22,27,30,32] four for extension,[18,22,27,31] three for internal rotation[18,30,32] and only two studies for flexion and adduction.[18,32] Israel and Richter[24] reported that combination of a large number of studies increases the statistical power by reducing the interval confidence and, therefore, by increasing the precision of the estimated population mean difference effect size. The results of studies in which participants were evaluated with isokinetic dynamometry demonstrated strength deficits in abduction but contradictory results were found for peak torques of extensors and rotators. Therefore, more studies are necessary to determine whether concentric, eccentric, or isometric deficits in hip muscles strength are comparable in females with PFP and which deficits is most likely related to function. The isometric strength of the hip in the side with PFP versus the unaffected side was evaluated in three studies.[18,22,32] Data from two studies were pooled and showed a decrease significant in hip abductors compared with the unaffected side.[18,32] Data from Robinson and Nee[22] also demonstrated a decrease in isometric external rotation and extension strength when examined versus unaffected side.

Cause or consequence of PFP

In a prospective cohort study, Boling et al[36] longitudinally followed 1597 healthy participants and included isometric hip muscle strength evaluation in their baseline data collection, using hand held dynamometer. A total of 40 participants developed PFP during the follow-up period (maximum of 2.5 years of follow up) but initial hip muscle strength deficits were not significantly associated with occurrence of PFP. Finnoff et al[37] evaluated baseline isometric hip strength of high school running athletes at the beginning of the running season, using hand held dynamometery. The objective of this prospective study was to determine if pre-injury hip abductors weakness was associated with the development of PFP when compared to non-injured groups. Results showed that stronger hip abductors and weaker hip external rotators were risk factors of PFP. In addition, in the injured group, hip abduction and external rotation strengths decreased in post-injury when compared with their pre-injury evaluation. To date, it is difficult to determine whether deficits in hip muscle strength are a predisposing factor or consequence of PFP. Furthermore, none of these prospective studies evaluated hip muscle endurance.

Hip muscle strength and motion patterns in PFP

Researchers have shown that abnormal lower leg and thigh motions in the transverse and frontal planes during weight-bearing activities could affect or increase retropatellar stress when compared to non-weight bearing activities.[16,38] Powers[19] determined that subjects with hip weakness demonstrate increased hip adduction, hip internal rotation, and knee valgus when compared with controls. Dierks et al[35] compared hip strength and lower extremity kinematics before and after a prolonged run in patients with PFP and controls. The authors reported hip abductor weakness and alteration in the lower extremity kinematics in the PFP group and concluded that weaker hip abductor muscles were associated with increased hip adduction during running. Conversely, Bolgla et al[7] reported that females with PFP and hip weakness did not demonstrate altered hip and knee kinematics and other authors have not shown association between hip muscle weakness and lower extremity kinematics during single-legged 40 cm drop landings in healthy groups.[39] Additional investigations are needed to fully understand relationship between hip muscle strength and lower extremity kinematics during functional activities in subjects with PFP.

Effects of interventions

Researchers have recently investigated the effectiveness of hip strengthening for patients with PFP. Four studies, with variable protocols, reported a significant decrease of pain and amelioration of function following an exercise program targeting the hip muscles.[40,41,42,43] Dolak et al[40] investigated the benefits of a four weeks strengthening program of hip abductors and external rotators compared to quadriceps strengthening. Thirty-three females with PFP were randomly assigned to a hip strengthening program (hip group) or a quadriceps strengthening program (quadriceps group) for four weeks. After completing the fourth week of rehabilitation, participants from both groups performed similar program of functional weight-bearing exercises for four additional weeks. The hip group reported less pain than the quadriceps group at four weeks (respectively 43% and 3% on the visual analogic scale). After eight weeks, results were similar for both approaches and showed significant improvement of function and decrease of pain. The authors emphasized the use of isolated hip strengthening exercises in the early rehabilitation stages to in order to reduce pain more efficiently. Moreover, exercises described in the study used simple equipment such as elastic bands and can be easily included in a home training program.

Limitations

Because PFP is a diagnosis is based on a group of symptoms and not a specific test, inclusion criteria often differed between studies. The studies included patients with some variability in terms of localization and history of pain and type of provocative activities. Moreover, only five studies used valid and reliable scales, responsive in this specific population, like the Kujula scale.[22,30,31,32,34] The systematic use of the Kujula scale in studies on PFP could allow optimal comparability between participants. PFP is a multifactorial and complex condition and it is evident that the target population is often heterogeneous and could be separated in subgroups. Additionally, participant characteristics were variable or unclear. Females included in the examined studies were sedentary,[32]athletes,[27] reported recreational sports participation,[21,34] or their activity level was not specified.[7,22,31,32,33] Authors should systematically describe participants demographic data and, similarly, there is a need to provide recommendations for selection of patients with PFP to improve the quality and consistency of research on this syndrome.

Methods for assessing hip strength were variable. Subject and dynamometer position, type of contractions, measurement device and stabilization of the pelvis and upper leg differed among studies. Good to high reliability of hip strength evaluation using hand held or isokinetic dynamometery measures has been reported in the literature,[44,45,46] except for measures of the internal rotators, which showed moderate reliability.[44] Lower reliability could explain why authors who studied the strength of the internal rotators in female patients with PFP reported no strength deficit. Krause et al[45] examined the effect of different testing positions on test–retest reliability and showed that the relative reliability of hip abduction and adduction strength evaluation in the side lying position was higher when using a long lever compared with a short lever. Thorborg et al[46] reported less measurement variation in supine than in the side lying position when testing abduction and adduction. These results can explain the lack of agreement between studies and confirm the utility of establishing a standard method for hip strength and endurance evaluations.

Finally, the results of studies need to be interpreted with caution because, in most studies, the primary evaluator was not blinded to subject's condition and bias might have been introduced during evaluation.

CONCLUSION

This systematic review provides strong statistically significant evidence that females with PFP have significant isometric strength deficits in hip abduction, extension, and external rotation when compared with healthy controls. Moderate evidence was obtained concerning isometric strength deficit in flexion because the data of only two studies were pooled. There was no evidence that females with PFP have strength deficits in adduction and internal rotation. Moderate statistical evidence was found for isokinetic deficits in abduction and conflicting evidence for a deficit in rotation and extension. When compared with the uninjured limb, moderate evidence was found for a strength deficit in abduction, conflicting with evidence for deficiencies in extension and external rotation strength and no evidence for internal rotation, adduction and flexion strength deficiencies. Finally, conflicting evidence was found regarding whether a decrease in hip muscular endurance exists in patients with PFP.

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Appendix A. *Combinations of keywords for searches in varied Databases.*

Combinations of keywords				
("Patellofemoral Pain Syndrome" OR "Anterior Knee Pain") AND ("Muscle Strength" OR "Muscle Endurance")	85	8	8	40
("Hip" OR "Muscle Strength" OR "Muscle Endurance") AND ("Patellofemoral Pain Syndrome" OR "Anterior Knee Pain")	195	0	0	73
("Patellofemoral Pain Syndrome" OR "Anterior Knee Pain") AND ("Muscle Strength" OR "Muscle Endurance") AND "Hip"	40	0	0	22
("Hip" OR "Muscle Strength" OR "Muscle Endurance" OR "Muscle Endurance") AND ("Patellofemoral Pain Syndrome" OR "Anterior Knee Pain") AND "Female"	146	0	0	21
("Hip" AND "Muscle Strength" OR "Muscle Endurance") AND ("Patellofemoral Pain Syndrome" OR "Anterior Knee Pain") AND "Female"	39	0	0	9
Total	505	8	8	165

Appendix B. *Outcomes and mean differences of hip muscle strength and endurance.*

Study	Modalities	Outcome	MD (95% CI)
Abduction			
Baldon et al[31]	Isokinetic strength (eccentric) at 30°/s, (Nm/kg) x 100	PFPS, 88.89 ±10.27 Control, 123.37 ±5.85 P = .008	-34.48 (-41.81, -27.15)
Bolgla et al[7]	Isometric strength, (Nm/N.m) x 100	PFPS, 23 ±6 Control, 30±10 P = .0006	-7.00 (-12.39, -1.61)
Cichanowski et al[18]	Isometric strength, %BW	PFPS, 29 ±8 Control, 36.8±6 P = .010	-7.80 (-13.24, -2.36)
Cichanowski et al[18]	Isometric strength, %BW	Injured leg, 29±8 Noninjured leg 33±7 P = .003	-4.00 (-9.78, 1.78)
Ireland et al[21]	Isometric strength, %BW	PFPS, 23.3 ±6.9 Control, 31.4±6.2 P < .01	-8.10 (-12.79, -3.41)
Magalhaes et al[32]	Isometric strength, %BW	PFPS, 11.7 ±4.2 Control, 14.6±2.9 P < .002	-2.90 (-4.34, -1.46)
Magalhaes et al[32]	Isometric strength, %BW	Injured leg, 11.7±4.2 Noninjured leg 14.8 ±4.1 P < .002	-3.10 [-5.26, -0.94]
Magalhaes et al [32]	Isometric strength, %BW	Bilateral PFPS, 9.6 ±2.8 Control, 14.6 ±2.9 P < .0001	-5.00 (-6.30, -3.70)
McMoreland et al[30]	Isometric strength, Nm/kg x 100	PFPS, 114.73 ±18.61 Control, 107.64 ±23.54 P = .42	7.09 (-9.89, 24.07)
McMoreland et al[30]	Isokinetic endurance (concentric) at 30°/s, j	PFPS, 493.69 ±174.25 Control, 492.4 ±135.2 P = .98	1.29 (-123.50, 126.08)
Nakagawa et al[33]	Isokinetic strength (eccentric) at 30°/s, (Nm/kg.m)x100	PFPS, 56 ±13 Control, 73 ±15 P < .001	-17.00 (-25.70, -8.30)
Robinson and Nee[22]	Isometric strength, %BW	PFPS, 16 ±8 Control, 22±3 P = .007	-6.00 (-11.30, -0.70)
Robinson and Nee[22]	Isometric strength, %BW	Injured leg, 16±8 Noninjured leg 20.5±NM	- 4.5
Souza and Powers[27]	Isometric strength, Nm/kg x 100	PFPS, 139 ±41 Control, 162±26 P = .04	-23.00 (-44.83, -1.17)
Willson and Davis[34]	Isometric strength, %BW	PFPS, 21.1 ±NM Control, 24.9 ±NM P = .05	-3.8
Adduction			
Baldon et al[31]	Isokinetic strength (eccentric) at 30°/s, (Nm/kg) x 100	PFPS, 170.96 ±13,43 Control, 197.44 ±12,11 P =.009	-26.48 (-37.69, -15.27)
Cichanowski et al[18]	Isometric strength, %BW	PFPS, 19.8 ±7 Control, 23.6 ±4 P = .087	-3.80 (-8.18, 0.58)

Appendix B. *(Continued)*

Cichanowski et al[18]	Isometric strength, %BW	Injured leg, 19.8±7 Noninjured leg, 19.5 ±5 P = .65	-0.30 (-4.38, 4.98)
Magalhaes et al[32]	Isometric strength, %BW	PFPS, 14.1 ±5.7 Control, 15.1±3.7 P = NS	-1.00 (-2.88, 0.88)
Magalhaes et al[32]	Isometric strength, %BW	Injured leg, 14.1±5.7 Noninjured leg 14.0 ±5.2 P > .05	0.11 [-2.72, 2.94]
Magalhaes et al[32]	Isometric strength, %BW	Bilateral PFPS, 11.4 ±3.3 Control, 15.1 ±3.7 P < .0001	-3.70 (-5.28, -2.12)
External rotation			
Baldon et al[31]	Isokinetic strength (eccentric) at 30°/s, (Nm/kg) x 100	PFPS, 51.69 ±2.98 Control, 51.48 ±3.81 P = .96	0.21 (-2.79, 3.21)
Bolgla et al[7]	Isometric strength, (Nm/N.m) x 100	PFPS, 11 ±3 Control, 15 ±3 P = .002	-4.00 (-5.96, -2.04)
Cichanowski et al[18]	Isometric strength, %BW	PFPS, 17 ±4 Control, 20.1 ±3 P = .033	-3.10 (-5.82, -0.38)
Cichanowski et al[18]	Isometric strength, %BW	Injured leg, 17±4 Noninjured leg, 18.2 ±4 P = .049	-1.20 (-4.28, 1.88)
Ireland et al[21]	Isometric strength, %BW	PFPS, 10.8 ±4 Control, 16.8 ±5.5 P < .001	-6.00 (-9.44, -2.56)
Magalhaes et al[32]	Isometric strength, %BW	PFPS, 12.7 ±4.1 Control, 14.5 ±3.5 P < .01	-1.80 (-3.29, -0.31)
Magalhaes et al[32]	Isometric strength, %BW	Injured leg, 12.7±4.1 Noninjured leg 13.8 ±3.9 P > .05	-1.10 (-3.16, 0.96)
Magalhaes et al[32]	Isometric strength, %BW	Bilateral PFPS, 12.1 ±3.9 Control, 14.5 ±3.5 P < .0001	-2.40 (-4.12, -0.68)
McMoreland et al[30]	Isometric strength, Nm/kg x 100	PFPS, 60.7 ±8.38 Control, 65.21 ±10.55 P = .26	-4.51 (-12.13, 3.11)
McMoreland et al[30]	Isokinetic endurance (concentric) at 30°/s, j	PFPS, 448.24 ±95.76 Control, 481.03 ±138.38 P = .51	-32.79 (-125.69, 60.11)
Nakagawa et al[33]	Isokinetic strength (eccentric) at 30°/s, (Nm/kg.m) x 100	PFPS, 35 ±0.7 Control, 44 ± 0.6 P < .0001	- 9.00 (-13.04, -4.96).
Robinson and Nee[22]	Isometric strength, %BW	PFPS, 16 ±6 Control, 23 ±4 P = .004	-7.00 (-11.47, -2.53)

Appendix B. *(Continued)*

Robinson and Nee[22]	Isometric strength, %BW	Injured leg, 16±6 Noninjured leg 20±NM	-4
Souza and Powers[27]	Isometric strength, Nm/kg x 100	PFPS, 56 ±13 Control, 69 ±11 P = .002	-13.00 (-20.66, -5.34)
Willson and Davis[34]	Isometric strength, %BW	PFPS, 9.1 ±NM Control, 10.8 ±NM P = .04	-1.7
Internal rotation			
Baldon et al[31]	Isokinetic strength (eccentric) at 30°/s, (Nm/kg) x 100	PFPS, 113.30 ± 8.33 Control, 122.51 ±9.20 P = .47	-9.21 (-16.90, -1.52)
Cichanowski et al[18]	Isometric strength, %BW	PFPS, 17.9 ±4 Control, 21.1 ±3 P = .049	-3.20 (-5.92, -0.48)
Cichanowski et al[18]	Isometric strength, %BW	Injured leg, 17.9±4 Noninjured leg, 19 ±4 P = .11	-1.10 (-4.18, 1.98)
Magalhaes et al[32]	Isometric strength, %BW	PFPS, 13.6 ±4.4 Control, 14.3 ±3.1 P < .0001	-0.70 (-2.19, 0.79)
Magalhaes et al[32]	Isometric strength, %BW	Injured leg, 13.6±4.4 Noninjured leg 14.8 ±4.3 P > .05	-1.20 (-3.43, 1.03)
Magalhaes et al[32]	Isometric strength, %BW	Bilateral PFPS, 12.7 ±3.8 Control, 14.3 ±3.1 P < .0001	-1.60 [-3.23, 0.03]
McMoreland et al[30]	Isometric strength, Nm/kg x 100	PFPS, 85.3 ±16.12 Control, 89.97 ±21.96 P = .56	-4.67 (-20.08, 10.74)
McMoreland et al[30]	Isokinetic endurance (concentric) at 30°/s, j	PFPS, 694.42 ±186.15 Control, 656.5 ±191.6 P = .42	37.92 (-113.22, 189.06)
Flexion			
Cichanowski et al[18]	Isometric strength, %BW	PFPS, 27.4 ±7 Control, 32.9 ±5 P = .033	-5.50 (-10.18, -0.82)
Cichanowski et al[18]	Isometric strength, %BW	Injured leg, 27.4±7 Noninjured leg, 28.2 ±6 P = .46	-0.80 (-5.81, 4.21)
Magalhaes et al[32]	Isometric strength, %BW	PFPS, 16.3 ±6 Control, 19.4 ±4.3 P < .0001	-3.10 (-5.15, -1.05)
Magalhaes et al[32]	Isometric strength, %BW	Injured leg, 16.3±6 Noninjured leg 18.5 ±5.5 P > .05	-2.20 (-5.18, 0.78)
Magalhaes et al[32]	Isometric strength, %BW	Bilateral PFPS, 14.9. ±4.3 Control, 19.4 ±4.3 P < .0001	-4.50 (-6.47, -2.53)

Appendix B. *(Continued)*

Extension			
Cichanowski et al[18]	Isometric strength, %BW	PFPS, 30.4 ±8 Control, 36.3 ±5 P = .029	-5.90 (-11.03, -0.77)
Cichanowski et al[18]	Isometric strength, %BW	Injured leg, 30.4±8 Noninjured leg, 30.9 ±9 P = .56	-0.50 (-7.05, 6.05)
Magalhaes et al[32]	Isometric strength, %BW	PFPS, 19.1 ±10 Control, 21.8 ±5.6 P < .0001	-2.70 (-5.88, 0.48)
Magalhaes et al[32]	Isometric strength, %BW	Injured leg, 19.1±10 Noninjured leg 20.6 ±10 P > .05	-1.50 (-6.60, 3.60)
Magalhaes et al[32]	Isometric strength, %BW	Bilateral PFPS, 15.8 ±9.0 Control, 21.8 ±5.6 P < .0001	-6.42 (-10.04, -2.80)
Robinson and Nee[22]	Isometric strength, %BW	Injured leg, 23±9 Noninjured leg, 32 ±NM	- 9
Souza and Powers[27]	Isometric strength, Nm/kg x 100	PFPS, 198 ±50 Control, 235 ±38 P = .01	-37.00 (-65.24, -8.76)
Souza and Powers[27]	Isokinetic strength (eccentric) at 10°/s, Nm/kg x 100	PFPS, 87 ±34 Control, 92 ±27 P = .59	-5.00 (-24.52, 14.52)
Souza and Powers[27]	Isokinetic strength (concentric) at 10°/s, Nm/kg x 100	PFPS, 78 ±28 Control, 94 ±15 P = .03	-16.00(-30.28, -1.72)
Souza and Powers[27]	Isotonic endurance , total of repetitions	PFPS, 16.6 ±7.5 Control, 31.9 ±7.8	- 15.30 (-20.17, -10.43)

Abbreviations: BMI=body mass index; BW=body weight; CI=confidence interval; M= mean difference; PFPS=patellofemoral pain syndrome