Effect of hip abductors and lateral rotators' muscle strengthening on pain and functional outcome in adult patients with patellofemoral pain: A systematic review and meta-analysis

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Abstract

BACKGROUND:

Even though literature indicates presence of weak hip abductors and lateral rotators' in Patellofemoral Pain (PFP), studies evaluating the effect of hip abductors and lateral rotator strengthening to improve knee function and quality of life in PFP are limited.

OBJECTIVE:

This study systematically reviews and meta-analyzes the best evidence on the therapeutic value of strengthening hip abductors and lateral rotators muscles for treating PFP with a presumptive

hypothesis that strengthening hip muscles stabilizes the patellofemoral joint, relieves pain, and enhances knee functions.

METHOD:

Medline, EMBASE, CINAHL, PEDro and PubMed Central databases were searched between January 1994 and September 2019 using the PICOS tool. The methodological quality of the selected studies were appraised individually using the 20-item McMaster Critical Review Form for Quantitative Studies. Supplemental quality appraisal of randomized controlled clinical trials performed using the Cochrane Collaboration's 'Risk of bias' quality criteria. Data on patient population demographics, interventions, duration of intervention, and outcome measures were extracted and summarized in evidence tables and descriptive analysis. Meta-analyses under both fixed and random-effects models determined pooled effects size from appropriate RCTs.

RESULTS:

All fourteen studies demonstrated that hip muscle strengthening improved pain and knee function. All RCTs, except one, demonstrated that hip muscle strengthening is superior to quadriceps strengthening. Of the five RCTs accessing the additional effect of hip-quad versus quadriceps strengthening, four suggested that hip-quad strengthening is superior to standard quadriceps strengthening alone to improve PFP and knee function.

CONCLUSION:

In adult patients with PFP, strengthening hip abductors and lateral rotators' have beneficial therapeutic effects than the conventional quadriceps exercises in improving knee pain and function both in the short- and long term. However, the present review data can be used to develop a standardized hip-quad protocol in the future.

1.Introduction

Patellofemoral pain (PFP) is characterized by anterior knee pain emanating from the patellofemoral joint involving patella and fibrous tissue on the mediolateral retinaculum [1]. The aetiology is irregular patellar kinematics due to excessive pressure on the patellofemoral joint, poor proximal neuromuscular control, and hip muscle weakness [2, 3, 4]. The pain in PFP is because of inflammation coupled with damage to the bony, cartilaginous or connective tissues of the patellofemoral joint [1, 2, 5].

The PFP incidence rate is 25–40% of all cases of anterior knee pain, which is considerably high. Hence, therapeutic interventions are imperative to reduce permanent knee disabilities and improve quality of life [5, 6, 7]. The prevalence of PFP is higher in women and athletes than males (2:1) and is even higher (4:1) among athletes [6].

The works of literature on musculoskeletal injuries indicate a positive correlation between hip muscles weakness and PFP [8, 9, 10]. In a case report on PFP, authors noted that excessive hip adduction coupled with the weakness of the hip extensors and abductors are predominantly musculoskeletal concerns [10]. The current physiotherapy evidence strongly supports quadriceps muscle strengthening as an effective strategy to improve overall knee function in patients with PFP [11, 12, 13]. The proximal hip muscle exercises effectively relieved patellofemoral pain and improved knee function compared to knee exercises alone [14]. Therefore, strengthening these muscles underlie the objective treatment of PFP. While quadriceps strengthening is already the standard physiotherapeutic target for PFP, it is plausible that strengthening hip muscles will serve greater benefits because of its effect on greater control over the knee biomechanics [5, 15].

1.1Relationship between hip muscles (abductors and lateral rotators) strength and PFP

Hip muscles (abductors and lateral rotators) are essential for knee and pelvic stabilization during ambulation [5]. The hip abductors and lateral rotators act synergistically to eccentrically control the hip adduction and internal rotation movements [15, 16, 17]. The diminished strength of hip abductors and lateral rotator muscles may result in poor neuromuscular control during activities that require loading on the patellofemoral joint [5, 8, 15]. The weak hip abductors may cause excessive femoral adduction, thereby augmenting lateral forces (Knee Valgum) acting on the patella [16]. In contrast, weak hip lateral rotators result in unrestricted internal rotation of the femur that augments contact pressure between the lateral facet of the patella and lateral femoral condyle [16]. Hence, weak hip muscles (mainly abductors and lateral rotators) are an important aetiological factor for PFP [5, 17, 18, 19].

Many studies compared the effectiveness of hip muscles strength in patients with PFP to matched healthy controls [19, 20, 21, 22]. Ireland et al. reported eccentric muscle strength reduction of 26% in hip abductors and 36% in hip lateral rotators among females with PFP, while Souza and Powers found a reduction of 14% in hip abductors and 17% in hip lateral rotators eccentric muscle strength compared to healthy matched controls [19, 21]. Nevertheless, Piva et al. found no significant muscle strength differences for hip abductors and lateral rotators in patients with PFP compared to healthy age/gender-matched controls; however, Baldon et al. reported significantly reduced strength for eccentric hip abductors, but not for hip lateral rotators among females with PFP to healthy matched controls [20, 22].

The weak hip lateral rotators cause unrestricted internal rotation of the femur about the tibia, enhancing misalignment at the knee joint that in turn leads to a biomechanical imbalance between the hip extensors and lateral rotators that overload the retinaculum and subchondral bone and subsequently potentiate patellofemoral pain and knee dysfunction [19]. Nevertheless, Earl et al. argued that strong hip muscles (abductors and lateral rotators) reverse these effects over the knee joint [3]. Moreover, rotational malalignment and patellar instability are well documented, and weak hip lateral rotator muscles are identified as important contributors [23, 24, 25]. It is important to consider the biomechanical assistance provided by the hip lateral rotator group muscles to maintain the normal alignment of the patella [26].

Ireland et al. and Souza and Powers noted more weakness in hip lateral rotators than hip abductors in patients with PFP [21, 19]. Ferber et al. found that in patients with PFP, the three weeks of isolated hip abductors strengthening reduced patellofemoral pain and increased gait-related knee-joint stability [9]. Two recent randomized controlled trials found that isolated strengthening of hip abductors and lateral rotators effectively relieves pain and improvise knee function in females [4, 27]. The available evidence for PFP considered exercises to strengthen the hip muscles that reduce pain and enhance long-term knee function [3, 4, 6, 27, 28].

1.2Outcome measures of pain, knee function and health status in PFP

The available studies used self-reported Kujala Anterior Knee Pain Scale (AKPS), Visual Analogue Pain (VAS) scale, 11-point Numerical Pain Rating Scale (NPRS) and Pain Severity Scale (PSS) as an outcome measure to document patellofemoral pain in patients with PFP receiving therapeutic interventions [14, 29, 30].

The knee functions for patellofemoral pain were assessed using the Lower Extremity Functional Scale (LEFS), Tegner Activity Scale (TAS), Lysholm Knee Scoring Scale (LKSC)/Tegner Lysholm Knee Scoring Scale (TLKSS), Knee Outcome Survey-Activities of Daily Living Scale (KOS-ADL) and Functional Index Questionnaire (FIQ) [30, 31, 32, 33, 34].

Although the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) is tailored to examine the functional status of osteoarthritis, it is also used to measure health status for patients with patellofemoral pain (because patients with osteoarthritis often present with anterior knee pain, which is similar to patellofemoral pain) [29].

Since systematic reviews evaluating the effect of hip abductors and lateral rotator strengthening for patellofemoral pain, knee function and quality of life in patients with PFP are extremely limited, primarily this study systematically reviews and meta-analyzes the best evidence on the therapeutic value of strengthening hip abductors and lateral rotators muscles for the treatment of PFP. The presumptive hypothesis is that strengthening hip muscles stabilizes the patellofemoral joint, relieves pain and enhances knee functions.

2.Methods

2.1Justification of the systematic review approach

Systematic reviews and meta-analyses are important methodologies for the qualitative and quantitative synthesis of published evidence. Shreds of evidence presented in systematic reviews are key for continuous quality and safety improvements in evidence-based clinical practice and, therefore, useful for clinicians and healthcare policymakers. The present review study used Centre for Reviews and Dissemination (CRD) guidance for undertaking reviews in health interventions to assess the value of hip muscle strengthening as therapeutic interventions in patellofemoral pain and knee function in patients with PFP [35]. Additionally, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, recommended in CRD's guidance, is used in

literature searches to minimize article selection and reporting bias [36]. This study is exempt from Institutional Review Board approval as it is a literature review. The review has been registered with the Open Science Framework with reference doi: 10.17605/OSF.IO/CWZ8V.

2.2Electronic bibliographic database searches

The controlled clinical trials (randomized and non-randomized), controlled comparative studies and cohort studies ((prospective and retrospective) published in the last 25 years (January 1994 to September 2019) in English language journals were performed across five electronic databases [Medical Literature Analysis and Retrieval System Online (Medline); Excerpta Medica Database (EMBASE); Clinical Index of Nursing and Allied Health Literature (CINAHL); Physiotherapy Evidence Database (PEDro) and The Cochrane Central Register of Controlled Trials (CENTRAL)]. Appropriate combinations of Medical Subject Headings (MeSH) or CINAHL headings with keywords (Table 1) using Boolean Operators (AND, OR and NOT) along with PICOS (target population, intervention, comparator, outcomes and study design) were used [37].

Table 1

Medical Subject Headings (MeSH) terms and keywords for PICOS search strategy

Common MeSH terms	Text words (keywords)
Population	Humans, adult, female, male Adolescents and young adults	“Patellofemoral pain”, “Anterior knee pain”, “Chondromalacia patella”
Intervention	Exercise Therapy, Exercise Therapy/methods, Physical Therapy Modalities, Patellofemoral Pain Syndrome/rehabilitation, Hip Physiology, Knee Joint Physiopathology, Combined Modality Therapy	Exercise-based interventions targeting hip muscles strengthening “hip Exercises” or “hip-strengthening exercises.”
Comparator	Quadriceps Muscle physiology/physiopathology,	Exercise-based interventions targeting knee muscles strengthening or Stretching (quadriceps protocol): “quadriceps strengthening exercise”, “Knee strengthening exercise”, “Knee stretching exercises,” and “knee Stabilizing exercises” OR no treatment
Outcomes	Treatment Outcome, Pain Measurement, Recovery of Function	Anterior knee pain: “pain measurement”, “The Kujala Anterior Knee Pain Scale” (AKPS), “The Visual Analogue Pain Scale” (VAS), 11-Point “Numerical Pain Rating Scale” (NPRS), “self-reported pain”, “Pain Severity Scale” (PSS) Function: “knee function”, “functional outcome questionnaire for the knee pain,” “Lower Extremity Functional Scale” (LEFS), “Tegner Activity Scale” (TAS), “Lysholm Knee Scoring Scale” (LKSS), “Tegner Lysholm Knee Scoring Scale” (TLKSS), “Knee Outcome Survey-Activities of Daily Living Scale” and “Functional Index Questionnaire” (FIQ), “Patello-femoral joint evaluation scale” (PFJES) Health status: “Western Ontario and McMaster Universities Osteoarthritis Index” (WOMAC)

Study types (design) Publication types: controlled clinical trial, randomised controlled trial, non-randomised controlled trial, controlled Comparative study, comparative study, cohort studies, follow-up studies, observational studies (prospective study, Retrospective study, case series), systematic reviews

Additional electronic searches are done in the Meta Register of Controlled Trials (mRCT) via the Current Controlled Trials (CCT) database to locate ongoing RCTs with potentially relevant data useful for the present systematic review. The potentially relevant clinical controlled trials and cohort studies (otherwise not indexed in any of the five electronic bibliographic databases and mRCT), electronic searches were supplemented by searching unpublished papers from the OpenGrey (formerly SIGLE) database. The literature searches were additionally supplemented with manual bibliographic searches of relevant systematic reviews, editorials and thesis reports published by the digital libraries of the University of Manchester, University of Central Lancashire and Australian Digital Thesis programmes, including ProQuest. Authors of potentially relevant unpublished reports were contacted by e-mails seeking clarification of their respective studies with the possibility of inclusion in the present review.

2.3Study selection

The study selection was performed using thePRISMA flowchart (Fig. 1), where returned hits for each electronic bibliographic database were screened by two independent reviewers initially based on title and abstracts. The number of potentially relevant articles was noted, citations were imported into the Endnote citation manager (EndNote X7), and full-text articles were retrieved for further eligibility screening by the two independent reviewers. Studies were included based on the following criteria:

Figure 1.

PRISMA flowchart for articles search strategy, screening and eligibility evaluation.

PRISMA flowchart for articles search strategy, screening and eligibility evaluation.

Table 2

Methodological quality of selected studies rated on McMaster critical review form

Author (s)	Study design	Level of evidence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score/16
Avraham et al. [41]	RCT	Level 2b	√	√	√	√	×	×	×	×	√	√	×	√	√	√	√	√	10/16
Baldon et al. [42]	RCT	level 1b	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	15/16
Dolak et al. [6]	RCT	level 2b	√	√	√	√	×	√	√	×	√	×	×	√	√	√	√	√	12/16

Fukuda et al. [4]			RCT		level 1b	√		√		√		√		√		√		√		√		√		√
	√		√		√		√		√		√		16/16										
Fukuda et al. [28]			RCT		level 1b	√		√		√		√		√		√		√		√		√		√
	√		√		√		√		√		√		16/16										
Ismail et al. [43]		RCT		Level 2b			√		√		√		√		×		√		√		√		√	
	√		√		√		√		√		√		14/16										
Khayambashi et al. [44]			CCT		Level 2b			√		√		√		√		×		√		√		√		√
	√		√		√		√		√		√		14/16										
Khayambashi et al. [27]			RCT		Level 2b			√		√		√		√		×		√		√		√		√
	√		√		√		√		√		√		14/16										
Nakagawa et al. [45]			RCT-p		Level 2b			√		√		√		√		√		√		√		√		√
	√		√		√		√		√		√		15/16										
Song et al. [46]		RCT		level 1b		√		√		√		√		√		√		√		√		√		√
	√		√		√		√		√		16/16												
Tyler et al. [48]		CS		Level 2b			√		√		√		√		√		√		√		√		√	
	√		n/a		√		√		√		×		√		14/16									
Boling et al. [47]			CS		Level 2b			√		√		√		√		√		×		√		√		√
	√		√		n/a		√		√		√		√		√		14/15							
Earl and Hoch. [3]			CSr		Level 4	√		√		√		√		√		√		√		√		√		√
	√		n/a		√		√		√		√		√		15/15									
Ferber et al. [9]		CS		Level 4		√		√		√		√		√		√		×		×		√		
	√		√		√		√		×		√		13/16										
Total	14		14		14		14		8		11		12		11		14		6		12		14	
	14		14		12		14																	

RCT = randomised controlled trial, CCT = comparative control trial RCT-p = randomised controlled pilot study, CS = cohort study, CSr = case series: Key: √= yes (criterion fulfilled), ×= No (criterion not fulfilled/not clear), n/a = Not applicable. 1. Is the study question and aims clear? 2. Is the background literature review adequate leading to the research questions and objectives? 3. Is the selected study design and study setting appropriate? 4. Is the study sample characteristic suitable? 5. Is the sample size adequate and justified? 6. Is the study ethical? 7. Is the reliability of outcome measures reported? 8. Is the validity of outcome measures reported? 9. Is intervention descriptions clear and adequate? 10. Was contamination of sample populations avoided? 11. Is co-interventions are avoided? 12. Are results reported in terms of statistical significance? 13. Were appropriate statistical analyses were performed? 14. Were clinical significance of the findings are reported? 15. Were participants' drop-outs and withdrawals the reported? 16. Are the author's conclusions appropriate?

2.4Inclusion criteria

1. Studies that enrolled adolescents (⩾ 14 to ⩽ 19 years) and/or adults (⩾ 50 years).

2. Studies involving patients with the confirmed clinical diagnosis of patellofemoral pain presented with anterior or retro patellar knee pain during physical activities, i.e. running, climbing a staircase, squatting, hopping, and kneeling or prolonged sitting.

3. Only controlled clinical trials (RCTs, Non-RCTs, and comparative studies) and cohort studies assessing the effect of hip abductors and/or lateral rotators strengthening on pain and functional outcomes of patients with a confirmed diagnosis of patellofemoral pain.

4. Studies published as books, chapters or conference abstracts or interim results in the mRCT database provided that authors were contacted successfully.

5. Studies comparing strengthening of hip abductors and/or lateral rotators muscles with standard quadriceps strengthening or no exercises.

6. Studies where the intervention group received hip muscles strengthening exercises coupled with quadriceps strengthening provided that the comparator group received only the quadriceps strengthening protocol.

7. Studies measuring pain by VAS, AKPS, 11-point NPRS, PSS, and functional outcomes examined on TAS, LKSS, FIQ, TLKSS LEFS, PFJES, or WOMAC instruments.

8. Studies published in English only were included for the review.

2.5Exclusion criteria

1. Studies that were not quantitative such as reviews, editorials, commentaries, which merely reviewed the physiotherapeutic benefits of hip muscle strengthening to patients with patellofemoral pain.

2. Studies published more than 20 years ago.

3. Studies that recruited PFP patients with other underlying knee pathologies, such as knee osteoarthritis, cartilaginous knee injuries, meniscal tears or knee surgery.

4. Studies that included the non-exercise co-inter-ventions such as electro-muscular stimulation (electrotherapy), patella taping, and orthotics.

5. Studies reported neither patient pain nor function.

A third senior reviewer was contacted to reach a consensus on any disagreement among the two reviewers regarding the inclusion or exclusion of an article.

2.6Critical appraisal of methodological quality

The McMaster Critical Review Form for Quantitative Studies was applied to examine the methodological quality of all selected studies for study's objectives, literature survey, study design, sample population, intervention, outcome measures, results, significance, limitations, and conclusions (Table 2) [14]. Knowing that biases are the main threats to RCTs' internal and external validity, quality appraisal of RCTs was performed using The Cochrane Collaboration's 'Risk of bias' tool tailored specifically for RCTs [38]. The risk of patient selection bias was examined for the selected RCTs for the sufficiency of random sequence generation and concealment allocation to interventional and control groups. This helped to determine the comparability of the study groups at baseline. The risk of performance bias was evaluated based on measures (e.g. single blinding or double-blinding) employed to ensure study participants and personnel are blinded to interventions and outcomes. The risk of detection bias was assessed to know if the assessors were adequately blinded to patient group allocation. The risk of attrition bias and incorporation bias were examined based on the dropout rate and pattern of participants, handling incomplete outcome data, and the indications of intention-to-treat (ITT) analysis. Finally, the risk of reporting bias is evaluated based on the possibility of selective outcome reporting. The reproducibility of exercise therapies prescribed confounding/modifying effects of co-interventions and the levels of supervision and patient compliance to the prescribed physiotherapy during the trial were also evaluated across the RCTs studies.

2.7Data extraction and qualitative synthesis

Data on effect measures were extracted for baseline patellofemoral pain levels, hip exercise interventions, including the comparator treatment, quantitative assessment of patient outcomes for patellofemoral pain and functions, follow-up duration and post-intervention practices during the follow-up periods. Statistical results (mean differences from baseline and effect measures P value at 95% confidence interval) were taken from the evidence tables for interventional studies (separately for controlled clinical trials and cohort studies).

2.8Quantitative synthesis (meta-analysis)

Using MedCalc software version 14.10.2 (MedCalc Software Ltd., Ostend Belgium), data from RCTs that provided the mean difference of pain or knee function between the intervention and the comparator groups were pooled by random or fixed-effect models to obtain standardized mean differences. Separate forest plots were generated for pain and knee function outcomes.

Table 3

Participants allocation in intervention and non-intervention groups with the duration of intervention and frequency of therapy in weeks

Study (n)	Duration of intervention		Frequency of therapy			Hip (N)	Quad (n)	Hip-Quad
	No exercise (n)	Total (N)						
Dolak et al. [6]	4 wks	3 per Wk	17	16		–	33	
Baldon et al. [42]	8 wks	3 per Wk	15	16			31	
Khayambashi et al. [44]	8 wks	3 per Wk	18	18			36	
Nakagawa et al. [45]	6 wks	4 per Wk		7	7		14	
Fukuda et al. [4]	4 wks	3 per Wk	20	21		41		
Fukuda et al. [28]	4 wks	3 per Wk	24	25		49		
Ismail et al. [43]	6 wks	3 per Wk	16	16		32		
Avraham et al. [41]	3 wks	2 per Wk	10	10		10		30
Song et al. [46]	8 wks	3 per Wk	–	30	29	30	89	
Khayambashi et al. [27]	8 wks	3 per Wk	14	–		14	28	
Total (N)	74	157	108	44	383			

3.Results

Using the PICOS search strategy, the primary electronic searches in the five bibliographic databases returned 114 potentially relevant citations. Through careful screening for duplicates based on titles and authors, 50 citations were excluded. The 43 articles were excluded after careful screening of titles and abstracts from the remaining 64 articles because they were irrelevant. The full texts of the remaining 21 articles were evaluated rigorously for eligibility based on the inclusion and exclusion criteria, and through this process, ten studies were excluded because of the following reasons.

1. Six articles were excluded because they involved patients with knee osteoarthritis or mixed participants with PFP and osteoarthritis,

2. Two studies were excluded because they focused on hip/quadriceps muscle strengths as the only outcome measure after interventions without assessing pain or functional outcomes,

3. One study appeared relevant but lacked the description of exercise interventions administered,

4. Lastly, one study contained duplicate experimental data from another included original study.

Three potentially relevant studies were identified through manual bibliographic hand searches of three recent systematic reviews [14, 39, 40]. The complete process yielded 14 studies. Ten were controlled clinical trials (CCTs), three were cohort studies, and one was a case series [3, 4, 6, 9, 27, 28, 41, 42, 43, 44, 45, 46, 47, 48]. The three cohort studies met the inclusion criteria for qualitative synthesis. Nine controlled clinical trials were true randomized controlled trials (RCTs) presenting data suitable for quantitative synthesis (meta-analysis) [4, 6, 27, 28, 41, 42, 43, 45, 46]. The literature search strategy and article selection process are summarised in the PRISMA flowchart (Fig. 1) [36].

3.1Controlled clinical trials

A total of 383 participants from the 10 CCTs received either hip-strengthening exercises (N= 74) or quadriceps strengthening exercises (N= 157) or hip/quadriceps strengthening exercises (N= 108) or no exercise (N= 44) (Table 2). All CCTs involved true randomization of participants except one, where participants were allocated to their respective groups alternately in a consecutive manner [44].

3.2Intervention protocol

In all CCTs, the hip muscles strengthening protocol focused on hip abductors and lateral rotators. The hip exercise protocol included hip abduction against an elastic band while standing, or with weights in side-lying position coupled with lateral hip rotation against an elastic band while seated and hip extension; quadriceps strengthening involved closed kinetic chain exercise or seated knee extension, leg press, squatting and stretching of hamstrings and quadriceps; and, hip-quadriceps strengthening involved the combination of hip-quadriceps protocol. The duration of intervention ranged from 3 to 8 weeks, while the frequency of therapy sessions ranged from 2 to 4 per week (Table 3).

3.3Outcome measures

All CCTs examined both pain and functional outcomes except one, which assessed only pain [45]. The pain was commonly evaluated using 10-cm VAS by all CCTs except two, which used the 11-point NPRS [4, 28]. The pain was evaluated during ascending and descending stairs [4, 28, 45], squatting, usual pain [45], and worst knee pain in the previous week [6, 27, 43, 44, 45, 46]. Functional outcomes were assessed using LEFS [4, 6, 28, 42], AKPS [4, 6, 28, 43], PFJES [41], TLKSS [46] and WOMAC [27, 44].

3.4Follow-up duration

Post-intervention measures were immediately carried out in all studies, at the end of the intervention period. However, the post- interventional follow-up period ranged from one to twelve months (Table 4).

Table 4

Follow-up duration and interval post-intervention pain/functional outcome measures

AuthorsImmediately	1-mo*	3-mo	6-mo	12-mo	
Avraham et al. [41]	√	×	×	×	×
Baldon et al. [42]	√	√	×	×	×
Dolak et al. [6]	√	×	×	×	×
Fukuda et al. [4]	√	×	√	√	√
Fukuda et al. [28]	√	×	√	√	√
Ismail et al. [43]	√	×	×	×	×
Khayambashi et al. [44]	√	×	×	√	×
Khayambashi et al. [27]	√	×	×	√	×
Nakagawa et al. [27]	√	×	×	×	×
Song et al. [46]	√	×	×	×	×

*Month.

3.5Critical appraisal

Methodological quality assessment of the 10 CCTs based on the Cochrane Collaboration's 'Risk of bias' tool tailored for RCTs is detailed in Tables 5 and 6 [38].

3.5.1Cohort and case series studies

The three cohort studies had 88 participants [PFP (n= 64); healthy controls (n= 24)]. The one case series involved 19 participants with PFP.

Intervention protocol

In one cohort study, the experimental group was given hip muscles exercise protocol (strengthening of hip abductors and lateral rotators), and the control group received knee exercises. The subjects of the other two cohort studies received quadriceps-strengthening [47, 48]. The duration of intervention ranged between three and six weeks. The case series participants completed an eight-week exercise programme focusing on hip muscles strengthening and improving dynamic misalignment (Table 7).

3.5.2Meta-analysis (pooled effect size)

The meta-analysis was done to determine the additional effect of hip muscle strengthening as adjunctive therapy to the standard quadriceps strengthening for PFP and knee function.

The comparative effect size of hip versus Quadriceps strengthening on pain and function

Two RCTs [6, 42] and one comparative control trial [44] provided data that compared the effect of the isolated strengthening of hip muscles (abductors and lateral rotators) versus the standard quadriceps strengthening on PFP and knee function. One hundred participants were randomly assigned to receive hip (n= 50) or quadriceps (n= 50) strengthening protocols. The standardized mean difference (SMD) of PFP and functional outcomes after intervention with 95% CI under both fixed and random effects models favoured hip muscles strengthening over quadriceps strengthening ($p< 0.001$) (Figs 2 and 3).

Additional effect of hip-quad versus quadriceps strengthening on pain and function

Five RCTs contributed data assessing the additional effect of hip muscle strengthening coupled with quadriceps strengthening compared to the standard quadriceps strengthening alone on PFP and knee function [4, 28, 43, 45, 46]. For both groups (hip-quad and quadriceps alone), 16 data sets were collected from 98 participants. The pooled effects of results are presented in forest plots Figs 4 and 5 as cumulative SMD with 95% CI, under both fixed and random-effects models.

4.Discussion

Two recent systematic reviews have demonstrated that proximal exercises targeting quadriceps and hip muscles strengthening effectively relieved pain and improved knee function in patients with PFP, both the short- and long-term [14, 40]. However, this systematic review was important to delineate the effect of the isolated strengthening of hip abductors and lateral rotators on pain and knee function in patients with PFP compared to non-exercise interventions, and to identify if hip muscle strengthening is superior to the quadriceps strengthening alone, among them.

4.1Quality of the summarised evidence

The methodological quality of the fourteen studies except five, i.e., [6, 9, 41, 47, 48] included in the present review is excellent because it fulfilled 14 of the 16-item McMaster critical review criteria. The common methodological issue observed in most of the selected studies was the lack of sample size justification (sample size not determined or not achieved) [6, 27, 41, 43, 44, 47]. All studies with sample power inadequacy issues achieved results with statistical significance, suggesting that the measured pain and functional outcomes reflect the comparative effect of the interventions. However, subject contamination in Dolak et al. was evident because hip and quadriceps groups were combined to receive functional strengthening exercises (as co-interventions for the last four weeks of the intervention) [6]. Such subject contamination might have caused patient bias for their pain and functional outcomes, especially if they know

Table 5

Evidence table for controlled clinical trials

Authors study design	Patient sample size and characteristics	Description of interventions and setting	Comparator exercise and setting	Follow-up duration and outcome measures	Effect size and summary of key findings
Avraham et al. [41] Single-blinded randomised clinical trial (A pilot trial)	N= 30; Patients with a confirmed diagnosis of PFPRatio of male: female not indicatedMean age: 35 yrs	Hip group (N= 10)Participants underwent an exercise program targeting strengthening of hip external rotators3-week exercise protocol with supervision involved: 90◦ knee flexion/extension exercise, hamstring/iliotibial band stretches coupled with electrotherapy 2 times per week.Hip/quadriceps group (N= 10)Participants received exercise targeting hip and quadriceps musculature. This was coupled with electrotherapy 2 times per weekSetting: Rehabilitation facility	Quadriceps group (N= 10)Participants received quadriceps strengthening exercise involving: straight leg raise (SLR), single-leg squats coupled with electrotherapy 2 times per weekSetting: rehabilitation facility.	Pain assessed by numeric visual analogue scale (VAS)Function assessed by Patello-Femoral Joint Evaluation Scale(PFJES)Measured at baseline and 3 wks post-intervention	All groups exhibited significant improvements in VAS and PFJES scores (p< 0.0001).Between-group differences in pain and function were not statistically significant (p> 0.05).
Nakagawa et al. [27]Prospective, single-blinded randomised controlled design(A pilot trial)	N= 14; (10 females and 4 males)Patients with a confirmed diagnosis of PFPAge range: 17–40 yrs [mean ± SD 23.6 ± 5.9 yrs]Hip/quadriceps group (n= 7)- Group characteristics not definedQuadriceps group (n= 7)- Group characteristics not defined	Hip/quadriceps group (N= 7)Hip/quadriceps protocol involved strengthening of hip abductors, lateral rotators and transverse abdominis coupled with quadriceps protocolExercise performed once a week under supervisions and 4-times a week at home under no supervision for 6 weeksSetting: rehabilitation facility with a home programme	Quadriceps group (N= 7)Quadriceps protocol involved patellar mobilization, stretching of the quadriceps, gastrocnemius, hamstrings and iliotibial band coupled with open and closed kinetic chain exercises for quadriceps strengthening.Exercise performed once a week under supervisions and 4-times a week at home under no supervision for 6 weeks.Setting: rehabilitation facility with a home programme	Perceived pain symptoms during functional activities assessed by VASMeasured at baseline and 6 wks. post-intervention	The hip/quadriceps group exhibited significant improvement in pain symptoms (p= 0.02 − 0.04) except during prolonged sitting:Mean difference (at 6 weeks-baseline) in usual pain −3.6± 2.6 (p= 0.03*), worst pain −2.6± 2.5 (p= 0.03*),Stair climbing −3.0± 3.2 (p= 0.04*),Descending stair −4.1± 2.9 (p= 0.03*), and Squatting −5.4± 3.0 (p= 0.02*) significant, but not prolonged sitting −1.9± 2.9 (p= 0.14).No significant pain improvement in the quadriceps group (P> 0.05).

Table 5, continued

Authors study design	Patient sample size and characteristics	Description of interventions and setting	Comparator exercise and setting	Follow-up duration and outcome measures	Effect size and summary of key findings
Song et al. [46]Randomised controlled trial	N= 89; (69 females and 20 males)with a confirmed diagnosis of PFPMean age: 41 yrsHip adduction/leg-press Exercise (LPHA) group: (N= 29) – (8 men;				

21 women); Mean ± SD age: 38.6 ± 10.8 yrsMean ± SD duration of symptoms: 41.8 ± 36.1 monthsLeg-press Exercise only (LP) group (N= 30) – (8 men; 22 women); Mean ± SD age: 40.2 ± 9.9 yrsMean ± SD duration of symptoms: 38.3 ± 34.2 monthsNo Exercise group (N= 30) – (4 men; 26 women); Mean ± SD age: 43.9 ± 9.8 yrsMean ± SD duration of symptoms: 27.7 ± 41.0 months

LPHA group (N= 29)50-N isometric hip adduction/abduction for strengthening hip abductors coupled with leg-press exercise for quadriceps strengthening.3 weekly sessions for 8 wks. with full supervisionSetting: Clinical (kinesiology laboratory) LP group (N= 30)Leg-press exercise performed unilaterally from 45◦ of knee flexion to full extension assisted by an EN-Dynamic Track machine3 weekly sessions for 8 wks. with full supervisionSetting: Clinical (kinesiology laboratory)No exercise group: (N= 30)Given health educational materials on PFP self-efficacyAdvised not to enrol in any exercise program during the study period. Worst pain in the previous week rated on a 10-cm visual analogue scale (VAS-W). Knee function evaluated by Tegner Lysholm Knee Scoring ScaleFollow-up: Immediately and at 8 wks. post-intervention The LPHA group:Exhibited significant improvements in VAS-W ratings ($p< 0.005$) with mean difference of 2.18 (3.17–1.19; 95% CI) and Tegner Lysholm ($p< 0.005$) with a mean score difference of 10.93 (7.27 to 14.59; 95% CI)LP group: Significant improvements in VAS-W ratings ($p< 0.005$) with mean difference of 2.58 (3.56–1.61) and Tegner Lysholm scale ($p< 0.005$) with a mean score difference of 10.93 (7.27–14.59; 95% CI).Non-exercise group had no significant pain improvements ($p= 0.714$–0.715)Effect difference between LPHA and LP was not significant in VAS-W ratings ($p= 0.577$) and TLKSS ($p= 0.776$), respectively

Fukuda et al. [4]Randomised controlled clinical trial N= 54 (females) Sedentary womenwith a confirmed diagnosis of PFPAge range:20–40 yrsKnee and hip Exercise (KHE) group (N= 25);Mean ± SD age: 22 ± 3 yrsMean ± SD duration of symptoms: 23.2 ± 19.0 monthsKnee KHE group (N= 25)Knee exercise coupled with hip abductor and lateral rotator strengthening Exercise protocol included hip abduction against elastic band while standing or with weights in the side-lying positionHip lateral rotation against elastic band while seated and hip extension KE group (N=24)Hamstrings/plantar flexors/quadriceps/iliotibial band stretchesKnee extension at an angle of 90◦ to 45◦Leg presses and squats at an angle of 0◦ to 45◦, single-leg calf raises, and prone knee flexion3 sessions per week for 4 weeks Pain assessed by 11-point NPRS during ascending and descending stairsKnee function assessed by LEFS and AKPSFollow-up: at 3, 6, and 12months post-intervention Within KHE group change in mean NPRS scores:For ascending stairs at 3, 6 and 12 months post-treatment were −5.0 ± 1.5 (95% CI: −5.6, −4.4), −4.5 ± 1.4 (95% CI: −5.0, −4.0) and −3.3 ± 1.1 (95% CI: −3.7, −2.9), respectively; ($p< 0.05$)For descending stairs at 3, 6 and 12 months post-treatment were −4.2 ± 1.7 (95% CI: −4.9, −3.5), −3.8 ± 1.4 (95% CI: −4.4, −3 2), and −3.3 ± 1.1 (95% CI: −3.7, −2 9), respectively: ($p< 0.05$)

Table 5, continued

Authors study design Patient sample size and characteristics Description of interventions and setting Comparator exercise and setting Follow-up duration and outcome measures Effect size and summary of key findings

Exercise (KE) group (N=24); Mean ± SD age: 23 ± 3 yrsMean ± SD duration of symptoms: 21.0 ± 17.7 months It was coupled with knee exercise for the KE group.3 sessions per week for 4 weeks Setting: Rehabilitation facility. Setting: Rehabilitation facility. Within KE group change in mean NPRS scores: For ascending stairs at 3, 6 and 12 months post-treatment were −1.3 ± 1.2 (95% CI: −2.9, 0.3), −1.1 ± 1.1 (95% CI: −1.6, −0.6) and −0.1 ± 1.0 (95% CI: −0.7, 0.5), respectively: ($p< 0.05$)For

descending stairs at 3, 6 and 12 months post-treatment were −1.4 ± 0.9 (95% CI: −1.7, −1.1), −0.8 ± 0.9 (95% CI: −1.2, −0.4), and 0.0 ± 0.9 (95% CI: −0.3, 0.3), respectivelyWithin KHE group change in mean LEFS scores: at 3, 6 and 12 months post-treatment were 22.4 ± 10.5 (95% CI: 18.4, 26.4), 20.7 ± 11.0 (95% CI: 16.5, 24.9), and 17.9 ± 9.7 (95% CI: 14.2, 21.6), respectively: (p< 0.05)Within KE group change in mean LEFS scores: at 3, 6 and 12 months post-treatment were 0.4 ± 5.2 (−1.7, 2.5) −1.3 ± 5.3 (−3.4, 2.1) −2.9 ± 4.9 (−4.9, −0.9), respectivelyFor descending stairs at 3, 6 and 12 months post-treatment were −1.4 ± 0.9 (95% CI: −1.7, −1.1), −0.8 ± 0.9 (95% CI: −1.2, −0.4), and 0.0 ± 0.9 (95% CI: −0.3, 0.3), respectively: (p< 0.05)Within KHE group change in mean AKPS scores: at 3, 6 and 12 months post-treatment were 19.8 ± 9.1 (95% CI: 16.2, 23.4), 15.8 ± 8.1 (95% CI: 12.6, 19.0) and 13.1 ± 8.3 (95% CI: 9.8, 16.4), respectively: (p< 0.05)Within KE group change in mean AKPS scores: at 3, 6 and 12 months post-treatment were 2.8 ± 8.9 (95% CI: −0.7, 6.3) 0.2 ± 8.4 (95% CI: −3.2, 3.6), and −1.8 ± 8.4 (95% CI: −5.1, 1.5), respectively: (p< 0.05)*Overall KHE outcomes were superior over those of the KE group (p< 0.05)

Table 5, continued

Authors study design	Patient sample size and characteristics	Description of interventions and setting	Comparator exercise and setting	Follow-up duration and outcome measures	Effect size and summary of key findings
Dolak et al. [6]Randomised Clinical Trial	N=33; Females with a confirmed diagnosis of PFPAge range: 16–35 yrsHip group (N=17) Mean age: 25 ± 5 yrsMean ± SD duration of symptoms: 36 ± 34 months Quadriceps group (n=16) Mean age: 26 ± 6 yrsMean ± SD duration of symptoms: 27 ± 34 months	Hip group (n=17) Hip protocol involved combined hip abduction and external rotation in side-lying and standing positions coupled with seated hip external rotationParticipants supervised during 1 session and unsupervised during 2 weekly home-based sessions for 4 weeksSetting: Rehabilitation facility and home	Quadriceps group (n=16) Quadriceps protocol involved quad sets, short-arc quads, straight leg raises and terminal knee extensions This protocol performed for 4 consecutive weeks with full supervision Setting: Rehabilitation facility and home	Pain: VAS-WFunction: LEFS, AKPSFollow-up: ImmediatelyOutcome measured at baseline and 4 weeks post-intervention	Hip group exhibited significant improvements in pain: 47.9% (p< 0.001) and knee function: 18.7% (p< 0.001)Quadriceps group exhibited significantimprovements in knee function (9.3%; p< 0.001) but not pain (p=0.88)Pain significantly reduced in the hip group compared to the quadriceps group with a mean difference of 1.7 (p=0.035)No significant difference in knee function (p>0.05) between the two groups at the end of the study
Fukuda et al. [28]Randomised controlled trial with 1-year follow-up	N=49; Sedentary females with a confirmed diagnosis of PFPAge range20–40 yrsHip/quadriceps group (n=25) Mean ± SD age: 22.0 ± 3.0 yrsMean ± SD duration of symptoms: 23.2 ± 19.0 monthsQuadriceps group (n=24) Mean ± SD age: 23.0 ± 3.0 yrs Mean ± SD duration of symptoms: 21.0 ± 17.7 months	Hip/quadriceps group (N=25) Hip abductor and external rotators coupled with quadriceps strengthening/stretching knee exercise: seated knee extension, leg press, squatting, stretching of hamstrings, quadriceps, ankle plantar flexors and iliotibial band3 sessions per week for 4 weeksSetting: Rehabilitation facility	Quadriceps group (N=24) Quadriceps strengthening/stretching knee exercise; seated knee extension, leg press, squatting, stretching of hamstrings, quadriceps, ankle, plantar flexors and iliotibial bandSetting: Rehabilitation facility	Pain: 11-point NPRS during ascending and descending stairsFunction: LEFS, AKPSAt baseline Follow-up: immediately and post-intervention at 3, 6, and 12 months	For interventional group: Pain during upstairs gait reduced to 80.7% (p<

0.05) at 3 months, 73.2% (p< 0.05) at 6 months and 53.2% (p< 0.05) at 12 monthsPain during downstairs gait reduced to 72.4% (p< 0.05) at 3 months, 65.5 % (p< 0.05) at 6 months and 56.9 % (p< 0.05) at 12 monthsKnee function score on AKPS improved to 30.1 % (p< 0.05) at 3 months, 20.4 % (p< 0.05) at 6 months and 19.9 % (p< 0.05) at 12 monthsFor comparator group:Pain during downstairs gait reduced to 21.9% (p< 0.05) at 3 months, 12.5% (p< 0.05) at 6 monthsAt 6 months pain during upstairs gait reduced to 16.7% (p< 0.05)No significant change in both AKPS and LEFS scores at 3, 6 and 12 months

Table 5, continued

Authors study design Patient sample size and characteristics Description of interventions and setting Comparator exercise and setting Follow-up duration and outcome measures Effect size and summary of key findings

Khayambashi et al. [27]Randomised controlled trial N= 28; Sedentary femaleswith patellofemoral pain (PFP)Hip exercise group (n= 14); Mean ± SD age: 28.9 ± 5.8 yrs Duration of symptoms: not indicatedNon-exercise group (N= 14); Mean ± SD age: 30.5 4.8 ± 3.2 yrsDuration of symptoms: not indicated Hip exercise group (n=14) Supervised isolated hip abductor strengthening to 30◦ in standing positionSupervised isolated hip external rotator strengthening to 30◦ in the seated positionExercise protocol performed 3 times per week for 8 weeks Setting: Rehabilitation facility Non-exercise group (n= 14) Participants also prescribed 1000 mg of Omega-3 and 400 mg of calcium daily for 8 weeks Setting: homeWorst pain in the previous week assessed by VASSelf-reported health status assessed by the Western Ontario and McMaster Universities (WOMAC) questionnaireVAS and WOMAC scores recorded at baseline (pre-intervention), week 8 (post-intervention), and 6 months post-intervention For hip exercise group:Exhibited significant improvements in VAS score (p<0.001):Mean VAS score difference from baseline (7.9 ± 1.7) to 8 wk. post-intervention (1.4 ± 1.9) was −6.4 ± 2.7; 95% CI: −7.9, −4.9 (p< 0.001)Mean VAS score difference from baseline (7.9 ± 1.7) to 6 months post-intervention (1.7 ± 2.7) was −6.2 ± 1.4; 95% CI: −7.9, −4.3 (p< 0.001)Significant improvements were seen in WOMAC score (p< 0.001):Mean WOMAC score difference from baseline (54.0 ± 18.1) to 8 wk. post-intervention (10.7 ± 16.1) was −43.3 ± 20.1; 95% CI: −54.9, −31.7 (p< 0.001)Mean WOMAC score difference from baseline (54.0 ± 18.1) to 6 months post-intervention (10.8 ± 17.7) was −43.2 ± 7.7; 95% CI: −55.9, −30.0 (p< 0.001)Non-exercise group: No noticeable improvements in VAS and WOMAC scores (p> 0.05)

Table 5, continued

Authors study design Patient sample size and characteristics Description of interventions and setting Comparator exercise and setting Follow-up duration and outcome measures Effect size and summary of key findings

Ismail et al. [43]Prospective randomised controlled trial N= 32; (23 females 9 males); with a confirmed diagnosis of PFPAge range 18–30 yrsClosed kinetic chain (CKC) + hip exercise (CKCH) group (n=16); (11 women, 5 men)Mean ± SD age: 20.8 ± 2.7 yrsMean ± SD duration of symptoms: not indicatedCKC group (n=16); (12 women, 4 men)Mean ± SD age: 21.2 ± 3.2 yrsMean ± SD duration of symptoms: not indicated CKCH group (n=16)Hip abductors and lateral rotators strengthening exercise coupled with CKC exercises for hip/quadriceps strengtheningHip abductor strengthening performed in a side-lying position on the non-affected sideLateral rotators strengthening performed

while seated and hip flexed to 90◦ Training sessions: 3 times per week for 6 weeks Setting: Rehabilitation facility CKC group (n=16) Closed kinetic chain exercises for quadriceps strengtheningProtocol involved stretching of hamstrings, iliotibial band and gastrocnemiusAlso involved mini wall squats, forward/lateral step-ups and terminal knee extensionsTraining sessions: 3 times per week for 6 weeks Setting: Rehabilitation facility Worst pain in the previous week assessed by VAS Knee function assessed by AKPS Follow-up: ImmediatelyOutcome measured at baseline and 6 weeks post-intervention For CKCH group: Significant improvements in VAS and Kujala scores ($p< 0.05$) Mean VAS score difference from baseline (5.3 ± 1.6) to 6 wk. (2.0 ± 1.1) post-intervention 3.2 ± 0.9Mean Kujala score difference from baseline (71.5 ± 7.8) to 6 wk. (85.1 ± 6.2) post-intervention 13.7 ± 5.5For CKC group: Significant improvements in VAS and Kujala scores $p< 0.05$) Mean VAS score difference from baseline (4.5 ± 1.8) to 6 wk. (2.3 ± 1.1) post-intervention 2.26 ± 1.3Mean Kujala score difference from baseline (76.4 ± 10.4) to 6 wk. (85.0 ± 6.7) post-intervention 8.6 ± 7.3*Overall pain and function outcome in the CKCH group was superior to the CKC group ($p< 0.05$)

Table 5, continued

Authors study design Patient sample size and characteristics Description of interventions and setting Comparator exercise and setting Follow-up duration and outcome measures Effect size and summary of key findings

Baldon et al. [42]Randomised, comparative-controlled single-blinded study N=31 (Females); with a confirmed diagnosis of PFPAge range: 18–30 yrsHip exercise group (n=15); Mean ± SD age: 27.7 ± 3.2 yrsMean duration of symptoms: not indicatedQuadriceps group (n=16); Mean ± SD age:21.3 ± 2.6 yrs Mean duration of symptoms: not indicated Hip exercise group (n=15)Hip extension/lateral rotation in prone, side-lying, standingIsometric hip abduction/lateral rotation in standing knee and hip flexion in side-lyingPelvic drop in standingHip lateral rotation in closed kinetic chainPlus the standard knee exercise Sessions performed 3 times a week for 8 wks Sessions lasted between 90 to 120 minutes with supervision by a physical therapist Setting: Laboratory of Intervention and Orthopaedics and Traumatology laboratory Quadriceps group (n=16) Quadriceps strengthening and lateral retinaculum stretchesHamstrings, soleus, gastrocnemius, and iliotibial band stretchesSessions performed 3 times a week for 8 wks) Sessions lasted between 75 to 90 minutes with supervision by a physical therapist Setting: Laboratory of Intervention and Orthopaedics and Traumatology laboratory Worst-pain in the previous week rated on 10cm-VAS Knee function: LEFSBaseline, immediately and 3-month post-intervention For Hip exercise group: Mean differences in VAS score at end of intervention (−5.2 ± 1.6) and 3-months post-intervention (−5.7 ± 2.3) were significant ($p< 0.05$*). Pain reduced. Mean difference in LEFS at end of intervention (−18.9 ± 12.5) and 3-months post-intervention −19.5 ± 11.9) were significant ($p< 0.05$*). Knee function improved For quadriceps group:Pain improved significantly ($p< 0.05$), but not knee function ($p>0.05$). Mean difference in VAS at the end of intervention (−3.0 ± 2.4) and 3-months post-intervention (− 3.6 ± 3.3) were significant ($p< 0.05$). Mean difference in LEFS score at the end of intervention (−12.9 ± 7.5) and 3-months post-intervention (−12.7 ± 6.2) was not significant ($p> 0.05$) Between-group difference in VAS scores only significant at 3-months post-intervention ($p< 0.05$)Between-group differences not significant in VAS at any time-point

Table 5, continued

Authors study design	Patient sample size and characteristics	Description of interventions and setting	Comparator exercise and setting	Follow-up duration and outcome measures	Effect size and summary of key findings
Khayambashi et al. [44]Comparative control trial	N= 36 (18 men, 18 women); with clinical diagnosis of PFP Hip exercise group (n= 18); (9 men and 9 women); Mean ± SD age: 28.2 ± 7.9 yrs Mean duration of symptoms: not indicatedQuadriceps group (n= 18); (9 men and 9 women); Mean ± SD age: 27.3 ± 6.7yrs Mean duration of symptoms: not indicated	Hip exercise group (n=18)Underwent supervised exercise programs targeting hip muscles strengthening.Hip exercise protocol included hip abductor and external rotator strengthening exercises in side-lying and knee flexed to 90◦ while seated, respectively Quadriceps protocols include knee flexion to 30◦ coupled with partial squats 3 times a week for 8 wksSetting: Rehabilitation facility	Quadriceps group (n=18) Received supervised quadriceps strengthening exercises (3 times a week for 8wks)Quadriceps protocols included knee flexion to 30◦ coupled with partial squats Setting: Rehabilitation facility	Worst pain in the previous week assessed by VASSelf-reported health status assessed using the WOMAC questionnaireVAS and WOMAC scores recorded at baseline (pre-intervention), week 8 (post-intervention), and 6 months post-intervention	For Hip exercise group:Significant improvements in VAS and WOMAC scores (p< 0.001):Mean VAS score difference from baseline (7.63 ± 1.79) to 8 wk. (2.11 ± 1.6) and 6 months (2.00 ± 1.97) post-intervention was −5.53 ± 1.60; 95% CI and −5.64 ± 1.99; 95% CI, respectively (p< 0.001)Mean WOMAC score difference from baseline (46.83 ± 21.86) to 8 wk. (6.22 ± 3.87) and 6 months (6.94 ± 5.70) post-intervention was −40.61 ± 20.68; 95% CI and −39.89 ± 21.35; 95% CI, respectively (p< 0.001)For Quadriceps group:Significant improvements in VAS and WOMAC scores (p< 0.001):Mean VAS score difference from baseline (6.91 ± 1.94) to 8 wk. (3.27 ± 2.19) and 6 months (4.00 ± 2.44) post-intervention was −3.64 ± 1.39; 95% CI and −2.92 ± 1.72; 95% CI, respectively (p< 0.001)Mean WOMAC score difference from baseline (44.11 ± 22.05) to 8 wk. (21.89 ± 16.55) and 6 months (23.16 ± 14.15) post-intervention was −22.22 ± 10.59; 95% CI and −20.94 ± 14.30; 95% CI, respectively (p< 0.001)*Between-group difference was statistically significant p ⩽0.05, where outcomes in the hip group were superior over the quadriceps group

Table 6

Descriptions and critique of the reviewed 10 controlled clinical trials (CCTs)

Authors	Study design	Level of evidence	Critique
Avraham et al. [41]	RCT	Level 2b	• Inadequate sample size (pilot study) • Participants were not truly randomized to the three intervention groups • Allocation concealment probably not done • The physiotherapist who assessed the patients was blinded to the study

• Blinding of outcome assessment achieved by using patient-reported outcomes on VAS For patellofemoral pain

• Evaluation scale PES

Baldon et al. [42] RCT Level 1b

• Participants recruited a/c to sample power estimation

• Participants were truly randomized by random sequences in a block randomization Manner

• Allocation concealment evident

• Double blinding evident (participants and therapists)

• Blinding of outcome assessment evident because the only patient-reported pain and Function outcomes collected.

Dolak et al. [6] RCT Level 2b

• Inadequate sample power

• Participants truly randomized by random sequence or block randomization

• Allocation concealment evident with a random number

• Outcome assessors partially blinded to participants (probable detection bias)

• Outcome assessment blinded (the only patient-reported pain and function outcomes Recorded).

Fukuda et al. [4] RCT Level 1b

• Participants recruited a/c to sample power calculation

• Participants truly randomized

• Allocation concealment not evident

• Therapists not blinded

• Incomplete outcome data managed by intention-to-treat analysis

• Outcome assessment blinded (the only patient-reported pain and function outcomes Recorded).

Fukuda et al. [28] RCT Level 1b

• Participants recruited based on the calculated sample power

• Participants were truly randomized

• Allocation concealment not evident

• Therapists not blinded

• Incomplete outcome data managed by intention-to-treat analysis

• Outcome assessment blinded (the only patient-reported pain and function outcomes Recorded).

Ismail et al. [43] RCT Level 2b

• Inadequate sample power (Estimated sample power size not followed)

• Random allocation of participants concealed

• Therapists and assessors blinded to group allocation details

• Outcome assessment blinded (the only patient-reported pain and functional outcomes)

Khayambashi et al. [44] CCT Level 2b

• Inadequate sample power

• Participants not allocated to restive groups by random allocation

• Participants and therapists not blinded

• Outcome assessment blinded (the only patient-reported pain and functional outcomes)

Khayambashi et al. [27] RCT Level 2b

• Inadequate sample power

• Participants random allocation not followed

• Participants and therapists not blinded

• Outcome assessment blinded (the only patient-reported pain and functional outcomes)

Nakagawa et al. [45] RCT-p Level 2b

• Inadequate sample size (pilot study)

• Group allocation concealed using sealed envelopes

• Therapist not blinded

• Principle investigator partially blinded (only at baseline phase)

• Blinded assessors employed

Song et al. [46] RCT Level 1b

• Participants randomized to group

• Participants and therapists blinded

RCT, randomised controlled trial; CCT, comparative control trial; RCT-p, randomised controlled pilot study; CS, cohort study; CSr, case series.

Table 7

Evidence table for follow-up studies (cohort, case-control, case series and case reports)

Authors study design Patient sample size and characteristics Description of interventions and setting Comparator exercise and setting Follow-up duration and outcome measures Effect size and summary of key findings

Boling et al. [47]Pre-test and post-test 6-week intervention cohort study N= 28; Participants with and without PFPAge range: 18–42 yrsExperimental group (n= 14) participants with a confirmed diagnosis of PFP (5 men, 9 women)Mean ± SD age: 24 ± 6 yrsMean ± SD duration of symptoms: 22 ± 25 monthsControl group (n= 14) healthy participants (5 men and 9 women)Mean ± SD age: 23 ± 2 yrs All participants received weight-bearing exercises focusing on strengthening of hip abductors, gluteus medius, and quadriceps strengthening coupled with lower-extremity neuromuscular control for 6 weeksSetting: Musculoskeletal research laboratory N/A VAS and Functional Index Questionnaire (FIQ) administered at pre-test and post-test and the end of every week of the 6-wk intervention At the end of the intervention, the PFP participants exhibited significant improvements in both VAS (p= 0.001) and FIQ (p= 0.001) scores from the baseline Based on Post hoc analyses, no significant changes in both VAS and FIQ scores were observed in the control group

Ferber et al. [9]Cohort study (Pre-test and post-test) N= 25; Participants with and without PFPExperimental group (n= 15) participants with a confirmed diagnosis of PFP (5 men, 10 women)Mean ± SD age: 35.2 ± 12.2 yrsMean duration of symptoms not indicated Control group (n= 10) Healthy participants (4 men and 6 women)Mean ± SD age: 29.9 ± 8.3 yrsMean duration of symptoms not indicated. Experimental group completed a 3-week exercise training targeting the strengthening of hip-abductor musclesSetting: University-based clinical research laboratory No exercises Hip abductor muscle strength and pain (VAS) measured at baseline and after 3-week training 3-week hip-abductor muscle-strengthening protocol administered to participants with PFP was effective in increasing isometric muscle strength, which improved by 32.69% from baseline (p= 0.04)Mean difference between pre-training and post-training VAS scores was 3.30 ± 1.90, (p= 0.01) which translated into 43.10% reduction in VAS score

Table 7, continued

Authors study design	Patient sample size and characteristics	Description of interventions and setting	Comparator exercise and setting	Follow-up duration and outcome measures	Effect size and summary of key findings
Earl and Hoch [3]Case series; Level of evidence, 4 (with Pre-test and post-test design)	N= 19; Women with a confirmed diagnosis of PFP Age range 16–40 yrsMean ± SD age: 22.68 ± 7.19 yrs Mean duration of symptoms: 17 months (range, 1-60 months)	Completed 8-weeks exercise program targeting hip and core muscles strengthening and improving dynamic malalignmentExercises were administered in 3 phases:Phase I: Abdominal draw-in exercises, side-lying clamshells/straight-leg raises, supine arm/leg extensions, quadruped leg extensions, isometric single-legged stance (SLS), quadriceps/hamstring/calf stretchesPhase II: Isometric SLS with hip abduction, SLS quick kicks, prone/side planks, quadriceps/hamstring/calf/iliotibial band stretchesPhase III: Monster walks, SLS, quadriceps/hamstring/calf/iliotibial band stretchesSetting: Both at research laboratory and rehabilitation facility settings	N/A	Pain and function assessed at baseline, 8 weeks and 6 months post-training Pain assessed by VASFunction assessed by AKPS	Significant improvements in pain and functional ability (p< 0.0005). Effects lasted at least 6 months post-rehabilitation
Tyler et al. [48]Cohort study; Level of evidence, 2 (with Pre-test and post-test design)	N=b35; Participants with and without PFP (6 men; 29 women)Mean ± SD age: 33 ± 16 yrsMean duration of symptoms: not recorded	All participants underwent 6-week partially supervised exercise program targeting strengthening of hip and knee muscles Exercise protocol involved seated hip flexion, adduction, extension, abduction; Stretching of hip flexors, quadriceps, iliotibial bandSetting: rehabilitation centre supplemented with a home exercise program manual	N/A	Pain and knee discomfort during normal activities of daily living and exercise were assessed by VAS Mean VAS score during normal daily activities improved from 4.9 ± 0.3 to 2.7 ± 0.3 (p< 0.001)	Mean VAS score during exercise also improve form 5.8 ± 0.4 to 3.0 ± 0.4 (p< 0.001).

Figure 2.

Hip versus quadriceps strengthening on PFP .

Hip versus quadriceps strengthening on PFP .

Figure 3.

Comparative effect of hip versus quadriceps strengthening on knee function.

Comparative effect of hip versus quadriceps strengthening on knee function.

Figure 4.

Hip-quad strengthening results in significant pain improvements compared to the standard quadriceps strengthening alone.

Hip-quad strengthening results in significant pain improvements compared to the standard quadriceps strengthening alone.

Figure 5.

Hip-quad strengthening resulted in a greater functional improvement than the standard quadriceps strengthening alone.

Hip-quad strengthening resulted in a greater functional improvement than the standard quadriceps strengthening alone.

the intervention of their cohorts in the opposite arm of the study [49].

This risk of bias is a critical methodological issue in RCTs and warranted supplementary quality appraisal of all RCTs on the Cochrane Collaboration's Risk of bias tool [38] to highlight methodological flaws (indicative of 'Risk of bias' threatening interval consistency) (Table 6). All RCTs except two recruited participants with a confirmed diagnosis of PFP [27, 44]. However, these studies were included because they enrolled patients presented with anterior keen pain based on symptoms matching the inclusion criteria of the remaining RCTs, which recruited patients with a confirmed diagnosis of PFP. Here, 383 participants from all RCTs presented with anterior knee pain associated with prolonged sitting, climbing stairs and descending stairs in the absence of signs/symptoms of meniscal or other intra-articular pathological conditions or history of other knee pathologies, surgeries and injuries. These are classical symptoms for the diagnosis of PFP [14, 40]. However, these symptoms may indicate knee osteoarthritis, but it may not be so likely because patients enrolled in RCTs were not older than 50 years of age and therefore not likely to present with ageing associated PFP [50].

Four studies included a mixed population of both adults and adolescents aged 17 to 50 years [6, 42, 43, 45]. Since adolescents are physically active and at risk of PFP, hence, the inclusion of this age group [50]. To minimize the possibility of recruiting participants with underlying knee pathologies, i.e. knee osteoarthritis, no studies recruited patients with PFP who were older than 50 [50]. The four studies examined only female participants; therefore, the outcome may only be generalized for the female patients with PFP, but not for the males [4, 6, 28, 42]. The three studies [43, 45, 46] included both male and female participants (proportion of females was higher than males), indicative of females being at a greater risk of PFP than males [6]. This may be attributed to females' lower hip muscle mass compared to males [51]; therefore, females exhibit lower hip muscle strength than males [51, 52].

The symptom duration is a direct measure of severity of PFP that has a significant influence on therapeutic outcome [53]. Therefore, patients with an early diagnosis of PFP are likely to respond well to therapy compared to those with late diagnoses [18]. Thus, symptom duration is a key confounding variable that must be adjusted via the subject's stratification. In this systematic review, the mean duration of symptoms of participants with PFP in eight studies ranged from 17 to 21 months. However, six studies [27, 41, 42, 43, 44, 45] did not report the mean duration (months) of PFP symptoms. None of the studies performed the subject's stratification for the PFP severity and symptom duration. This might have positively skewed pain and functional outcomes in patients with a shorter mean duration of symptoms [18]. Additionally, the subject's characteristics were barely

explained in three studies [42, 44, 45] and not detailed in one study [41]. These findings undermine the quality of the summarised shreds of evidence.

Supervised therapeutic exercises enhance participants' compliance because unsupervised participants may refrain from pain-provoking exercises [18, 54]. Two previous RCTs reported that supervised exercises for PFP result in less pain and better knee function at short- and long-term follow-up than usual care [18, 54]. In the present systematic review, all studies involved exercises administered in physiotherapy facility/rehabilitation setting under supervision by qualified physiotherapists, except two [6, 45], where two-thirds of exercise sessions were self-administered in patient's homes (unsupervised). At the same time, one-third had rehabilitation under supervision in a facility. It had an important bearing on patient compliance to intervention and the outcome. Even then, results were significant in these two studies, suggesting that partial supervision too can yield clinically significant results.

4.2Isolated hip musculature strengthening

All fourteen studies demonstrated that isolated strengthening exercises of hip abductors and lateral rotators for two to four times per week up to three to eight weeks duration effectively relieve pain and improve knee function compared to quadriceps strengthening and non-exercise interventions. Kooiker et al. reported variations in quadriceps, hip and hip-quadriceps strengthening protocols in selected studies and opined for the unavailability of standardized protocols for PFP [40]. The common hip exercise protocol included hip abduction against an elastic band while standing and with weights in a side-lying position coupled with lateral hip rotation against an elastic band while seated and hip extension (3 sets of 10 repetitions). Conversely, quadriceps strengthening in all studies generally involved weight-bearing and non-weight-bearing exercises such as closed kinetic chain exercises, seated knee extension, leg press, squatting and stretching of hamstrings and quadriceps (3 sets of 10 repetitions).

The hip protocol generally improved pain and knee function after three to eight weeks of training, with long-term effects observed as late as twelve months post-intervention [28]. Four studies evaluated the comparative therapeutic value of quadriceps versus hip muscle strengthening in treating PFP [6, 41, 42, 44]. One study by Khayambashi et al. reported superiority of hip muscles strengthening strategy over the quadriceps strengthening for both pain and functional improvement in PFP [44]. The remaining three studies argued that isolated hip and quadriceps strengthening strategies have comparable therapeutic value for the PFP [6, 41, 42]. However, a meta-analysis of the effect measures (pain and function) as measured on VAS and LEFS or WOMAC revealed that hip strengthening significantly favours the standard quadriceps strengthening ($p< 0.001$) in PFP treatment [6, 42, 44]. Moreover, these findings are strengthened by a study by Na et al., who reviewed the studies related to isolated hip muscle strengthening vs knee strengthening protocol and suggested that isolated hip strengthening is more beneficial in reducing the pain earlier [55]. Thus, these results may aid in providing additional data to fill the existing knowledge gap in the guidelines pertaining to hip targeted exercise therapy in improving the functional performance of patients with PFP [56].

4.3Additional therapeutic effect of hip muscles strengthening

Although the proximal strengthening exercises involving quadriceps and hip muscles are commonly effective in treating PFP, Kooiker et al., Peters and Tyson argued that a combination of hip-quadriceps strategy could add to the therapeutic outcome for patients with PFP [6, 14, 40, 41, 42]. The present systematic review included five RCTs to examine the additional therapeutic outcome of hip-quadriceps strengthening exercises over the standard quadriceps [4, 28, 43, 45, 46]. Except for one, all studies; supported that the hip-quadriceps strategy was superior to the standard quadriceps [46].

The findings of these five RCTs have both internal and external validity and are, therefore, acceptable. Furthermore, meta-analyzed data of these five studies strongly indicated that quadriceps coupled with hip muscle strengthening has significant additional therapeutic benefits over the conventional quadriceps or hip exercises in the treatment of PFP ($p< 0.001$). Therefore, a hip-quadriceps strategy should be adopted in clinical practices for pain relief and optimal functional improvements in patients with PFP.

4.4Limitations

The summarised evidence supported by meta-analyses indicates that strengthening hip muscles is effective in treating PFP for pain and knee function of physically active male/female adolescents and adults. However, a few important limitations must be noted;

1. This systematic review and meta-analysis initially were intended to review a minimum of 20 studies to examine the therapeutic outcome of hip muscle strengthening versus quadriceps alone on pain and knee functions for patients with PFP. The expanded literature search yielded only 14 studies that are adequate for systematic review, limiting the strength and generalisability of the summarised findings over a wider population of patients with PFP.

2. Avraham et al. study (included in this review) used a non-exercise (electrotherapy) as a co-intervention that might have uni-directionally augmented the therapeutic effects [41].

3. Although the proportion of females to males is higher in all studies (included in this review), this may not be considered as a limitation to generalisability for a wider group of patients with PFP because it truly reflects the characteristics of patients with PFP that would be encountered in day-to-day clinical practice.

4.5Implications for routine physiotherapy practice

The evidence from the present review has important implications in routine clinical practice for the patients with PFP:

1. Strong shreds of evidence favour hip muscle strengthening exercises for two to four times a week, up to three to four weeks, to have effective therapeutic outcomes compared to standard quadriceps strengthening exercises alone in patients with PFP. This implies that therapists should consider hip muscle strengthening as a standard therapeutic measure while treating patients with PFP.

2. Meta-analysis of the effect measures (both pain and function) has strongly supported that hip muscles coupled with quadriceps (hip-quad) strengthening have superior therapeutic effects than the individual isolated hip or quadriceps strengthening exercises. This evidence strongly implies that therapists should consider a combination of hip and quadriceps strengthening exercises to treat patients with PFP. However, this may imply longer duration of intervention lasting 6 to 8 weeks and more sessions per week that may influence patients' compliance to intervention, especially if prescribed as self-efficacy [57].

3. In the present review, only one study [28] out of fourteen had followed patients up to twelve months, which was a good attempt to determine the long-term therapeutic effect of hip versus quadriceps strengthening exercises on PFP and knee function. This indicates evidence to be generalized only for the short-term instead of long-term pain and functional outcomes.

5.Future research

Must consider stratification of patients/results based on the symptom duration before the intervention to eliminate the effect of time-delay modification on pain and functional outcomes following hip muscles strengthening in patients with PFP.

6.Conclusion

This systematic review and meta-analysis indicate that isolated strengthening of hip abductors and lateral rotators have therapeutic benefits compared to quadriceps strengthening alone for the treatment of PFP. It is also clear that the hip-quadriceps strategy gives a beneficial therapeutic outcome than isolated quadriceps or hip muscle strengthening. Therefore, we recommend developing a hip-quadriceps exercise strategy for the treatment of PFP to encourage improved compliance, even in unsupervised patients.

Conflict of interest

The authors have no financial or non-financial conflicts of interest to declare that are relevant to the content of this article.

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References

[1]

Dixit S, DiFiori JP, Burton M, Mines B. Management of patellofemoral pain syndrome. Am Fam Physician. 2007; 75: 194-202.

[2]

Atanda A, Ruiz D, Dodson CC, Frederick RW. Approach to the active patient with chronic anterior knee pain. Phys Sportsmed. 2012; 40: 41-50. doi: 10.3810/psm.2012.02.1950.

[3]

Earl JE, Hoch AZ. A proximal strengthening program improves pain, function, and biomechanics in women with patellofemoral pain syndrome. Am J Sports Med. 2011; 9: 154-163. doi: 10.1177/0363546510379967.

[4]

Fukuda TY, Rossetto FM, Magalhães E, Bryk FF, Lucareli PRG, de Almeida Carvalho NA. Short-term effects of hip abductors and lateral rotators strengthening in females with patellofemoral pain syndrome: A randomized controlled clinical trial. J Orthop Sports Phys Ther. 2010; 40: 736-42. doi: 10.2519/jospt.2010.3246.

[5]

Lankhorst NE, Bierma-Zeinstra SMA, van Middelkoop M. Risk factors for patellofemoral pain syndrome: A systematic review. J Orthop Sports Phys Ther. 2012; 42: 81-94. doi: 10.2519/jospt.2012.3803.

[6]

Dolak KL, Silkman C, Mckeon JM, Hosey RG, Lattermann C, Uhl TL. Hip strengthening prior to functional exercises reduces pain sooner than quadriceps strengthening in females with

patellofemoral pain syndrome: A randomized clinical trial. J Orthop Sports Phys Ther. 2011; 41: 560-70. doi: 10.2519/jospt.2011.3499.

[7]

Sherman SL, Plackis AC, Nuelle CW. Patellofemoral anatomy and biomechanics. Clin Sports Med. 2014; 33: 389-401.

[8]

Bolgla LA, Malone TR, Umberger BR, Uhl TL. Comparison of hip and knee strength and neuromuscular activity in subjects with and without patellofemoral pain syndrome. Int J Sports Phys Ther. 2011; 6: 285-96.

[9]

Ferber R, Kendall KD, Farr L. Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. J Athl Train. 2011; 6: 142-9. doi: 10.4085/1062-6050-46.2.142.

[10]

Mascal CL, Landel R, Powers C. Management of patellofemoral pain targeting hip, pelvis, and trunk muscle function: 2 case reports. J Orthop Sports Phys Ther. 2003; 33: 647-60. doi: 10.2519/jospt.2003.33.11.647.

[11]

Chiu JKW, Wong YM, Yung PSH, Ng GYF. The effects of quadriceps strengthening on pain, function, and patellofemoral joint contact area in persons with patellofemoral pain. Am J Phys Med Rehabil. 2012; 91: 98-106. doi: 10.1097/PHM.0b013e318228c505.

[12]

Eapen C, Nayak CD, Zulfeequer CP. Effect of eccentric isotonic quadriceps muscle exercises on patellofemoral pain syndrome: An exploratory pilot study. Asian J Sports Med. 2011; 2: 227-34. doi: 10.5812/asjsm.34747.

[13]

Kaya D, Doral MN, Callaghan M. How can we strengthen the quadriceps femoris in patients with patellofemoral pain syndrome? Muscles Ligaments Tendons J. 2012; 2: 25-32. https//www.ncbi.nlm.nih.gov/pmc/articles/PMC3666499/.

[14]

Peters JSJ, Tyson NL. Proximal exercises are effective in treating patellofemoral pain syndrome: A systematic review. Int J Sports Phys Ther. 2013; 8: 689-700. https//pubmed.ncbi.nlm.nih.gov/22402677/.

[15]

Robinson RL, Nee RJ. Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. J Orthop Sports Phys Ther. 2007; 37: 232-8. doi: 10.2519/jospt.2007.2439.

[16]

Bell DR, Oates DC, Clark MA, Padua DA. Two- and 3-dimensional knee valgus are reduced after an exercise intervention in young adults with demonstrable valgus during squatting. J Athl Train. 2013; 48: 442-9. doi: 10.4085/1062-6050-48.3.16.

[17]

Flack NAMS, Nicholson HD, Woodley SJ. The anatomy of the hip abductor muscles. Clin Anat. 2014; 27: 241-53. doi: 10.1002/ca.22248.

[18]

Prins MR, van der Wurff P. Females with patellofemoral pain syndrome have weak hip muscles: A systematic review. Aust J Physiother. 2009; 55: 9-15. doi: 10.1016/S0004-9514(09)70055-8.

[19]

Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. J Orthop Sports Phys Ther. 2009; 39: 12-9. doi: 10.2519/jospt.2009.2885.

[20]

Baldon R de M, Nakagawa TH, Muniz TB, Amorim CF, Maciel CD, Serrão FV. Eccentric hip muscle function in females with and without patellofemoral pain syndrome. J Athl Train. 2009; 44: 490-6. doi: 10.4085/1062-6050-44.5.490.

[21]

Ireland ML, Willson JD, Ballantyne BT, Davis IMC. Hip Strength in Females with and without Patellofemoral Pain. J Orthop Sports Phys Ther. 2003; 33: 671-6. doi: 10.2519/jospt.2003.33.11.671.

[22]

Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther. 2005; 35: 793-801. doi: 10.2519/jospt.2005.35.12.793.

[23]

Kaiser P, Schmoelz W, Schoettle P, Zwierzina M, Heinrichs C, Attal R. Increased internal femoral torsion can be regarded as a risk factor for patellar instability – A biomechanical study. Clin Biomech (Bristol, Avon). 2017; 47: 103-9. doi: 10.1016/j.clinbiomech.2017.06.007.

[24]

Passmore E, Graham HK, Pandy MG, Sangeux M. Hip- and patellofemoral-joint loading during gait are increased in children with idiopathic torsional deformities. Gait Posture. 2018; 63: 228-235. doi: 10.1016/j.gaitpost.2018.05.003.

[25]

Yang GM, Wang YY, Zuo LX, Li FQ, Dai YK, Wang F. Good outcomes of combined femoral derotation osteotomy and medial retinaculum plasty in patients with recurrent patellar dislocation. Orthop Surg. 2019; 11(4): 578-585. doi: 10.1111/os.12500.

[26]

Neumann DA. Kinesiology of the hip: A focus on muscular actions. J Orthop Sports Phys Ther. 2010; 40(2): 82-94. doi: 10.2519/jospt.2010.3025.

[27]

Khayambashi K, Mohammadkhani Z, Ghaznavi K, Lyle MA, Powers CM. The effects of isolated hip abductor and external rotator muscle strengthening on pain, health status, and hip strength in females with patellofemoral pain: A randomized controlled trial. J Orthop Sports Phys Ther. 2012; 42: 22-9. doi: 10.2519/jospt.2012.3704.

[28]

Fukuda TY, Melo WP, Zaffalon BM, Rossetto FM, Magalhães E, Bryk FF, et al. Hip posterolateral musculature strengthening in sedentary women with patellofemoral pain syndrome: A randomized controlled clinical trial with 1-year follow-up. J Orthop Sports Phys Ther. 2012; 42: 823-30. doi: 10.2519/jospt.2012.4184.

[29]

Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOSADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index

(WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). Arthritis Care Res. 2011; 63: 208-28. doi: 10.1002/acr.20632.

[30]

Cunha RA, Pena Costa LO, Hespanhol Junior LC, Pires RS, Kujala UM, Lopes AD. Translation, cross-cultural adaptation, and clinimetric testing of instruments used to assess patients with patellofemoral pain syndrome in the Brazilian population. J Orthop Sports Phys Ther. 2013; 43: 332-9. doi: 10.2519/jospt.2013.4228.

[31]

Briggs KK, Kocher MS, Rodkey WG, Steadman JR. Reliability, validity, and responsiveness of the Lysholm knee score and tegner activity scale for patients with meniscal injury of the knee. J Bone Joint Surg – Series A. 2006; 88: 698-705. doi: 10.2106/JBJS.E.00339.

[32]

Piva SR, Gil AB, Moore CG, Fitzgerald GK. Responsiveness of the activities of daily living scale of the knee outcome survey and numeric pain rating scale in patients with patellofemoral pain. J Rehabil Med. 2009; 41: 129-35. doi: 10.2340/16501977-0295.

[33]

Cruz-Díaz D, Lomas-Vega R, Osuna-Pérez MC, Hita-Contreras F, Fernández ÁD, Martínez-Amat A. The Spanish lower extremity functional scale: A reliable, valid and responsive questionnaire to assess musculoskeletal disorders in the lower extremity. Disabil Rehabil. 2014; 36: 2005-11. doi: 10.3109/09638288.2014.890673.

[34]

Williams VJ, Piva SR, Irrgang JJ, Crossley C, Fitzgerald GK. Comparison of reliability and responsiveness of patient-reported clinical outcome measures in knee osteoarthritis rehabilitation. J Orthop Sports Phys Ther. 2012; 42: 716-23.

[35]

Tacconelli E. Systematic reviews: CRD's guidance for undertaking reviews in health care. Lancet Infect Dis. 2010; 10: 226. doi: 10.1016/s1473-3099(10)70065-7.

[36]

Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. PLoS Med. 2009; 6: e1000100. https//pure.qub.ac.uk/en/publications/the-prisma-statement-for-reporting-systematic-reviews-andmeta-an.

[37]

Sayers A. Tips and tricks in performing a systemic review. Br J Gen Pract. 2008; 58: 136.

[38]

Higgins JPT, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ (Online). 2011; 343: 1-9. doi: 10.1136/bmj.d5928.

[39]

Frye JL, Ramey LN, Hart JM. The effects of exercise on decreasing pain and increasing function in patients with patellofemoral pain syndrome: A systematic review. Sports Health. 2012; 4: 205-10. doi: 10.1177/1941738112441915.

[40]

Kooiker L, van de Port IGL, Weir A, Moen MH. Effects of physical therapist-guided quadricepsstrengthening exercises for the treatment of patellofemoral pain syndrome: A systematic review. J Orthop Sports Phys Ther. 2014; 44: 391-402.

[41]

Avraham F, Aviv S, Ya'akobi P, Faran H, Fisher Z, Goldman Y, et al. The efficacy of treatment of different intervention programs for patellofemoral pain syndrome – A single blinded randomized clinical trial. Pilot study. Scientific World Journal. 2007; 7: 1256-62. doi: 10.1100/tsw.2007.167.

[42]

de Marche Baldon R, Serrão FV, Silva RS, Piva SR. Effects of functional stabilization training on pain, function, and lower extremity biomechanics in women with patellofemoral pain: A randomized clinical trial. J Orthop Sports Phys Ther. 2014; 44: 240-51. doi: 10.2519/jospt.2014.4940.

[43]

Ismail MM, Gamaleldein MH, Hassa KA. Closed Kinetic Chain exercises with or without additional hip strengthening exercises in management of Patellofemoral pain syndrome: A randomized controlled trial. Eur J Phys Rehabil Med. 2013; 49: 687-98.

[44]

Khayambashi K, Fallah A, Movahedi A, Bagwell J, Powers C. Posterolateral hip muscle strengthening versus quadriceps strengthening for patellofemoral pain: A comparative control trial. Arch Phys Med Rehabil. 2014; 95: 900-7. doi: 10.1016/j.apmr.2013.12.022.

[45]

Nakagawa TH, Muniz TB, Baldon R de M, Dias Maciel C, de Menezes Reiff RB, Serrão FV. The effect of additional strengthening of hip abductor and lateral rotator muscles in patellofemoral pain syndrome: A randomized controlled pilot study. Clin Rehabil. 2008; 22: 1051-60. doi: 10.1177/0269215508095357.

[46]

Song CY, Lin YF, Wei TC, Lin DH, Yen TY, Jan MH. Surplus value of hip adduction in leg-press exercise in patients with patellofemoral pain syndrome: A randomized controlled trial. Phys Ther. 2009; 89: 409-18. doi: 10.2522/ptj.20080195.

[47]

Boling MC, Bolgla LA, Mattacola CG, Uhl TL, Hosey RG. Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome. Arch Phys Med Rehabil. 2006; 87: 1428-35. doi: 10.1016/j.apmr.2006.07.264.

[48]

Tyler TF, Nicholas SJ, Mullaney MJ, McHugh MP. The role of hip muscle function in the treatment of patellofemoral pain syndrome. Am J Sports Med. 2006; 34: 630-6. doi: 10.1177/0363546505281808.

[49]

Singal AG, Higgins PDR, Waljee AK. A primer on effectiveness and efficacy trials. Clin Transl Gastroenterol. 2014; 5: 1-4. doi: 10.1038/ctg.2013.13.

[50]

Calmbach WL, Hutchens M. Evaluation of patients presenting with knee pain: Part II. Differential diagnosis. Am Fam Physician. 2003; 68: 917-22.

[51]

Shultz SJ, Dudley WN, Kong Y. Identifying multiplanar knee laxity profiles and associated physical characteristics. J Athl Train. 2012; 47: 159-69. doi: 10.4085/1062-6050-47.2.159.

[52]

Nadler SF, Malanga GA, DePrince M, Stitik TP, Feinberg JH. The relationship between lower extremity injury, low back pain, and hip muscle strength in male and female collegiate athletes. Clin J Sport Med. 2000; 10: 89-97. doi: 10.1097/00042752-200004000-00002.

[53]

Näslund JE, Odenbring S, Näslund UB, Lundeberg T. Diffusely increased bone scintigraphic uptake in patellofemoral pain syndrome. Br J Sports Med. 2005; 39: 162-5. doi: 10.1136/bjsm.2004.012336.

[54]

Hart L. Supervised exercise versus usual care for patellofemoral pain syndrome. Clin J Sport Med. 2010; 20: 133-4. https//pubmed.ncbi.nlm.nih.gov/20215901/.

[55]

Na Y, Han C, Shi Y, Zhu Y, Ren Y, Liu W. Is Isolated Hip Strengthening or Traditional Knee-Based Strengthening More Effective in Patients With Patellofemoral Pain Syndrome? A Systematic Review With Meta-analysis Orthop J Sports Med. 2021; 9(7): 1-8. doi: 10.1177/23259671211017503.

[56]

Willy RW, Hoglund LT, Barton CJ, Bolgla LA, Scalzitti DA, Logerstedt DS, et al. Patellofemoral Pain. J Orthop Sports Phys Ther. 2019; 49(9): CPG1-CPG95. doi: 10.2519/jospt.2019.0302.

[57]

Campbell R, Evans M, Tucker M, Quilty B, Dieppe P, Donovan JL. Why don’t patients do their exercises? Understanding non-compliance with physiotherapy in patients with osteoarthritis of the knee. J Epidemiol Community Health. 2001; 55: 132-8. doi: 10.1136/jech.55.2.132.