

Effect of Resistance Training for the Treatment of Patellofemoral Pain: A Systematic Review

Short title: Resistance Training for Patellofemoral Pain

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Abstract

This systematic review aimed to synthesise the work conducted in this area to guide professional practice in decision-making. A comprehensive search was conducted in PubMed, ScienceDirect, SPORTDiscus, BVS, and SciELO databases for randomised controlled trials (RCTs) from inception to September 18, 2024. Randomised clinical trials investigating the effects of resistance training programs on pain and muscle function outcomes in individuals PFPS were included. The methodological quality of the studies was assessed using the PEDro Scale, and the risk of bias was evaluated using the Cochrane Risk of Bias tool (version 2). Study screening and data extraction were performed independently and in duplicate, encompassing intervention characteristics and the assessment of the outcomes of interest. Thirty RCTs involving 1,733 participants (74.3% female; mean age 28.8 ± 5.5 years) were included. Resistance training, whether isolated or combined, consistently improved pain and function. Combined hip and quadriceps strengthening showed superior effects compared to isolated protocols. Core-focused programs and adjunctive strategies (e.g., assistive technologies, biofeedback) also produced benefits, though not consistently superior to conventional training. Whole-body vibration and neuromuscular electrical stimulation yielded mixed results, with limited evidence of clinical superiority. Resistance training is an effective therapeutic strategy for PFPS, with combined hip and quadriceps strengthening offering better benefits. Complementary approaches may enhance outcomes, but evidence is insufficient to confirm superiority over standard resistance exercise. Future high-quality RCTs with standardised protocols are recommended to strengthen the evidence base.

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Keywords: Rehabilitation, exercise therapy, knee disorders, randomised controlled trials, physical function.

INTRODUCTION

Resistance training has been established as a fundamental therapeutic approach for treating several musculoskeletal conditions, including patellofemoral pain, as it strengthens the region, corrects muscle imbalances, enhances joint stability, and helps prevent future injuries (Crossley, Callaghan, & van Linschoten, 2016).

Patellofemoral pain syndrome (PFPS) is one of the most common causes of knee pain, affecting about 22.7% of adolescents and young adults, especially in athletes and physically active people, with a prevalence in recreational runners of 37% to 56% of chances of injury during a period of one year of training (Neal et al., 2019). Most traditional treatment programs and plans focus on strengthening the quadriceps to improve knee joint stability, as decreased quadriceps strength and flexibility, as well as increased atrophy, are commonly reported in people with gradual-onset knee disorders (Jakobsen et al., 2019).

Studies indicate that strengthening the hip muscles (especially abductors and external rotators) may play a key role in relieving pain and improving functionality in patients with PFPS. Such studies suggest that instability in the hip muscles can increase the overload on the patellofemoral joint, highlighting the need for broader rehabilitation approaches that include both the hip and the knee (Collins et al., 2018; Sahin, Ayhan, Borman, & Atasoy, 2016).

Evidence from a meta-analysis of 14 studies demonstrates that hip muscle strengthening improves pain and knee function, with all randomised controlled trials (except one) showing it to be superior to quadriceps strengthening alone. Furthermore, among five RCTs evaluating combined hip and quadriceps strengthening versus quadriceps strengthening alone, four showed greater improvements in pain and function with the combined approach (Alammari, Spence, Narayan, Karnad, & Ottayil, 2023).

Although resistance training has been shown to improve function in women with PFPS, current evidence reveals important gaps in understanding its mechanisms and optimal application. In

particular, the amount of prescribed resistance exercise does not appear to significantly affect pain reduction, suggesting that the pathways through which resistance training alleviates pain remain unclear (de Oliveira, Lopez P, Severo-Silveira, Almeida, & Baroni, 2023). In addition, there is limited research on optimal training volumes, frequencies, and progression strategies, as well as on sustaining long-term adherence and therapeutic effects. The integration of patient education and the potential benefits of combining resistance training with aerobic activities also remain underexplored, highlighting the need for further studies to establish the most effective and sustainable interventions for this population (Cardoso, Caputo, Rombaldi, & Del Vecchio, 2017).

Therefore, given the substantial variability in resistance training protocols for patellofemoral pain (PFP) regarding targeted muscle groups, dosage parameters, progression criteria, and comparator conditions, there remains uncertainty about the relative effectiveness of different strengthening approaches. Furthermore, previous trials have presented methodological limitations, including small sample sizes, heterogeneous outcome measures, and inconsistencies in intervention duration and intensity, which hinder direct comparison across studies.

The primary objective of this systematic review was to evaluate the effectiveness of resistance training interventions in treating patellofemoral pain. Specifically, we aimed to compare the clinical effects of isolated (quadriceps- or hip-focused) versus combined strengthening strategies on pain and functional outcomes. A secondary objective was to describe intervention characteristics and identify patterns associated with more consistent improvements. We hypothesised that combined strengthening approaches would yield more consistent clinical benefits than isolated protocols.

METHODS

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Page et al., 2021). This protocol for carrying out this

research was registered in the International Prospective Register of Systematic Reviews (PROSPERO) on September 18, 2024, under CRD 42024592233 (Schiavo, 2019).

Search strategy

The search strategy was conducted using the PICOS methodology (Population, Intervention, Comparator, Outcome, and Study Type) to structure the research question and establish eligibility criteria (Table 1). The complete search strategy for PubMed was as follows: (“patellofemoral pain” OR “anterior knee pain” OR “patellofemoral pain syndrome”) AND (“resistance training” OR “strength training” OR “muscle strengthening” OR “exercise therapy”) AND (“randomised controlled trial” OR “clinical trial”). The full search strategies for all databases are provided in Table 2.

Table 1. Overview of the inclusion and exclusion criteria applied

Category	Inclusion Criteria
Population	Adult patients (over 18 years old) diagnosed with PFPS.
Intervention	Strength training approaches or strength exercises as part of the intervention.
Comparator	Patients without relevant interventions (e.g., compared to counseling/information or placebo for PFPS treatment), or those who underwent quadriceps-only muscle exercise programs, or manual therapy.
Outcome	Pain assessed by VAS, functional outcomes measured by standardised questionnaires (AKPS, LEFS, WOMAC), or other standardised criteria for patellofemoral pain.
Study Design	Randomised controlled trials.

Note: PFPS = Patellofemoral Pain Syndrome; VAS = Visual Analog Scale; AKPS = Anterior Knee Pain Scale; LEFS = Lower Extremity Functional Scale; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; MVC = Maximal Voluntary Contraction; RCT = Randomised controlled trials.

Table 2. Search strategy

Database	Search strategy
Pubmed	((Strength training) OR (Strength exercise)) OR (resistance training) OR (Resistance exercise) AND (patellofemoral pain syndrome) OR (retropatellar pain) AND (rehabilitation) OR (treatment)
Science Direct	("Strength training" OR "Strength exercise" OR "resistance training" OR "Resistance exercise") AND ("patellofemoral pain syndrome" OR "retropatellar pain") AND ("rehabilitation" OR "treatment")
SPORTDiscus	("Strength training" OR "Strength exercise" OR "resistance training" OR "Resistance exercise") AND ("patellofemoral pain syndrome" OR "retropatellar pain") AND ("rehabilitation" OR "treatment")
BVS	("Strength training" OR "Strength exercise" OR "resistance training" OR "Resistance exercise") AND ("patellofemoral pain syndrome" OR "retropatellar pain") AND ("rehabilitation" OR "treatment")
SciELO	("Strength training" OR "Strength exercise" OR "resistance training" OR "Resistance exercise") AND ("patellofemoral pain syndrome" OR "retropatellar pain") AND ("rehabilitation" OR "treatment")

Inclusion criteria

Population

The selected clinical trials were included based on the criterion of the approach of adult patients (> 18 years old) with PFPS, with a diagnosis from a qualified healthcare professional supported by clinical examination, pain assessment, and orthopaedic tests. It should be noted that participants at any level of physical activity were included, and, to be eligible, trials had to include aerobic training approaches or strength exercises as part of the intervention.

Intervention

Progressive exercise programs that focused on the knee muscle groups, regardless of their duration, whether practised alone or in combination with lower-limb exercises, were included. As well as dynamic programs, involving concentric exercises and/or eccentric, isometric and isokinetic contractions.

Comparator

Control groups included participants who received either no intervention, informational sessions, or placebo treatments, compared with those who underwent isolated quadriceps muscle exercise programs or manual therapy. Therefore, we highlight that studies on patients who underwent any invasive intervention or rehabilitation method (surgery or injections) were excluded, as were those involving the implantation of orthoses, bandages, or supports of any kind.

Given the heterogeneity of comparator conditions across studies, control groups were conceptually classified as either passive controls (no intervention, informational sessions, or placebo) or active comparators (isolated quadriceps strengthening or manual therapy). Due to variability in control conditions, differences in intervention protocols, and outcome measures, quantitative pooling was

not considered methodologically appropriate. Therefore, comparator effects were interpreted within the context of each study in the narrative synthesis.

Outcomes

The outcomes considered for inclusion were: a) Pain measured using the Visual Analogue Scale (VAS), b) Functional outcomes questionnaire: Anterior Knee Pain Scale (AKPS); Lower Extremity Functional Scale (LEFS); Western Ontario and McMaster University Arthritis Index (WOMAC) or c) any other standardised criteria used in the study to assess patellofemoral pain.

Study design

A systematic review based on Randomised Controlled Trials (RCTs), including at least one intervention and control group, as well as evaluating adjacent muscle exercise programs.

Exclusion criteria

In this categorisation, studies in preprint, review, thesis, dissertation, book chapter, protocol, and cross-sectional studies, cohort studies, and any articles developed in animal models were excluded. Thus, the review focused on the interventions implemented in both research settings, controlled and real-world clinical, to evaluate the effectiveness of these interventions in reducing pain and functional improvements in patients with PFPS.

Sources of information and bibliographic research

The search strategy included terms related to strength training and the influence on PFPS (Table 2), applying the Boolean operators AND and OR that were searched (PubMed, ScienceDirect, Sport Discus, VHL and SciELO), using specific descriptors concerning strength training (“strength training”, “strength exercise”, “resistance training”, “resistance exercise”), patellofemoral pain

(“patellofemoral pain syndrome”, “retropatellar pain”) and rehabilitation "(rehabilitation, treatment).

The search began on October 1, 2024, and included works in English, Spanish, and Portuguese, with no date restriction (Table 3).

Table 3. Search strategy for all databases

Related to strength training	Patellofemoral Pain Terms	Rehabilitation-related
Strength training	Patellofemoral pain syndrome	Rehabilitation
Strength exercise	Retropatellar pain	Treatment
Resistance training		
Resistance exercise		

Data extraction

Data extraction was conducted by a reviewer (WNS) using a pre-piloted data extraction form in an Excel spreadsheet. It was independently verified by two members of the review team (NJBAF and EFP). Any discrepancies were resolved by reviewing the original article, and consensus was reached through discussions during meetings (WNS, NJBAF, and EFP) or, when necessary, via consultation with a fourth reviewer (VSQ).

In addition, for incomplete data, the authors were contacted to obtain the relevant information and were given 4 weeks to respond. If no response were received within that period, the articles would be excluded, and no relevant data would be extracted from the published version of the paper.

Selection process

Initially, duplicate articles were excluded. The titles and abstracts of articles retrieved during the searches were screened for relevance; those identified as potentially relevant were read in full and evaluated for eligibility, and included or excluded as appropriate. It is noteworthy that two independent researchers evaluated the studies, and a third resolved any discrepancies. Thus, after reading the articles in full, the reasons for the exclusions were recorded, and searches were then carried out in the reference lists of the included articles to identify possible studies not captured in

the initial search. Thus, all stages were conducted using the Rayyan Web Application (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016), which had a researcher registered as an administrator, allowing the processes to be carried out blindly by the reviewers.

Assessment of quality and risk of bias

The PEDro scale was used to assess the quality of the included studies, as it specifically analyses the quality of RCTs related to physiotherapy interventions; it consists of 11 items and is used where each of them, satisfied, added one point to the overall score (range from 0 to 10), thus, the higher the quality of the RCT (De Morton, 2009). Two reviewers evaluated studies to eliminate any discrepancies, and those that scored 9-10 were rated as excellent quality, 6-8 as Good quality, 4-5 as Moderate quality, and less than 4 as Low quality.

To assess the methodological quality of the included randomised controlled trials (RCTs), the Risk of Bias 2 (RoB 2) tool, developed by the Cochrane Collaboration, was used (Minozzi, Cinquini, Gianola, Gonzalez-Lorenzo, & Banzi, 2020). This tool evaluates the risk of bias across five key domains: (1) bias arising from the randomisation process, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in measurement of the outcome, and (5) bias in selection of the reported result. Each domain is rated as having "low risk," "some concerns," or "high risk" of bias, which informs an overall risk of bias judgment for each study. The assessment was conducted independently by two reviewers, and disagreements were resolved through discussion.

Data synthesis strategy

Data extraction included baseline and post-intervention means and Standard Deviations (SD) for all outcome measures for both the intervention and control groups. In addition, the given demographics (age, sex, height, body mass, and body mass index) were extracted. Basic characteristics of the

intervention, such as duration (in weeks), weekly frequency, the interval between exercises or sets, guidance and supervision during the intervention, exercise progression, and compliance with the program, were also collected.

Data extraction also included details about the type of load used (machine, body weight, free weights, and resistance bands), exercise intensity (expressed as a percentage of a repetition maximum or using subjective measures such as the Borg scale), and any missing data were resolved by contacting the corresponding authors via e-mail.

All data was imported into MS Excel 2019 (Microsoft, Redmond, USA) for analysis, and in cases where they are presented as graphs, Adobe Illustrator software (version CS5, Adobe Inc., San Jose, USA) was used to accurately determine the mean and DP values, allowing substantial enlargement of the graphs, enabling high accuracy in the measurement of the relevant data, and reducing any errors introduced by this method. A quantitative meta-analysis was not performed due to substantial clinical and methodological heterogeneity across studies. Clinical heterogeneity was observed in the targeted muscle groups (quadriceps, hip, or combined protocols), exercise dosage (frequency, intensity, progression criteria), intervention duration, and follow-up periods. Methodological heterogeneity included variability in outcome measures (e.g., VAS, NPRS, Kujala score, LEFS), reporting formats, and comparator definitions. Given these differences, statistical pooling was deemed inappropriate, and the results were synthesised narratively.

Protocol changes

The outcomes of any strength measurements were excluded to enhance objectivity in summarising and analysing studies related to pain and functionality.

RESULTS

A total of 613 records were initially identified through database searches. After full reading, 30 studies were considered eligible. Details of the screening process can be found in Figure 1. Studies excluded after full review, along with the respective reasons, are listed in the Table 4. The graph shows the geographic distribution of the included studies (Figure 2).

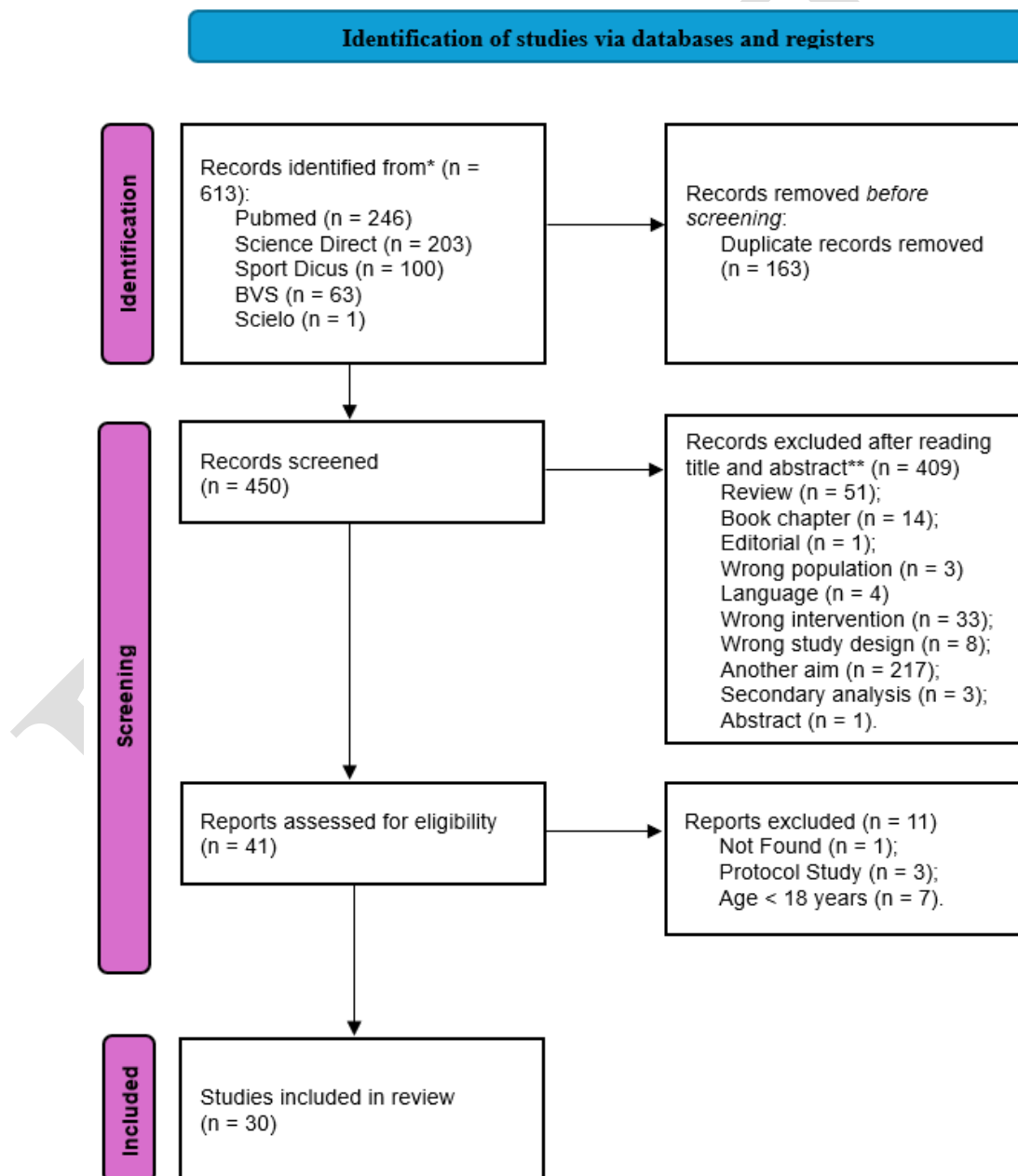
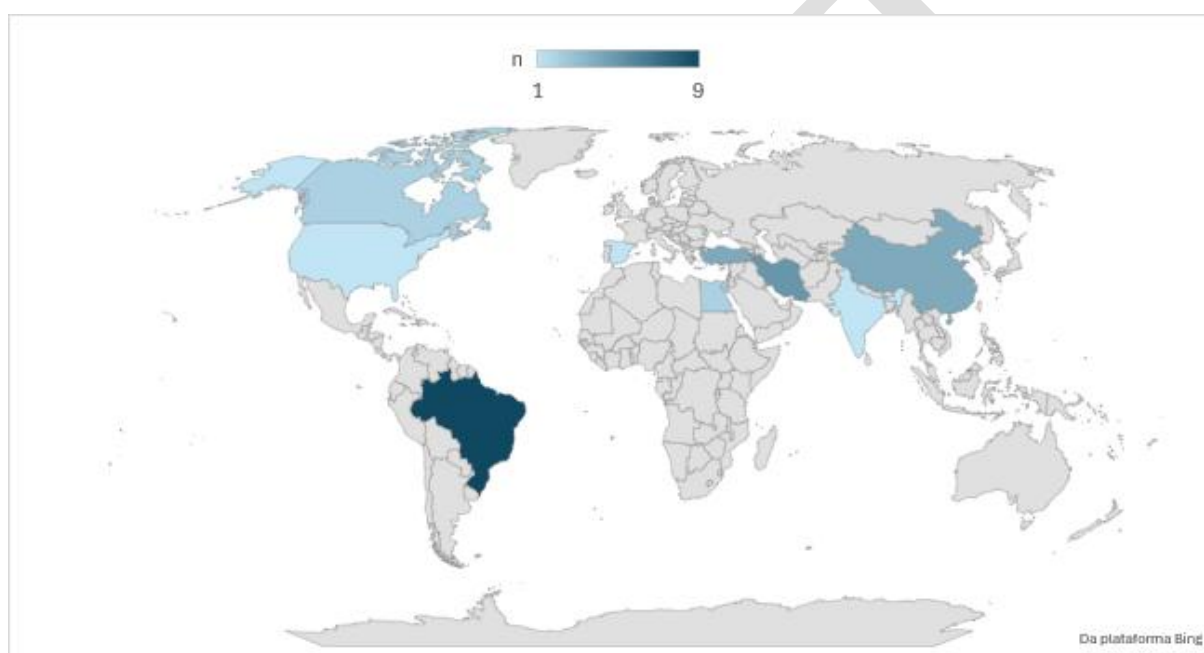


Figure 1. Flowchart of study selection according to PRISMA

Table 4. Excluded studies with reasons

Study (year)	Reason
Ramazzina et al., 2016 [1]	Not found
Steinberg et al., 2019 [2]	Included participants under 18 years of age
Hott et al., 2019 [3]	Included participants under 18 years of age
Nakagawa et al., 2008 [4]	Included participants under 18 years of age
Hott et al., 2020 [5]	Included participants under 18 years of age
Finnoff et al., 2011 [6]	Included participants under 18 years of age
Pietrosimone et al., 2020 [7]	Included participants under 18 years of age
Østerås et al., 2013 [8]	Included participants under 18 years of age
Hott et al., 2015 [9]	Protocol study
Rabelo et al., 2014 [10]	Protocol Study
Vasconcelos et al., 2021 [11]	Protocol Study

**Figure 2.** World map showing geographical distribution of studies included in this systematic review

Participant characteristics

The total sample of the included studies comprised 1,733 participants with patellofemoral pain syndrome, with an overall mean age of 28.8 ± 5.5 years and ages ranging from 18 to 55 years. In this scenario, females ($n = 1,288$; 74.3%) outnumbered males ($n = 445$; 25.7%), with young women also prevailing. Regarding physical activity levels, participants were typically classified as physically active or recreationally active, although some studies included sedentary individuals or did not report this variable (Table 5).

Table 5. General characteristics of the sample

Study	Sample Size; Sex; Age (Mean + SD or Age Range); Training Level	Morphological Characteristics	Symptomatic features (time with PFPS)
Hansen et al., 2023	n = 200; 138 female (69.0%); 62 male (31.0%) Age = 27.2 ±6.4 years TL = not specified	BW = 67.9 ±12.7 kg H = 172.8 ±9.6 cm BMI = 22.6 ±4.5 kg/m ²	~ 33 months
Kamel et al., 2024	n = 28; 7 female (25.0%); 21 male (75.0%) Age = 21.9 ±2.2 years (18 - 35 years) TL = not specified	BW = 71.3 ±13.1 kg H = 170.5 ±11.9 cm BMI = 24.3 ±2.5 kg/m ²	Not specified
Kısacık et al., 2021	n = 30; 25 female (83.3%); 5 male (16.7%) Age = 41.6 ±8.3 years (25 - 55 years) TL = not specified	BW = 69.9 ±13.5 kg H = 166.4 ±9.9 cm BMI = 25.2 ±2.5 kg/m ²	Not specified
Şahin et al., 2016	n = 50; all female Age = 34.1 ±6.2 years (20 -45 years) TL = sedentary	BW = not specified H = not specified BMI = 25.9 ±3.9 kg/m ²	6 - 8 months
Saad et al., 2018	n = 40; all female Age = 22.6 ±1.5 years (18 -28 years) TL = recreational athletes (at least 3 times per week for at least 30 min)	BW = 55.4 ±3.5 kg H = 159.7 ±4.5 cm BMI = 21.8 ±1.6 kg/m ²	> 3 months
Baldon et al., 2014	n = 31; all female Age = 22.0 ±2.9 years (18 - 30 years) TL = recreational athletes (at least 3 times per week for at least 30 min)	BW = 57.7 ±7.8 kg H = 163.0 ±1.0 cm BMI = 21.5 ±2.3 kg/m ²	~43.5 months
Shadloo et al., 2021	n = 30; all female Age = 27.5 ±2.5 years (20 - 40 years) TL = regular sports activity for at least 2 h/day and 3 times a week	BW = 69.6 ±3.8 kg H = 176.8 ±4.1 cm BMI = 22.5 ±3.9 kg/m ²	> 12 months
Wu et al., 2021	n = 36; 17 female (47.3%); 19 male (52.7.0%) Age = 27.4 years (18 - 40 years) TL = IPAQ classification (low/moderate/high)	BW = not specified H = not specified BMI = 22.0 kg/m ²	Not specified
Silva et al., 2023	n = 71; all female Age = 23.2 ±3.0 years (18 - 30 years) TL = physically active (IPAQ = regularly or irregularly)	BW = 64.5 ±14.3 kg H = 163.2 ±6.4 cm BMI = 22.5 ±3.9 kg/m ²	> 3 months
Sheikhi et al., 2024	n = 60; 24 female (40.0%); 36 male (60.0%) Age = 31.6 ±5.7 years (18 - 40 years) TL = not specified	BW = 72.5 ±10.7 kg H = 171.3 ±8.5 cm BMI = 24.7 ±3.3 kg/m ²	~58.7 months
Foroughi et al., 2019	n = 33; all female Age = 23.6 ±2.1 years (18 - 30 years) TL = physically active (at least 30 min/day)	BW = 57.9 ±9.9 kg H = 163.1 ±6.6 cm BMI = 21.8 ±1.6 kg/m ²	~37.1 months
Rabelo et al., 2017	n = 34; all female Age = 25.6 ±6.8 years (18 - 30 years) TL = not specified	BW = 57.3 ±7.3 kg H = 160.5 ±3.5 cm BMI = 22.2 ±2.3 kg/m ²	~47,7 months/
da Silva Boitrigo et al., 2021	n = 60; all female Age =26.8 ±6.6 years old (18 - 45 years old) TL = Sedentary	BW = 63.1 ±10.5 kg H = 163.5 ±6.5 cm BMI = 22.2 ±2.3 kg/m ²	Not specified
Aghakeshizadeh et al., 2021	n = 70; 40 female (57.1%); 30 male (42.9%) Age = 29.1 ±7.4 years (18 - 45 years) TL = recreationally active (at least 3 times per week for at least 30 min)	BW = 63.7 ±4.6 kg H = 163.9 ±3.7cm BMI = 23.8 ±1.6 kg/m ²	~60 months
Almeida et al., 2021	n = 52; all female Age = 24.9 ±4.8 years (18 - 35 years)	BW = 62.5 ±9.6 kg H = 161.5 ±7.0 cm	~49 months

	TL = physically active (at least 3 times per week for at least 30 min/day) n = 40; all female Age = 37.6 ±8.4 years (20 - 45 years) TL = not specified	BMI = 23.9 ±3.6 kg/m ² BW = 68.8 ±10.5 kg H = 164.2 ±5.5 cm BMI = 25.5 ±4.6 kg/m ²	~31.8 months
Balci et al., 2009			
Herrington et al., 2007	n = 45; all male Age = 26.9 ±5.6 years (20 - 45 years) TL = not specified	Not specified	Not specified
Celik et al., 2020	n = 58; 36 female (62.1%); 22 male (37.9%) Age = 31.2 ±6.6 years (18 - 45 years) TL = not specified	BW = 70.7 ±12.2 kg H = 164.2 ±7.4 cm BMI = 26.2 kg/m ²	Not specified
Hong et al., 2023	n = 38; 17 female (44.7%); 21 male (55.3%) Age = 32.1 ±6.3 years (18 - 40 years) TL = not specified	BW = 67.8 ±9.5 kg H = 170.0 ±10.0 cm BMI = 23.5 kg/m ²	Not specified
Song et al., 2009	n = 89; 69 female (77.5%); 20 male (22.5%) Age = 40.9 ±10.2 years (< 50 years) TL = not specified	BW = 58.6 ±6.9 kg H = 161.1 ±6.9 cm BMI = 22.5 ±2.7 kg/m ²	~35.9 months
Khayambashi et al., 2012	n = 28; all female Age = 28.7 ±5.3 years TL = sedentary and only participated in activities of daily living	BW = 61.7 ±10.5 kg H = 159.5 ±5.2 cm BMI = 24.3 kg/m ²	Not specified
Pompeo et al., 2022	n = 50; all female Age = 28.5 ±6.3 years (18 - 42 years) TL = physically active	BW = 61.8 ±9.1 kg H = 164.0 ±6.5 cm BMI = 23.0 ±3.1 kg/m ²	> 6 months
Esculier et al., 2018	n = 69; 43 female (62.3%); 26 male (37.7%) Age = 30.7 ±6.2 years (18 - 45 years) TL = runners	BW = 67.5 ±14.0 kg H = 169.8 ±8.9 cm BMI = 23.4 kg/m ²	~28,8 months
Albornoz-Cabello et al., 2024	n = 86; 52 female (60.5%); 34 male (39.5%) Age = 42.0 ±4.2 years (30 - 50 years) TL = not specified	BW = 78.3 ±14.8 kg H = 167.0 ±10.5 cm BMI = 28.2 ±4.9 kg/m ²	Not specified
Yip & Ng ,2006	n = 26; 16 female (61.5%); 10 male (38.5%) Age = 32.5 ±8.8 years (22 - 55 years) TL = not specified	Not specified	> 6 months
Raju et al., 2024	n = 45; 26 female (57.8%); 19 male (42.2%) Age = 25.6 ±4.3 years (18 - 35 years) TL = not specified	BW = 64.6 ±14.5 kg H = 163.1 ±7.3 cm BMI = 24.1 ±4.1 kg/m ²	Not specified
Ferber et al.,2015	n = 199; 133 female (66.8%); 66 male (33.2%) Age = 29.0 ±7.1 years (18 - 45 years) TL = recreationally active (at least 3 times per week for at least 30 min)	BW = 67,6 ±13.5 kg H = 170.4 ±9.4 cm BMI = 23.2 kg/m ²	Not specified
Ismail et al., 2013	n = 32; 23 female (71.9%); 9 male (28.1%) Age = 21.0 ±2.9 years TL =not specified	BW = 65,5 ±9.7 kg H = 164.6 ±6.5 cm BMI = 24.1 kg/m ²	Not specified
Fukuda et al., 2012	n = 54; all female Age = 22.5 ±3.0 years (20 - 40 years) TL =sedentary	BW = 60.7 ±3.1 kg H = 159.5 ±20. cm BMI = 24.1 ±2.7 kg/m ²	~22.1 months
Fukuda et al., 2010	n = 54; all female Age = 24.6 ±6.6 years (20 - 40 years) TL =sedentary	BW = 58,7 ±7.2 kg H = 162.0 ±56.6 cm BMI = 22.3 kg/m ²	Not specified

Note TL = training level; BW = body weight; H = height; BMI = body mass index.

Morphological characteristics were reported in 26 studies. Body weight ranged from 55.4 ± 3.5 kg to 78.3 ± 14.5 kg; height ranged from 157.0 ± 4.5 cm to 177.8 ± 9.3 cm; and BMI varied from 21.1 ± 2.5 kg/m² to 28.3 ± 3.6 kg/m², with most values within the normal range (18.5–24.9 kg/m²). The duration of patellofemoral pain was reported in 21 studies, with a mean of 28.5 ± 19.6 months, typically ranging from 6 to 36 months. However, nine studies did not specify this variable (Table 5).

Risk of bias

The risk of bias assessment of the 30 included studies, conducted using the RoB 2 tool for the effect of assignment to intervention (intention-to-treat), revealed that 13 studies (43.3%) presented a low overall risk of bias (Aghakeshizadeh, Letafatkar, & Thomas, 2021; Albornoz-Cabello et al., 2024; da Silva Boitrigo et al., 2021; Esculier et al., 2018; Hong et al., 2023; Pompeo et al., 2022; Rabelo et al., 2017; Raju et al., 2024; Saad et al., 2018; Shadloo, Kamali, & Salehi Dehno, 2021; Sheikhi, Rabiei, Letafatkar, & Rossetini, 2024; Silva et al., 2023; Wu et al., 2022). Seven studies (23.3%) were classified as having some concerns (Fukuda et al., 2012; Fukuda et al., 2010; Hansen, Brushoj, Rathleff, Magnusson, & Henriksen, 2023; Herrington, & Al-Sherhi, 2007; Ismail, Gamaleldein, & Hassa, 2013; Kamel, Ghuiba, Abd Allah, Fayaz, Abdelkader, 2024; Song et al., 2009). Ten studies (33.3%) were assessed as having a high risk of bias (Almeida, Rodrigues, Coelho, Rodrigues, & Lima, 2021; Balci, Tunay, Baltaci, & Atay, 2009; Baldon, Serrao, Scattone Silva, & Piva 2014; Celik, Argut, Turker, & Kilicoglu, 2020; Ferber, Bolgla, Earl-Boehm, Emery, & Hamstra-Wright, 2015; Foroughi, Sobhani, Yoosefinejad, & Motealleh, 2019; Khayambashi, Mohammadkhani, Ghaznavi, Lyle, & Powers, 2012; Kisacik et al., 2021; Sahin et al., 2016; Yip & Ng, 2006) (Figure 3).

Study ID	D1	D2	D3	D4	D5	Overall
Hansen R et al., 2023	+	!	+	+	+	!
Kamel AM et al., 2024	+	+	+	!	+	!
Kisaok P et al., 2021	+	-	-	!	!	-
Şahin M et al., 2016	+	-	-	+	!	-
Saad MC et al., 2018	+	+	+	+	+	+
Baldon RM et al., 2014	+	+	+	!	-	-
Shadloo N et al., 2021	+	+	+	+	+	+
Wu Z et al., 2021	+	+	+	+	+	+
Silva NC et al., 2023	+	+	+	+	+	+
Sheikhi B et al., 2024	+	+	+	+	+	+
Foroughi F et al., 2019	!	-	-	-	+	-
Rabelo ND et al., 2017	+	+	+	+	+	+
da Silva Boitrago MV et al., 2021	+	+	+	+	+	+
Aghakeshizadeh F et al., 2021	+	+	+	+	+	+
Almeida GPL et al., 2021	+	+	+	+	-	-
Balci P et al., 2009	!	-	-	-	-	-
Herrington L et al., 2007	+	!	+	+	!	!
Celik D et al., 2020	!	+	+	+	-	-
Hong QM et al., 2023	+	+	+	+	+	+
Song CY et al., 2009	+	+	+	+	!	!
Khayambashi K et al., 2012	-	+	+	-	-	-
Pompeo KD et al., 2022	+	+	+	+	+	+
Esculier JF et al., 2018	+	+	+	+	+	+
Albornoz-Cabello M et al., 2024	+	+	+	+	+	+
Yip SLM et al., 2006	!	-	-	-	-	-
Raju A et al., 2024	+	+	+	+	+	+
Ferber R et al., 2015	+	+	-	+	-	-
Ismail MM et al., 2013	+	+	+	+	!	!
Fukuda TY et al., 2012	+	+	+	+	!	!
Fukuda TY et al., 2010	+	+	+	+	!	!

Figure 3. Risk of bias assessment by domain for included studies. **Note** D1: Randomisation process; D2: Deviations from intended interventions; D3: Missing outcome data; D4: Measurement of the outcome; D5: Selection of the reported result. Colour codes: Green – Low risk; Yellow – Some concerns; Red – High risk.

An analysis of the individual domains shows that the best-rated area was “Missing outcome data”, where 80% of the studies were classified as low risk, and none were rated as having some concerns. Similarly, the domains “Deviations from intended interventions” and “Randomisation process” presented favourable profiles, with 76.7% and 83.3% of studies, respectively, showing low risk. In contrast, the domains “Measurement of the outcome” and “Selection of the reported result” revealed greater methodological fragility. Only 76.7% and 53.3%, respectively, were considered low risk in

these domains, and 13.3% and 23.3% had high risk, often related to lack of blinding or selective outcome reporting (Figure 4).

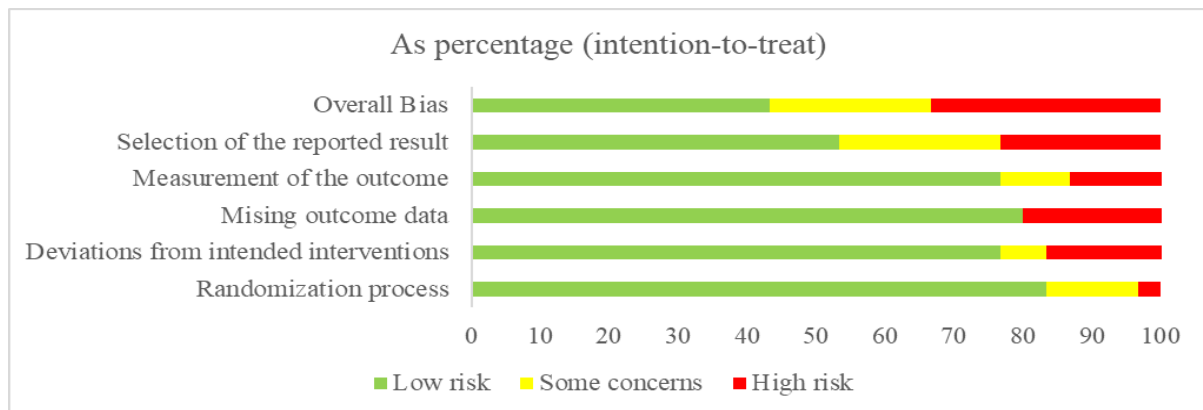


Figure 4. Summary of risk-of-bias ratings per domain.

Quality assessment

Complementary to the risk-of-bias analysis, methodological quality was assessed using the PEDro scale. Among the included studies, 17 (56.7%) were rated as excellent (score 9) (Aghakeshizadeh et al., 2021; Alborno-Cabello et al., 2024; da Silva Boitrigo et al., 2021; Esculier et al., 2018; Ferber et al., 2015; Fukuda et al., 2012; Fukuda et al., 2010; Hansen et al., 2023; Hong et al., 2023; Ismail et al., 2013; Rabelo et al., 2017; Raju et al., 2024; Saad et al., 2018; Sheikhi et al., 2024; Silva et al., 2023; Song et al., 2009; Wu et al., 2022), and 13 (43.3%) as good (scores between 6 and 8) (Almeida et al., 2021; Balci et al., 2009; Baldon, Piva, Scattone Silva, & Serrao, 2015; Celik et al., 2020; Foroughi et al., 2019; Herrington & Al-Sherhi, 2007; Kamel et al., 2024; Khayambashi et al., 2012; Kisacik et al., 2021; Pompeo et al., 2022; Sahin et al., 2016; Shadloo et al., 2021; Yip & Ng, 2006), with no study rated as poor. Most studies showed consistency in random allocation, baseline comparability, and between-group comparisons. Still, they failed to meet criteria for blinding of therapists and participants, which is common in exercise-based interventions (Table 6).

Table 6. Description of quality assessment with PEDro scale.

N	Reference	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Total	Rating
1	Hansen R et al., 2023	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
2	Kamel AM et al., 2024	1	1	1	1	0	0	0	1	1	1	1	8	Good
3	Kısacık P et al., 2021	1	1	1	1	0	0	0	1	0	1	1	7	Good
4	Şahin M et al., 2016	1	1	1	1	0	0	1	1	0	1	1	8	Good
5	Saad MC et al., 2018	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
6	Baldon RM et al., 2014	1	1	1	1	0	0	0	1	1	1	1	8	Good
7	Shadloo N et al., 2021	1	1	0	1	0	0	1	1	1	1	1	8	Good
8	Wu Z et al., 2021	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
9	Silva NC et al., 2023	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
10	Sheikhi B et al., 2024	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
11	Foroughi F et al., 2019	1	1	0	1	0	0	0	1	0	1	1	6	Good
12	Rabelo ND et al., 2017	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
13	da Silva Boitrage MV et al., 2021	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
14	Aghakeshizadeh F et al., 2021	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
15	Almeida GPL et al., 2021	1	1	1	1	0	0	0	1	1	1	1	8	Good
16	Balci P et al., 2009	1	1	0	1	0	0	0	1	0	1	1	6	Good
17	Herrington L et al., 2007	1	1	1	1	0	0	1	1	0	1	1	8	Good
18	Celik D et al., 2020	1	1	0	1	0	0	1	1	1	1	1	8	Good
19	Hong QM et al., 2023	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
20	Song CY et al., 2009	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
21	Khayambashi K et al., 2012	1	0	0	1	0	0	0	1	1	1	1	6	Good
22	Pompeo KD et al., 2022	1	1	0	1	0	0	1	1	1	1	1	8	Good
23	Esculier JF et al., 2018	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
24	Albornoz-Cabello M et al., 2024	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
25	Yip SLM et al., 2006	1	1	0	1	0	0	0	1	0	1	1	6	Good
26	Raju A et al., 2024	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
27	Ferber R et al., 2015	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
28	Ismail MM et al., 2013	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
29	Fukuda TY et al., 2012	1	1	1	1	0	0	1	1	1	1	1	9	Excellent
30	Fukuda TY et al., 2010	1	1	1	1	0	0	1	1	1	1	1	9	Excellent

Legend: I - eligibility criteria specified, II - random allocation, III - concealed allocation, IV - similar groups at baseline, V - blinding of participants, VI - blinding of therapists, VII - blinding of evaluators, VIII - outcome measures obtained in more than 85% of participants, IX - treatment received as allocated, X - statistical comparison between groups, XI - point measures and measures of variability.

Table 7. Summary of intervention protocols and main outcomes of included RCTs on resistance exercise for patellofemoral pain.

Study (country)	Volume	Intensity	Intervention (Activity Type, Duration, Weekly Frequency)	Control Group	Main Results
Hansen et al., 2023 (Denmark)	12 weeks 3 x per week 3 sets x 8–12 reps Rest interval: 1,5 - 2 min ~30 min/session Progression when 14 reps are achieved	8-12 RM	Home Based Exercise Structure per session: Warm-up was performing 20 reps of specific exercise (QE or HE) + 30 min of Hip or quadriceps exercises Equipment: elastic bands, free weights, and body weight Quadriceps-focused exercise (QE): seated knee extension, squat, forward lunge Hip-focused exercise (HE): clam shell, hip abduction, hip extension	N/A (Equivalence Study)	Both groups improved on the AKPS score at week 12: - QE group: +7.6 points (95% CI: 5.8 to 9.5) p<0.0001 - HE groups: +7.0 points (95% CI: 5.2 to 8.9) p<0.0001 No difference between groups
Kamel et al., 2024 (Egypt)	Short Foot Exercise (SFE) + Hip and Knee-focused Program 6 weeks 2 x per week 3 sets x 15 reps/day Hip-focused exercise (HE) + Knee-focused exercise (QE) 6 weeks 3 sets x 10–20 reps Rest interval: 30 s Progression: Reps is increased from 3 sets x 10 reps to a maximum of 3 sets x 20 reps.	10-20 RM	Short Foot Exercise (SFE) + Hip and Knee-focused Program Equipment: Weight cuffs and resistance tubing from 3 possible variants. In order of increasing resistance: red (medium), green (heavy), black (special heavy) - Short Foot Exercise (SFE) - Hip-focused exercise (HE): side-lying hip abduction, hip external rotation (clamshell), and prone hip extension - Knee-focused exercise (QE): supine straight leg raises, supine terminal knee extensions (from 10° flexion to full extension), and a mini-squat (45° flexion)	Hip and Knee-focused Program Frequency: 2 x per week - Hip-focused exercise (HE): side-lying hip abduction, hip external rotation (clamshell), and prone hip extension - Knee-focused exercise (QE): supine straight leg raises, supine terminal knee extensions (from 10° flexion to full extension), and a mini-squat (45° flexion)	- Pain (VAS): Intervention group: $\bar{} 5.1$ cm (95% CI: 4.3 to 5.9) Control group: $\bar{} 2.9$ cm (95% CI: 2.3 to 3.7) Between-group $\neq$: 2.6 cm (95% CI: 1.8 to 3.4), p < 0.001 - Function (AKPS): Intervention group: 17 points (95% CI: 14.3 to 19.6) Control group: 11.6 points (95% CI: 8.7 to 11.1) Between-group $\neq$: 4 points (95% CI: -7.1 to -1), p = 0.010
Kısacık et al., 2021 (Turkey)	6 weeks 2 x per week 1 set x 10 reps/exercise Progression: SFE is performed from sitting to bipedal, to unipedal-with minimal support and to unipedal-without support	Not specified	Structure per session: 5-min warm-up → 20 min of lower extremity stretching and strengthening exercises → 5-min cool-down Short Foot Exercise (SFE): SFE is described as targeting isolated contraction of the plantar intrinsic muscles + Conventional hip and knee strengthening + stretching exercises	Conventional hip and knee strengthening + stretching exercises	- Pain – Walking (VAS): Intervention group (SFEG): ↓ 2.13 cm (95% CI: 1.34 to 2.92) Control group (ConG): ↓ 0.66 cm (95% CI: -0.49 to 1.82) Between-group $\neq$: 1.60 cm (95% CI: -0.50 to 3.70), p = 0.131 (NS) - Sitting pain: Intervention group: ↓ 2.60 cm (95% CI: 1.47 to 3.72) Control group: ↓ 1.13 cm (95% CI: -0.95 to 1.21) Between-group $\neq$: 2.46 cm (95% CI: 0.97 to 3.95), p = 0.02 - Stair-up pain: Intervention group: ↓ 3.60 cm (95% CI: 2.31 to 4.88) Control group: ↓ 1.16 cm (95% CI: -0.06 to

			2.39) Between-group $\neq$: 2.43 cm (95% CI: 0.73 to 4.13), $p = 0.007$ - Stair-down pain: Intervention group: $\downarrow$ 2.26 cm (95% CI: 1.14 to 3.37) Control group: $\downarrow$ 1.03 cm (95% CI: -0.28 to 2.35) Between-group $\neq$: 1.56 cm (95% CI: -0.006 to 3.13), $p = 0.05$ - Squatting pain: Intervention group: $\downarrow$ 3.33 cm (95% CI: 1.86 to 4.80) Control group: $\downarrow$ 1.00 cm (95% CI: -0.30 to 2.30) Between-group $\neq$: 2.00 cm (95% CI: 0.08 to 3.91), $p = 0.041$ - Nocturnal pain: Intervention group: $\downarrow$ 2.26 cm (95% CI: 1.08 to 3.45) Control group: $\downarrow$ 0.50 cm (95% CI: -1.41 to 1.41) Between-group $\neq$: 2.26 cm (95% CI: 0.28 to 4.25), $p = 0.027$ - Function (Kujala Patellofemoral Score): Intervention group: $\uparrow$ 15.67 points (95% CI: 17.07 to -4.25) Control group: $\uparrow$ 8.73 points (95% CI: 13.23 to -4.25) Between-group $\neq$: 1.93 points (95% CI: -5.55 to 9.41), $p = 0.601$ (NS)
Sahin et al., 2016 (Turkey) 12 weeks 5 x per week Stretches: 3 sets x 10 sec hold x exercise (2$\times$/day) Strengthening: initially 5, 10 or 20 repetitions depending on the exercise (2$\times$/day) + isometric contraction for 3,5 - 10s-30 min/session Progression: +5 reps weekly Not specified	Hip-and-Knee Exercise Group (Intervention Group)- Equipment: green TheraBand latex exercise bands - Structure per session: 5-min warm-up $\rightarrow$ 20-min strengthening/stretching $\rightarrow$ 5-min cool-down - Stretches 3 repetitions, 10 sec hold (2$\times$/day): Supine hamstring stretch, standing quadriceps stretch, Iliotibial band stretch, Gastrocnemius stretch - Knee-focused Exercises (2$\times$/day): Isometric quadriceps contraction (start with 20 reps, add 5 weekly; 10 sec hold); Straight leg raise (10 reps; 3.5 sec hold); Mini squat (10 reps; 30°-45° flexion; 10 sec hold); Knee extension with resistance (start with 5 reps, add 5 weekly; 3.5 sec hold) - Hip-focused Exercises (2$\times$/day): Hip	Knee only Exercise Group (Intervention Group) - Frequency: 5 times/week - Structure per session: 5-min warm-up $\rightarrow$ 20-min strengthening/stretching $\rightarrow$ 5-min cool-down - Stretches 3 repetitions, 10 sec hold (2$\times$/day): Supine hamstring stretch, standing quadriceps stretch, Iliotibial band stretch, Gastrocnemius stretch - Knee-focused (2$\times$/day): Isometric quadriceps contraction (start with 20 reps, add 5 weekly; 10 sec hold); Straight leg raise (10 reps; 3.5 sec hold); Minisquat (10 reps; 30°-45° flexion; 10 sec hold); Knee extension with resistance (start with	- Pain (VAS): Intervention group (Hip+Knee): $\downarrow$ 2.8 points (from 5.4 to 2.6) Control group (Knee-only): $\downarrow$ 1.2 points (from 5.4 to 4.2) Between-group $\neq$: $\downarrow$ 1.6 points, $p < 0.017$ - Function (Kujala Score): Intervention group (Hip+Knee): $\uparrow$ 11.6 points (from 71.4 to 83.0; SD = 6.8) Control group (Knee-only): $\uparrow$ 5.6 points (from 72.4 to 77.9; SD = 6.6) Between-group $\neq$: $\uparrow$ 6.0 points, $p = 0.002$ - Function (3-Limb Hop Test – distance in cm): Intervention group (Hip+Knee): $\uparrow$ 12.6 cm (from 79.5 to 92.1) Control group (Knee-only): $\uparrow$ 5.2 cm (from 80.0 to 85.2) Between-group $\neq$: $\uparrow$ 7.4 cm, $p = 0.005$ - Function (One-Leg Squat Test – repetitions in

			abduction: Standing, 5 reps to 30°–35° with resistance, add 5 reps weekly (3.5 sec hold); Hip external rotation: Seated, 30° external rotation with towel between thighs, start with 5 reps, add 5 weekly (3.5 sec hold)	5 reps, add 5 weekly; 3.5 sec hold)	30 seconds): Intervention group (Hip+Knee): ↑ 5.0 repetitions (from 12 to 17.0) Control group (Knee-only): ↑ 4.0 repetitions (from 11 to 15.0) Between-group $\neq$: 1.0 repetition, $p = 0.027$ - Function (Step-Down Test – number of repetitions): Intervention group (Hip+Knee): ↑ 6.0 repetitions (from 10 to 16.0) Control group (Knee-only): ↑ 5.0 repetitions (from 9 to 14.0) Between-group $\neq$: 1.0 repetition, $p = 0.012$
Saad et al., 2018 (Brazil)	Strengthening Groups 8 weeks 2 x per week 3 set x 10 reps Isometric contraction for 10s ~50 min/session Stretching Group 8 weeks. 2 times/week 3 set x 30 seconds Progression: Based on RPE scale	Based on RPE scale Load: ankle weights	Quadriceps Strengthening Group (QG): -Structure per session: Bike warm-up – 15 minutes; Straight Leg Raise (ankle weights); Seated Knee Extension (open kinetic chain, 90°–60° of flexion), Leg Press (closed kinetic chain, 0°–45° of knee flexion); Wall Slide Squat – 3 sets of 1 minute each. Hip Strengthening Group (HG): - Structure per session: Bike warm-up – 15 minutes; Side-Lying Straight Leg Raise; Supine Bridge on Ball and Lateral Bridge + 10-second isometric hold on the last repetition; Seated Hip Abduction; Strengthening of Extensors, Abductors, and External Rotators – Performed in four-point support position (hands and knee, with ankle weights). Stretching Group (SG) - stretching protocol targeted muscles involved in hip and knee stabilization: - Structure per session: Quadriceps, Hamstrings, Gastrocnemius/Soleus, Hip Flexors, Hip External Rotators, IT Band, Adductors, and Abdominals.	Control Group (CG): - No intervention (Only underwent baseline and post-intervention assessments) - Received rehabilitation guidance after the study ended.	- Pain (VAS): Hip group (HG): ↓ 4.5 points (from 5.05 to 0.55) Quadriceps group (QG): ↓ 5.8 points (from 6.34 to 0.56) Stretching group (SG): ↓ 3.9 points (from 4.08 to 0.14) Control group (CG): ↓ 0.8 points (from 4.03 to 3.19) Between-group $\neq$: HG vs CG: 3.14 points ($p < 0.01$); QG vs CG: 3.02 points ($p < 0.01$); SG vs CG: 3.55 points ($p < 0.01$). No statistically significant difference between HG, QG, and SG. - Function (Kujala Anterior Knee Pain Scale): Hip group (HG): ↑ 14.3 points (from 77.4 to 91.8) Quadriceps group (QG): ↑ 13.2 points (from 76.9 to 90.1) Stretching group (SG): ↑ 11.2 points (from 79.8 to 91.0) Control group (CG): ↑ 6.1 points (from 80.8 to 87.0) Between-group $\neq$: HG vs CG: 4.8 points ($p = 0.04$); QG vs CG: 3.1 points ($p = 0.01$); SG vs CG: 4.0 points ($p < 0.01$). There is no statistically significant difference between HG, QG, and SG.
Baldon et al., 2014 (Brazil)	8 weeks 3 x per week 3 set x 10 reps Isometric contraction for 10s~90 - 120 min/session (FST group); ~75 - 90 min/session (ST group) Progression: Based on RM at week 3 and 6 and when patients could complete the exercise without knee pain, excessive fatigue, or lingering muscle soreness after 48 hours	50 - 75% 1RM, pain ≤ 3/10 Ankle Weights: 20% 1RM	FST Group: Program focused on motor control, endurance, and strength. Weeks 1 to 2: Initial Core & Hip Control (Motor Control Focus). Weeks 3 to 5: Strengthening + Motor Control Integration Weeks 6 to 8: Functional Emphasis & Increased Difficulty	ST group: Stretching (quads, hamstrings, calves, ITB; 3×30s). Strength: straight leg raises, knee extension, leg press, wall squat, step-up/down, single-leg stance	- Pain (VAS): FST group: ↓ 5.2 cm (from 6.6 to 1.4), $p < 0.05$ ST group: ↓ 3.0 cm (from 6.1 to 3.1), $p < 0.05$ Between-group $\neq$: FST vs ST: 2.2 cm (95% CI: -3.7 to -0.7; $p = 0.06$) - Function (LEFS): FST group: ↑ 18.9 points (from 55.4 to 74.3), $p < 0.05$ ST group: ↑ 12.9 points (from 57.6 to 70.6), $p < 0.05$ Between-group $\neq$: FST vs ST: 5.9 points (95%

Shadloo et al., 2021 (Iran)	WBVT group (Whole-Body Vibration Training) 4 weeks 3 x per week 10 min/session (5 × 1-min bouts Rest Interval: 1 min Control Group 3 sets x 30s (phase 1); 3 sets x 10s (phase 2) ~30 min/session	Parameters: 30 Hz, 3 mm peak-to-peak displacement	WBVT group (Whole-Body Vibration Training) Modality: Vibration platform (Fitvib excel pro) Exercise: barefoot, slight hip/knee flexion, arms at sides	Control Group Phase 1 (Weeks 1–2): Patellar mobilization; Self-stretching (hamstrings, gastroc-soleus, iliotibial band); 3 sets x 30s ; Quadriceps setting: 3 sets x 30s; Straight leg raise: 3 sets x 30s Phase 2 (Weeks 3–4): Mini-squats (30° flexion): 3 sets x 10s; Side step-up/down: 3 sets x 10s; Single-leg stance (eyes open/closed); Tilt board (eyes open/closed).	CI: -1.6 to 13.4; NS) - Global Rating of Change (GRC) FST group: 100% (14/14) ≥ moderately better ST group: 75% (12/16) ≥ moderately better Between-group #: 25% favoring FST (p = 0.04) - Pain (VAS): WBVT group: ↓ 5.53 points (from 7.53 ± 2.13 to 2.00 ± 1.66), p < 0.001 CT group: ↓ 5.53 points (from 7.53 ± 1.45 to 2.00 ± 1.54), p < 0.001 Between-group #: No significant difference (p = 0.896) - Function (Kujala Patellofemoral Score): WBVT group: ↑ 25.6 points (from 62.46 ± 8.25 to 88.06 ± 3.12), p < 0.001 CT group: ↑ 24.13 points (from 64.53 ± 7.49 to 88.66 ± 3.01), p < 0.001 Between-group #: No significant difference (p = 0.463) - Performance (Number of Leg Press repetitions): WBVT group: ↑ 6.8 reps (from 10.8 ± 1.01 to 17.6 ± 1.8), p < 0.001 CT group: ↑ 6.2 reps (from 11.07 ± 0.88 to 17.26 ± 1.53), p < 0.001 Between-group #: No significant difference (p = 0.796)
Wu et al., 2021 (China)	WHK group (Whole-Body Vibration Training + Hip-Knee Strengthening Program) 6 weeks 3 x per week 6 sets x 40 - 60 sec Rest interval: 1 min 40 min/session Progression: Weekly increasing contraction time by 5 s and amplitude level by 1 HK group (hip-knee strengthening only) 6 weeks 3 x per week 6 sets x 10 reps per exercise Rest interval: 1 min 40 min/session Progression: Weekly reassessment of 10RM or 1RM with pain ≤ 3 (VAS)	Conventional Exercises: 10 RM and 60% 1RM Execution velocity: 4 s/rep Whole Body Vibration: Frequency = 26 Hz; Amplitude level = 2 - 4	WHK Group (Whole-Body Vibration + Hip-Knee Strengthening Program) Structure per session: 5-min warm-up → 15 minutes of hip-knee strengthening + 15 minutes of WBV → 5 min of static stretching Equipment: TheraBand, sandbags, Galileo Med L vibration platform Conventional Exercises: Knee extension (prone, 90°–135°); Hip abduction–external rotation (supine, 0°–45°); Knee extension (sitting, 90°–135°); Hip abduction–external rotation (side-lying, 0°–45°); Straight leg raise (supine and side-lying, 0°–45°) using sandbags at 60% 1RM. WBV: Position: Knee and hip flexed to 90°, painful leg on platform + Isometric contraction: Hip abduction–external rotation against TheraBand at 10RM intensity	HK group (hip-knee strengthening only) Equipment: TheraBand, sandbags Conventional Exercises: Knee extension (prone, 90°–135°); Hip abduction–external rotation (supine, 0°–45°); Knee extension (sitting, 90°–135°); Hip abduction–external rotation (side-lying, 0°–45°); Straight leg raise (supine and side-lying, 0°–45°) using sandbags at 60% 1RM.	- Pain (VAS): WHK group: ↓ 14.3 points (from 45.3 to 31.0), p < 0.01 HK group: ↓ 8.2 points (from 46.4 to 38.2), p < 0.01 Between-group #: 7.2 points, p = 0.014 - Function (AKPS): WHK group: ↑ 5.8 points (from 76.0 to 81.8), p < 0.01 HK group: ↑ 4.2 points (from 76.0 to 80.1), p < 0.01 Between-group #: 1.8 points, p = 0.334 (NS) - Physical Component Summary (SF-36): WHK group: ↑ 2.0 points (from 45.4 to 47.4), p < 0.01 HK group: ↑ 1.8 points (from 44.6 to 46.3), p < 0.01 Between-group #: 0.2 points, p = 0.619 (NS) - Mental Component Summary (SF-36): WHK group: ↑ 1.8 points (from 39.4 to 41.2), p < 0.01 HK group: ↑ 0.1 points (from 39.5 to 39.6), p <

Silva et al., 2023 (Brazil)	Strengthening group - SG 12 weeks 2 x per week 3 sets x 10 reps per exercise Rest interval: 1 - 2 min 80 min/session – Neuromuscular training group – NMTG 60 min/session Progression: Weekly increase of 5–10% from week 3, if full ROM with VAS 0–1 and proper execution. Elastic band exercises followed pre-defined weekly progression.	70% 1 RM	Structure per session: 10-min warm-up →50 min of strengthening exercises Equipment: elastic bands; Balance discs; trampoline Exercises: Strengthening exercises that focused on the core, lateral rotator, abductor, hip extensor, and quadriceps muscles	Structure per session: 10-min warm-up →70 min of strengthening exercises Equipment: elastic bands; Balance discs; trampoline Exercises: Strengthening exercises that focused on the core, lateral rotator, abductor, hip extensor, and quadriceps muscles + neuromuscular exercises on stable and unstable surfaces	0.01 Between-group ≠: 1.7 points, p = 0.877 (NS) - Pain (VAS): Strengthening group (SG): ↓ 2.2 points (from 2.4 to 0.2), p < 0.001 Neuromuscular training group (NMTG): ↓ 1.7 points (from 1.9 to 0.2), p < 0.001 Between-group ≠: 0.0 points, p = 0.300 (NS) - Function (AKPS): Strengthening group (SG): ↑ 16.5 points (from 62.3 to 78.8), p < 0.001 Neuromuscular training group (NMTG): ↑ 16.7 points (from 65.2 to 81.9), p < 0.001 Between-group ≠: 3.1 points, p = 0.090 (NS) - Function (ADLS): Strengthening group (SG): ↑ 15.3 points (from 41.1 to 56.4), p < 0.001 Neuromuscular training group (NMTG): ↑ 16.9 points (from 43.7 to 60.6), p < 0.001 Between-group ≠: 4.1 points, p = 0.100 (NS)
	- Pain (VAS): Experimental: ↓ 2.99 (from 6.10 to 3.11), p < 0.001 Control: ↓ 1.76 (from 5.70 to 3.94), p < 0.001 Between-group ≠: -0.51 (95% CI [-0.899 to -0.131]), p = 0.011 - Function (KOS-ADL): Experimental: ↑ 11.46 (from 64.90 to 76.35), p < 0.001 Control: ↑ 9.20 (from 66.57 to 75.77), p < 0.001 Between-group ≠: -1.75 (95% CI [-7.10 to 3.04]), p = 0.471 (NS) - Pain Catastrophizing (PCS): Experimental: ↓ 7.14 (from 20.10 to 12.96), p < 0.001 Control: ↓ 4.93 (from 18.80 to 13.87), p < 0.001 Between-group ≠: -2.32 (95% CI [-4.59 to -0.028]), p = 0.047 - Kinesiophobia (TSK): Experimental: ↓ 10.56 (from 42.47 to 31.91), p < 0.001 Control: ↓ 3.65 (from 39.93 to 36.27), p < 0.001 Between-group ≠: -3.46 (95% CI [-6.46 to -0.46]), p = 0.024				
Sheikhi et al., 2024 (Iran)	8 weeks 3 x per weekIsometric Exercises: 3 sets x 10 to 20 s hold Dynamic Exercises: 3 sets x 10 reps Rest interval: 30 - 60 s60 min/session Progression increased based on participants' capacity: Increased hold time (10–20s); Stronger resistance bands (progressed from green to dark blue, purple, and red); Added external weights; Progressed to weight-bearing tasks; Used mirrors for alignment feedback.	Not specified	Education Intervention Three one-on-one sessions (30–45 minutes each)Patients in the experimental group received three supervised pre-intervention educational sessionsThemes: Understanding PFP, Pain management strategies, Activity modification, Addressing psychosocial factors and Patient-specific Q&A Exercise Intervention (Trunk and hip exercises) Equipment: Mirrors, possibly mats or weights for progression Weeks 1–2: Focus on motor control of trunk and hip muscles Weeks 3–5: Emphasis on strengthening and continued motor control Weeks 6–8: Load progression with more difficult, weight-bearing exercises	Exercise Intervention (Trunk and hip exercises) Equipment: Mirrors, possibly mats or weights for progression Weeks 1–2: Focus on motor control of trunk and hip muscles Weeks 3–5: Emphasis on strengthening and continued motor control. Weeks 6–8: Load progression with more difficult, weight-bearing exercises	
Foroughi et al., 2019 (Iran)	Strengthening 4 weeks 3 x per week 3 - 5 sets x 10 reps 30 - 45 min/session	Isometric and isotonic exercises focused on muscle	Equipment: mat and stable surface, inflatable hemispheres (50 cm, 30 cm, 22 cm) for progressive instability. Exercises: Stretching (Hamstring, iliotibial band, triceps surae); Knee Exercises (Quadriceps	Equipment: mat and stable surface Exercises: Stretching (Hamstring, iliotibial band, triceps surae); Knee Exercises (Quadriceps setting, Terminal knee extension, Seated	- Pain (NRS): Experimental group: ↓ 4.2 points (from 6.2 to 2.0), p < 0.001 Control group: ↓ 2.7 points (from 6.3 to 3.6), p < 0.001

	Progression: Week 2: Increased volume (from 3 to 4 sets of 10 repetitions); Week 3: Added external load (ankle weights at 3% of body weight) and introduced resistance bands; Week 4: Increased load to 5% of body weight and volume to 5 sets of 10 repetitions. Core postural control (Add to Strengthening) 4 weeks. 3 sets x 5 min hold Progression: Week 1: Balance on 50 cm hemisphere (most stable); Weeks 2–3: Progressed to 30 cm hemisphere + added arm movements; Week 4: Most advanced level using 22 cm hemisphere + eyes closed in final 3 minutes.	activation and control (no external load progression specified). Increased instability using smaller hemispheres (50 cm → 30 cm → 22 cm)	setting, Terminal knee extension, Seated knee extension, Straight leg raises); Hip Exercises (Side-lying hip abduction, Side-lying clamshell, Seated hip external rotation); Core postural control training (15 minutes total, 3 sets of 5 minutes, 2-minute rest between sets).	knee extension, Straight leg raises); Hip Exercises (Side-lying hip abduction, Side-lying clamshell, Seated hip external rotation).	Between-group ≠: 1.6 points, $p < 0.001$ - Postural Control (CoP Total Velocity): Experimental group: ↓ 17.7 mm/s (from 67.8 to 50.1), $p < 0.001$ Control group: ↓ 6.7 mm/s (from 49.9 to 43.2), $p < 0.05$ Between-group ≠: 11.0 mm/s, $p = 0.02$ - Function (AKPS): Experimental group: ↑ 12.2 points (from 76.2 to 88.4), $p < 0.001$ Control group: ↑ 6.7 points (from 75.3 to 81.9), $p < 0.001$ Between-group ≠: 5.5 points, $p = 0.002$
Rabelo et al., 2017 (Brazil)	Strengthening Group (SG) 4 weeks 3 x per week 3 sets x 10 reps 40 - 60 min/session Progression: Progressive load; new exercises added in weeks 2–4 Movement control and Strengthening Group (MC&S) 4 weeks 3 x 10–15 reps or 3 x 20–40 s 40 - 60 min/session Progression: Progressive load; proprioceptive training and control tasks added weekly	70% 1RM or max resistance for 10 - 15 reps	Equipment: Ankle weights, elastic bands, machines Exercises: Side-lying hip abduction, Side-lying clam exercise, Seated knee extension (90° to 45°), Squatting (0° to 45°), Lateral band walks, Forward lunge, Pelvic drop in standing.	Equipment: Elastic bands, mirrors, unstable surfaces Exercises: Squatting (0° to 45°) with elastic band around the knee, Single-leg stance with extended knee, Lateral band walks, Single-leg stance with 30° knee flexion, Forward lunge with elastic band, Single-leg squat (0° to 30°)	- Pain (NPRS): SG: ↓ 4.4 points (from 6.6 ± 1.0 to 2.2 ± 1.6), 95% CI [3.4, 5.3], $p < 0.001$ MC&S group: ↓ 4.0 points (from 6.1 ± 1.4 to 2.0 ± 1.7), 95% CI [3.1, 4.9], $p < 0.001$ Between-group ≠: 0.3 points, 95% CI [-1.7, 1.0], $p > 0.05$ (NS) - Function (AKPS): SG: ↑ 16.2 points (from 67.5 ± 11.3 to 83.7 ± 8.3), 95% CI [9.5, 22.7], $p < 0.001$ MC&S group: ↑ 18.7 points (from 67.1 ± 7.6 to 85.8 ± 9.2), 95% CI [12.8, 24.6], $p < 0.001$ Between-group ≠: 2.5 points, 95% CI [-10.7, 5.5], $p > 0.05$ (NS)
Da Silva Boitrigo et al., 2021 (Brazil)	6 weeks 3 x per week 3 sets x 15 reps Rest interval: 30 s 60 min/session Progression: Progressed every 2 weeks (e.g., deeper squats, increased band resistance)	70% 1RM	Structure per session: 10-min warm-up → 40-min strengthening & neuromuscular exercises → 10-min proprioceptive exercises Equipment: Elastic bands, machines (leg press, extension), mats, unstable surfaces Exercises: Hip abduction, hip rotation with abduction, knee extension (machine & leg press), squat, lateral gait, eccentric hip adduction, bridges (double & single-leg), plank, one-leg balance on stable & unstable surfaces	Guidance Group (GG): Educational, cognitive and behavioural guidance on health; single session (60 min). Themes: One 60-minute face-to-face session with education on PFPS, healthy habits, chronic pain management, and biopsychosocial factors.	- Pain (NPRS): Exercise group: ↓ 5.0 points (from 6.7 to 1.9), 95% CI not reported, $p < 0.001$ Guidance group: ↓ 0.6 points (from 6.67 to 6.07), 95% CI not reported, $p = ns$ Between-group ≠: 4.1 points, $p < 0.001$ - Function (AKPS): Exercise group: ↑ 18.2 points (from 67.6 to 85.8), 95% CI not reported, $p < 0.001$ Guidance group: ↑ 0.3 points (from 71.6 to 71.83), 95% CI not reported, $p = ns$ Between-group ≠: 14.0 points, $p < 0.001$ - Function (ADLS): Exercise group: ↑ 23.8 points (from 59.2 to 83.0),

Aghakeshizadeh et al., 2021 (Iran)	6 weeks 3 x per week Sets and reps (not specified) ~40 min/session Progression: Sets and reps adjusted every 2 weeks	Not specified	Structure per session: 35-min strengthening exercises → 5-min cool-down Equipment: Ankle weights, therabands, 20-cm step Exercises: Standing isometric hip abduction and lateral rotation; prone hip extension and lateral rotation; sidelying hip abduction and lateral rotation; single-leg deadlift; single-leg squat; forward lunge; sidelying hip abduction, lateral rotation and extension; step-up and step-down on 20 cm step; wall squat (0–60° knee flexion); resisted side stepping; seated hip internal rotation. EF group (External Feedback): Received external feedback during exercises: manual cues and used therabands to correct faulty movement patterns IF group (Internal Feedback): Received internal feedback through verbal cues to avoid compensations	Without exercise program	95% CI not reported, $p < 0.001$ Guidance group: ↓ 0.3 points (from 62.3 to 62.0), 95% CI not reported, $p = ns$ Between-group $\neq$: 21.0 points, $p < 0.001$ - Pain (VAS): Control group: ↓ 2.3 points (from 6.5 to 4.2), 95% CI [0.31, 1.03], $p = 0.03$ IF group: ↓ 4.3 points (from 7.0 to 2.7), 95% CI [0.23, 1.14], $p = 0.02$ EF group: ↓ 5.5 points (from 7.6 to 2.1), 95% CI [0.2, 1.4], $p = 0.01$ Between-group $\neq$: EF vs Control = 3.2 points, $p = 0.02$; IF vs Control = 1.5 points, $p = 0.03$; EF vs IF: 72.4% vs 61.4%, $p > 0.05$ (NS) - Function (Kujala Score): Control group: ↑ 5.8 points (from 68.4 to 74.2), 95% CI [−0.78, −0.21], $p = 0.04$ IF group: ↑ 9.3 points (from 70.6 to 80.0), 95% CI [−0.98, −0.23], $p = 0.03$ EF group: ↑ 20.1 points (from 65.4 to 85.6), 95% CI [−1.19, −0.36], $p = 0.01$ Between-group $\neq$: EF vs Control = 14.3 points, $p = 0.03$; IF vs Control: 13.3% vs 8.5%, $p > 0.05$ (NS); EF vs IF: 30.9% vs 13.3%, $p > 0.05$ (NS)
Almeida et al., 2021 (Brazil)	6 weeks 2 x per week 3 Sets x 8–12 reps Rest Interval: 30 s; 2 min between different exercises ~60 min/session Progression: Load increased 2–10% per session if patients performed ≥ 14 reps or rated $< 60\%$ RPE	RPE 60–80%	Posterolateral Hip Group (PLHG) Structure per session: 5-min warm-up → 55-min stretching and strengthening exercises. Equipment: Stationary bikes, ankle weight cuffs (1–15 kg), elastic bands, flex rings, stretchers, and chairs. Exercises: Seated knee extension; Squatting; Hip abduction in side-lying; Clam with elastic resistance; Hip external rotation with elastic resistance	Anteromedial Hip Group (AMHG) Structure per session: 5-min warm-up → 55-min stretching and strengthening exercises Equipment: Stationary bikes, ankle weight cuffs (1–15 kg), elastic bands, flex rings, stretchers, and chairs. Exercises: Seated knee extension; Squatting; Hip adduction in side-lying; Flex ring squeeze in side-lying; Hip internal rotation with elastic resistance	- Pain (VAS): PLHG: ↓ 4.15 points (from 5.27 to 1.15), 95% CI [−5.20 to −3.10], $p < 0.001$ AMHG: ↓ 4.46 points (from 5.04 to 0.57), 95% CI [−5.51 to −3.41], $p < 0.001$ Between-group $\neq$: 0.53 points, 95% CI [−0.55 to 1.63], $p = 0.33$ (NS) - Function (AKPS): PLHG: ↑ 10.61 points (from 68.5 to 79.1), 95% CI [7.22 to 14.0], $p < 0.001$ AMHG: ↑ 13.5 points (from 65.96 to 79.46), 95% CI [10.11 to 16.89], $p < 0.001$ Between-group $\neq$: −0.34 points, 95% CI [−5.68 to 4.99], $p = 0.89$ (NS)
Balci et al., 2009 (Turkey)	4 weeks 5 x per week (3 x per day) 3 Sets x 10 reps Progression: Increase by 10–12% of 1RM every 5 days	20–25% 1RM	Group I: Hip internal rotation + squat on MFSS Equipment: Bodyweight Exercises: Concentric and eccentric strengthening + proprioception, Knee flexion: 0–45°, Hip rotation at 45° internal + home exercises: Straight leg raises (supine), Hip adductor strengthening (side-lying), Multiple-angle isometric (sitting)	Group II: Hip external rotation + squat on MFSS Equipment: Bodyweight Exercises: Concentric and eccentric strengthening + proprioception, Knee flexion: 0–45°, Hip rotation at 45° external + home exercises: Straight leg raises (supine), Hip adductor strengthening (side-lying), Multiple-angle isometric (sitting)	- Pain (at rest): Group I: ↓ 1.3 points (from 1.9 ± 2.4 to 0.6 ± 1.4), $p < 0.001$ Group II: ↓ 2.0 points (from 2.8 ± 2.5 to 0.8 ± 1.4), $p < 0.001$ Between-group $\neq$: 0.2 points, $p > 0.43$ (NS) - Pain (during activity): Group I: ↓ 2.0 points (from 6.2 ± 1.9 to 4.2 ± 2.1), $p < 0.001$ Group II: ↓ 2.7 points (from 7.2 ± 2.3 to 4.5 ± 1.6), $p < 0.001$

Herrington et al., 2007 (Saudi Arabia)	6 weeks 3 x per week 4 Sets x 6-10 reps Rest Interval: 2 min Progression: The next session's load was based on the reps completed in the previous 4th set. 50%, 75% and 100% 6 RM	Structure per session: 5-min warm-up → 4 sets of exercises Equipment: Stationary bikes, knee extension equipment (SJNWBE) or leg press (MJWBE) Exercises: Only knee extension (SJNWBE) or leg press (MJWBE)	Without exercise program	Between-group #: 0.5 points, $p > 0.27$ (NS) - Function (Kujala Score): Group I: ↑ 12.4 points (from 60.5 ± 14.6 to 72.9 ± 7.2), $p < 0.001$ Group II: ↑ 10.3 points (from 56.4 ± 18.9 to 66.7 ± 11.4), $p < 0.001$ Between-group #: 6.2 points, $p > 0.100$ (NS) - Function – Modified Kujala Score SJNWBE group: ↑ ~25 points (from ~70 to ~95), $p = 0.03$ MJWBE group: ↑ ~22 points (from ~72 to ~94), $p = 0.01$ Control group: ↓ ~7 points (from ~67 to ~60), $p = 0.03$ Between-group #: SJNWBE and MJWBE > Control, $p < 0.001$; SJNWBE vs MJWBE: No significant difference, $p > 0.05$ (NS)- - Pain During Step-Up and Step-Down (VAS) SJNWBE group: ↓ ~2.5 points (from ~5.0 to ~2.5), $p < 0.001$ MJWBE group: ↓ ~2.5 points (from ~5.0 to ~2.5), $p < 0.001$ Control group: ↑ ~0.5 point (from ~5.0 to ~5.5), $p > 0.05$ (NS) Between-group #: SJNWBE and MJWBE < Control; SJNWBE vs Control: $p = 0.004$; MJWBE vs Control: $p < 0.001$; SJNWBE vs MJWBE: No difference, $p > 0.05$ (NS)
Celik et al., 2020 (Turkey)	6 weeks 3 x per week 3 Sets x 10 reps 45 - 60 min/session Progression: not specified Not specified	Structure per session: 5-min warm-up → 40 min strengthening exercises Equipment: a soft ball (for mini-squat), mat (for floor exercises), cold pack (applied post-session), portable two-channel neuromuscular electrical stimulation (NMES) device (50 Hz frequency, biphasic symmetrical pulses up to 400 μ s, 10s ON / 20s OFF) Neuromuscular electrical stimulation (NMES): 20 min/session; Device: Portable 2-channel NMES, 50 Hz, 400 μ s, 10s on / 20s off, 1s ramp up/down; Electrodes: 5×10cm; placed over vastus medialis (distal) and vastus lateralis (proximal) Exercises with NMES: Isometric quadriceps contractions (30 reps); Terminal knee extension (0–30°, 30 reps); Instruction: Voluntary co-contraction during NMES. Exercises: Isometric quadriceps strengthening, terminal knee extension, straight leg raise with 10° of hip external rotation, mini-squat at 30°	Structure per session: 5-min warm-up → 40 min strengthening exercises Equipment: a soft ball (for mini-squat), mat (for floor exercises), cold pack (applied post-session). Exercises: Isometric quadriceps strengthening, terminal knee extension, straight leg raise with 10° of hip external rotation, mini-squat at 30° using a softball, hip abduction, side-lying clam exercise, hamstring and calf stretching, and patellar mobilisation with lateral-to-medial glides.	- Function: Kujala Score (0–100): Group I: ↑ 12.6 points (from 60.4 ± 14.8 to 73.0 ± 14.3), p-intragroup not reported Group II: ↑ 14.1 points (from 60.9 ± 15.2 to 75.0 ± 8.1), p-intragroup not reported Between-group #: Not statistically significant, $p = 0.97$ (NS) - Function: Lysholm Score: Group I: ↑ 18.1 points (from 56.1 ± 16.4 to 74.2 ± 16.6), p-intragroup not reported Group II: ↑ 4.9 points (from 55.3 ± 15.7 to 60.1 ± 14.2), p-intragroup not reported Between-group #: Not statistically significant, $p = 0.73$ (NS)

			using a softball, hip abduction, side-lying clam exercise, hamstring and calf stretching, and patellar mobilisation with lateral-to-medial glides.	
Hong et al., 2023 (China)	6 weeks 3 x per week 3 Sets x 15 reps ~40 - 60 min/session Progression: Load and reps adjusted every 2 weeks by physiotherapist	OMNI scale to maintain RPE 6–7	Structure per session: 10-min warm-up → ~40 min strengthening exercises Equipment: Elastic bands, weights, cushion, wall, possibly mat Education: 3 biweekly health education sessions. Themes: Concepts of patellofemoral pain, joint protection, risk management in daily life Exercises: 9 exercises including stretching, core, hip, and quadriceps strengthening	Education: 1 session every 2 weeks (biweekly); Health education only (no exercises) Themes: Concepts of patellofemoral pain, joint protection, risk management in daily life - Pain (VAS – Worst Pain): Intervention group: ↓ 21.1 mm (from 50.5 to 29.4), $p < 0.01$ Control group: ↓ 1.8 mm (from 49.6 to 47.8), $p = 0.02$ Between-group $\neq$: 19.3 mm (95% CI: 23.2 to 15.5), $p < 0.01$ - Pain (VAS – ADL): Intervention group: ↓ 25.3 mm (from 49.0 to 23.7), $p < 0.01$ Control group: ↓ 2.4 mm (from 46.0 to 43.6), $p = 0.19$ (NS) Between-group $\neq$: 22.9 mm (95% CI: 28.3 to 17.4), $p < 0.01$ - Function (AKPS): Intervention group: ↑ 10.8 points (from 74.2 to 85.1), $p < 0.01$ Control group: ↑ 1.8 points (from 74.2 to 76.0), $p = 0.25$ (NS) Between-group $\neq$: 9.0 points (95% CI: 4.1 to 13.9), $p < 0.01$
Song et al., 2009 (China)	8 weeks 3 x per week 5 Sets x 10 reps Rest interval: 2 min Progression: Load and reps adjusted every 2 weeks	60% 1RM	Structure per session: 15-min hot pack on the quadriceps before exercises (warm-up) → strengthening exercises → Static stretching for quadriceps, hamstrings, iliotibial band, and calf (3×30 sec each) Equipment: EN-Dynamic Track machine, blue Thera-Band, digital metronome Exercises: One-legged leg press with 45° of flexion and full extension	No exercise intervention (only educational material about patellofemoral pain) - Pain (VAS-Worst) LPHA group: ↓ 2.18 points (from 4.80 to 2.62), 95% CI –3.17 to –1.19, $p < 0.005$ LP group: ↓ 2.58 points (from 4.85 to 2.26), 95% CI –3.56 to –1.61, $p < 0.005$ Control group: ↓ 0.18 points (from 4.99 to 4.81), 95% CI –1.16 to 0.80, $p = 0.715$ (NS) Between-group $\neq$: LPHA vs Control: –2.19 points, 95% CI –3.44 to –0.93, $p = 0.001$; LP vs Control: –2.54 points, 95% CI –3.79 to –1.30, $p < 0.005$; LPHA vs LP: 0.35 points, 95% CI –0.90 to 1.61, $p = 0.577$ (NS) Function (Lysholm Score) LPHA group: ↑ 10.93 points (from 74.8 to 85.7), 95% CI 7.27 to 14.59, $p < 0.005$ LP group: ↑ 10.73 points (from 75.7 to 86.5), 95% CI 7.13 to 14.33, $p < 0.005$ Control group: ↑ 0.67 points (from 75.1 to 75.7), 95% CI –2.93 to 4.27, $p = 0.714$ (NS) Between-group $\neq$: LPHA vs Control: 9.99 points, 95% CI 4.81 to 15.17, $p < 0.005$; LP vs Control: 10.73 points, 95% CI 6.50 to 15.87, $p < 0.005$; LPHA vs LP: –0.74 points, 95% CI –5.92 to 4.44,

Khayambashi et al., 2012 (Iran)	8 weeks 3 x per week 3 Sets x 20-25 reps 30 min/session Progression: Load and reps adjusted every 2 weeks (Therabands colour)	Theraband colour (red, medium; green, heavy; blue, extra heavy; black, special heavy)	Structure per session: 5-min Warm-up → 20-min main part (hip-strengthening exercises) → 5 min cool-down Equipment: Thera-Band (red, medium; green, heavy; blue, extra heavy; black, special heavy) Exercises: Bilateral hip abduction and external rotation strengthening using elastic tubing (Thera-Band)	Control group was instructed to take 1000 mg of Omega-3 and 400 mg of calcium daily for 8 weeks	p = 0.776 (NS) - Pain (VAS) Exercise group: ↓ 6.4 points (from 7.9 to 1.4), 95% CI: -7.9 to -4.9, p < 0.001 Control group: ↑ 0.1 points (from 6.6 to 6.7), 95% CI: -0.9 to 1.1, p > 0.05 (NS) Between-group $\neq$: 6.5 points, 95% CI: -8.5 to -4.5, p < 0.001 - Function (WOMAC, 0-96): Exercise group: ↓ 43.3 points (from 54.0 to 10.7), 95% CI: -54.9 to -31.7, p < 0.001 Control group: ↑ 4.1 points (from 55.9 to 59.9), 95% CI: -1.9 to 10.0, p > 0.05 (NS) Between-group $\neq$: 47.4 points, 95% CI: -62.6 to -32.2, p < 0.001
Pompeo et al., 2022 (Brazil)	12 weeks 2 x per week 1 - 4 Sets x 10-15 reps Rest interval: 1 min ~60 - 90 min/session Progression: Progression by microcycle, based on max rep tests on 1st and 13th sessions	Progressive: %MR (60-100%), overloading 5-10% of body mass at specific sessions	Structure per session: 5-min Warm-up → 55 - 85-min main part: Strengthening exercises (core/hip and lower limb) + Stretching (quadriceps/hamstring) Equipment: leg curl and press machines, elastic bands, floor mats. Exercises: seated leg curl, leg press, lateral step-up, walking lunge, single limb squat, quadriceps stretching, hamstring stretching, resisted sidestep with elastic band, front plank, bilateral side plank, clam exercise with elastic band, isometric hip abduction at 10° with elastic band, hip extension with elastic band.	Structure per session: 5-min Warm-up → 55 - 85-min main part: Strengthening exercises (lower limb and foot/ankle) + Stretching (quadriceps/hamstring) Equipment: leg curl and press machines, elastic bands, floor mats, balance surfaces. Exercises: seated leg curl, leg press, lateral step-up, walking lunge, single limb squat, quadriceps stretching, hamstring stretching, foot inversion with elastic band, short foot exercise, plantar flexors eccentric exercise with elastic band, toe curl, dorsiflexion with elastic band, soleus stretching.	- Pain (NPRS): Standard Rehabilitation Group (SRG): ↓ 2.84 points (from 5.40 to 2.56), p < 0.001 Distal Addition Group (DEG): ↓ 2.08 points (from 4.80 to 2.72), p < 0.001 Between-group $\neq$: 0.16 points, p > 0.05 (NS) - Function (AKPS): Standard Rehabilitation Group (SRG): ↑ 9.60 points (from 68.12 to 77.72), p < 0.001 Distal Addition Group (DEG): ↑ 6.36 points (from 72.32 to 78.68), p < 0.001 Between-group $\neq$: 0.96 points, p > 0.05 (NS)
Esculier et al., 2018 (Canada)	8 weeks 3 x per week (exercises) + daily (1 control exercise) 2 sets x 10 - 15 reps ~20 min/session Progression: every 2 weeks - increased reps, hold time, resistance, unilateral tasks	Not specified	Exercise Group (EG): Focus on strengthening hip/core/lower limb, proprioception and control Equipment: Elastic bands, step platform, floor mat Exercises: Progressive strengthening and motor control exercises targeting hip, core, and lower limb—e.g., side-lying hip abduction, bridges, squats, step-downs, resisted side steps, planks—performed 3x/week plus daily step-down control Gait Retraining Group (GRG): Gait retraining + load management education Equipment: Treadmill Exercises: Running	No exercise intervention (only educational intervention)	- Function: KOS-ADLS Exercises group: ↑ 18.8 points (from ~71.6 to ~90.4), 95% CI [12.2 to 25.5], p < 0.001 Gait retraining group: ↑ 14.7 points (from ~70.5 to ~85.2), 95% CI [8.1 to 21.4], p < 0.001 Education group: ↑ 18.1 points (from ~71.3 to ~89.4), 95% CI [11.5 to 24.8], p < 0.001 Between-group $\neq$: Exercises vs Education = 0.7 points, 95% CI [-6.0 to 7.4], p > 0.05 (NS); Gait retraining vs Education = -3.4 points, 95% CI [-10.4 to 3.5], p > 0.05 (NS); Exercises vs Gait retraining = 4.1 points, 95% CI [-3.1 to 11.3], p > 0.05 (NS) - Usual Pain (VAS-U) Exercises group: ↓ 2.2 points (from ~3.5 to ~1.3), 95% CI [-3.3 to -1.1], p < 0.001 Gait retraining group: ↓ 1.5 points (from ~3.2 to ~1.7), 95% CI [-2.7 to -0.9], p < 0.001

Albornoz-Cabello et al., 2024 (Spain)	3 weeks 5 x per week (1st week); 3 x per week (2nd week); 2 x per week (3rd week) 3 sets x 20 reps Rest interval: 1 min ~20 min/session Progression: without progression	Not specified	Structure session: radiofrequency diathermy + strengthening exercises Equipment: ABD Modular® (Biotronic Advance Develops®, Spain), Mattresses and basic materials Exercises: Hamstring bridge, Quadriceps squat, Gluteus medius clam, Gastrocnemius and soleus stretch	Structure session: just strengthening exercises Equipment: Mattresses and basic materials Exercises: Hamstring bridge, Quadriceps squat, Gluteus medius clam, Gastrocnemius and soleus stretch	~1.7), 95% CI [-2.5 to -0.4], $p < 0.001$ Education group: ↓ 1.6 points (from ~3.0 to ~1.4), 95% CI [-2.7 to -0.6], $p < 0.001$ Between-group #: Exercises vs Education = -0.6 points, 95% CI [-1.7 to 0.5], $p > 0.05$ (NS); Gait retraining vs Education = 0.2 points, 95% CI [-0.9 to 1.3], $p > 0.05$ (NS); Exercises vs Gait retraining = -0.7 points, 95% CI [-1.7 to 0.3], $p > 0.05$ (NS) - Worst Pain (VAS-W) Exercises group: ↓ 3.8 points (from ~7.0 to ~3.2), 95% CI [-5.3 to -2.4], $p < 0.001$ Gait retraining group: ↓ 3.0 points (from ~6.6 to ~3.6), 95% CI [-4.4 to -1.6], $p < 0.001$ Education group: ↓ 3.4 points (from ~6.5 to ~3.1), 95% CI [-4.9 to -2.0], $p < 0.001$ Between-group #: Exercises vs Education = -0.4 points, 95% CI [-1.8 to 1.0], $p > 0.05$ (NS); Gait retraining vs Education = 0.4 points, 95% CI [-1.2 to 2.0], $p > 0.05$ (NS); Exercises vs Gait retraining = -0.8 points, 95% CI [-2.2 to 0.6], $p > 0.05$ (NS) - Running Pain (VAS-R) Exercises group: ↓ 4.1 points (from ~6.5 to ~2.4), 95% CI [-5.4 to -2.9], $p < 0.001$ Gait retraining group: ↓ 3.3 points (from ~6.2 to ~2.9), 95% CI [-4.6 to -2.1], $p < 0.001$ Education group: ↓ 2.9 points (from ~6.1 to ~3.2), 95% CI [-4.2 to -1.7], $p < 0.001$ Between-group #: Exercises vs Education = -1.2 points, 95% CI [-2.4 to 0.1], $p > 0.05$ (NS); Gait retraining vs Education = -0.4 points, 95% CI [-1.7 to 1.0], $p > 0.05$ (NS); Exercises vs Gait retraining = -0.8 points, 95% CI [-2.1 to 0.4], $p > 0.05$ (NS) - Pain (VAS): Experimental group: ↓ 48.4 mm (from 55.2 to 6.7), 95% CI: 41.9–54.9; $p < 0.001$ Control group: ↓ 14.2 mm (from 61.1 to 46.9), 95% CI: 11.5–16.5; $p < 0.001$ Between-group #: 40.2 mm, 95% CI: 35.4–46.0; $p < 0.001$ - Function (Kujala Score): Experimental group: ↑ 19 points (from 55 to 74), 95% CI: 14–23; $p < 0.001$ Control group: ↑ 4 points (from 53 to 57), 95% CI: 3–5; $p < 0.001$ Between-group #: 17 points, 95% CI: 11–23; $p < 0.001$ - Function (LEFS): Experimental group: ↑ 17 points (from 57 to 74), 95% CI: 13–20; $p < 0.001$
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					Control group: ↑ 5 points (from 51 to 56), 95% CI: 4–7; $p < 0.001$ Between-group $\neq$: 18 points, 95% CI: 11–23; $p < 0.001$
Yip et al., 2006 (China)	8 weeks 7 x per week 3 sets x 10 reps ~20 min/session Progression: Weekly phone monitoring by physiotherapist; tailored advice based on patient functional level and needs	Not specified	Structure session: 5-min of flexibility Warm-up → 15-min strengthening exercises + EMG biofeedback during strengthening exercises Equipment: not specified Exercises: strengthening exercises for the quadriceps with emphasis on vastus medialis obliquus recruitment, balance and proprioception training and plyometric and agility training	Structure session: 5-min of flexibility Warm-up → 15-min strengthening exercises Equipment: not specified Exercises: strengthening exercises for the quadriceps with emphasis on vastus medialis obliquus recruitment, balance and proprioception training and plyometric and agility training	- Pain (Patellofemoral Pain Severity Scale): Biofeedback + Exercise group: ↓ 6.7% (from 41.9 ± 18.6 to 35.2 ± 22.7), $p = 0.088$ (NS) Exercise-only group: ↓ 9.8% (from 39.9 ± 19.6 to 29.9 ± 21.2), $p = 0.896$ (NS) Between-group $\neq$: 5.3%, $p = 0.896$ (NS)
Raju et al., 2024 (India)	4 weeks 3 x per week 3 Sets x 10 reps Rest interval: 30 s ~20 min/session Progression: Not specified	Not specified	Experimental Group 1 (Hip Strengthening + CPT) Equipment: Elastic bands Exercises: Side-lying hip abduction, Clamshell (hip abduction + rotation, Seated hip external rotation Experimental Group 2 (Proprioceptive Training + CPT) Equipment: body weight Exercises: One-leg stance (stable/unstable, eyes open/closed, arm movement), Ball throw while balancing, Stair climbing	Conventional physical therapy (Interferential Therapy + Knee Strengthening)	- Function (AKPS): Experimental Group 1 (hip strengthening + CPT): ↑ 51.2 points (from 41.7 ± 15.28 to 92.87 ± 4.82), 95% CI not reported, $p < 0.001$, $d = 4.275$ Experimental Group 2 (proprioceptive training + CPT): ↑ 38.8 points (from 39.3 ± 17.00 to 78.13 ± 10.00), 95% CI not reported, $p < 0.001$, $d = 4.680$ Control Group (CPT only): ↑ 8.3 points (from 40.1 ± 16.68 to 48.3 ± 15.25), 95% CI not reported, $p < 0.001$, $d = 2.352$ Between-group $\neq$: EG1 vs CG: 44.5 points, $p < 0.001$; EG2 vs CG: 29.8 points, $p < 0.001$; EG1 vs EG2: 14.7 points, $p = 0.002$
Ferber et al., 2015 (Canda and United States)	6 weeks 6 x per week 3 Sets x 10 - 15 reps ~45-60 min/session Progression: From unsupported to body-loaded, with a focus on core and balance; weekly adjustments by AT	TeraBand: Last 3 reps should be challenging while maintaining good form	Hip + Core Group (HIP) Equipment: TeraBand, mat, AirEx pad (unstable surfaces), steps Exercises: Standing hip abduction, standing and seated hip external rotation, standing hip internal rotation, hip extension at 45°, balancing on 2 feet and 1 foot using Airex® pad.	Knee Group (Knee) Equipment: TeraBand, mat, wall, steps Exercises: Isometric quadriceps setting, standing knee extensions, double- and single-legged squats (one-quarter, one-half, wall squats), terminal knee extensions with TeraBand®, forward quarter lunges, lateral and forward step-downs, and full lunges/squats up to 90° knee flexion.	- Pain (VAS): Experimental group (Hip): ↓ 3.11 cm (from 5.12 ± 1.66 to 1.96 ± 1.92), 95% CI [2.69, 3.52], $p < 0.001$ Control group (Knee): ↓ 2.98 cm (from 4.96 ± 1.66 to 1.99 ± 2.05), 95% CI [2.50, 3.36], $p < 0.001$ Between-group $\neq$: 0.13 cm, $p = 0.66$ (NS) - Function (AKPS): Experimental group (Hip): ↑ 12.58 points (from 75.00 ± 9.74 to 87.95 ± 11.26), 95% CI [9.79, 15.38], $p < 0.001$ Control group (Knee): ↑ 12.90 points (from 75.62 ± 9.81 to 87.67 ± 10.53), 95% CI [9.75, 16.05], $p < 0.001$ Between-group $\neq$: 0.32 points, $p = 0.90$ (NS)
Ismail et al., 2013 (Egypt)	6 weeks 3 x per week 2 Sets x 10 reps Rest interval: 1 min Progression: weekly based on 10 RM	60% 10 RM	CKK group Equipment: wall, ball, Wooden box or step, Therabands Exercises: mini wall squat exercise, forward step up, lateral step up, and terminal knee	CKCH group (CG) Equipment: ankle cuff weights Exercises: resistive exercise for hip abductors and external rotators.	- Pain (VAS): CKK group: ↓ 2.26 points (from 4.5 ± 1.8 to 2.3 ± 1.1), $p = 0.01$ CKCH group: ↓ 3.2 points (from 5.3 ± 1.6 to 2.0 ± 1.1), $p = 0.001$

		extension			Between-group $\neq$: 0.94 points, $p = 0.03$ - Function (Kujala Score): CKC group: $\uparrow$ 8.7 points (from 76.4 ± 10.4 to 85.1 ± 12.6), $p = 0.01$ CKCH group: $\uparrow$ 13.75 points (from 71.5 ± 7.8 to 85.1 ± 12.6), $p = 0.001$ Between-group $\neq$: 5.05 points, $p = 0.04$
Fukuda et al., 2012 (Brazil)	4 weeks 3 x per week 3 Sets x 10 reps Progression: load adjusted weekly according to individual assessment	70% 1RM	KE group Equipment: ankle weights, resistance bands, knee extension machines, bench/support surfaces, leg press Exercises: Stretching (hamstrings, plantar flexors, quadriceps, iliotibial band; 3×30s), seated knee extension (90°–45°), leg press (0°–45°), squats (0°–45°), single-leg calf raises, prone knee flexion	KHE group Equipment: ankle weights, resistance bands, knee extension machines, bench/support surfaces Exercises: Stretching (hamstrings, plantar flexors, quadriceps, iliotibial band; 3×30s), seated knee extension (90°–45°), leg press (0°–45°), squats (0°–45°), single-leg calf raises, prone knee flexion, hip abduction with weight (sidelying), hip abduction with elastic band (standing), hip external rotation with elastic band (sitting), hip extension on machine	- Pain (NPRS – ascending stairs): KHE group: $\downarrow$ 3.2 points (from 6.2 ± 1.1 to 3.0 ± 1.1), 95% CI $[-3.9, -2.5]$, $p < 0.001$ KE group: $\downarrow$ 1.1 points (from 6.6 ± 1.2 to 5.5 ± 1.2), 95% CI $[-1.6, -0.6]$, $p = 0.001$ Between-group $\neq$: 2.1 points, 95% CI $[1.3, 2.9]$, $p < 0.05$ - Pain (NPRS – descending stairs): KHE group: $\downarrow$ 3.3 points (from 5.8 ± 1.2 to 2.5 ± 1.0), 95% CI $[-3.7, -2.9]$, $p < 0.001$ KE group: $\downarrow$ 0.8 points (from 6.4 ± 1.4 to 5.6 ± 1.4), 95% CI $[-1.2, -0.4]$, $p = 0.01$ Between-group $\neq$: 2.5 points, 95% CI $[1.7, 3.3]$, $p < 0.05$ - Function (AKPS): KHE group: $\uparrow$ 15.8 points (from 65.9 ± 8.5 to 81.7 ± 8.6), 95% CI $[8.3, 16.4]$, $p < 0.001$ KE group: $\uparrow$ 6.2 points (from 61.8 ± 9.0 to 68.0 ± 9.3), 95% CI $[0.2, 12.2]$, $p = 0.043$ Between-group $\neq$: 9.6 points, 95% CI $[2.1, 17.2]$, $p < 0.05$ - Function (LEFS): KHE group: $\uparrow$ 20.7 points (from 51.7 ± 10.4 to 72.4 ± 6.1), 95% CI $[11.0, 30.5]$, $p < 0.001$ KE group: $\downarrow$ 1.3 points (from 49.0 ± 13.0 to 47.7 ± 10.5), 95% CI $[-3.4, 0.8]$, $p = 0.211$ Between-group $\neq$: 22.0 points, 95% CI $[7.1, 26.9]$, $p < 0.05$
Fukuda et al., 2010 (Brazil)	4 weeks 3 x per week3 Sets x 10 reps Progression: load adjusted weekly according to individual assessment	70% 1RM	KE group Equipment: ankle weights, resistance bands, knee extension machines, bench/support surfaces, leg press Exercises: Stretching (hamstrings, plantar flexors, quadriceps, iliotibial band; 3×30s), seated knee extension (90°–45°), leg press (0°–45°), squats (0°–45°), single-leg calf raises, prone knee flexion KHE group Equipment: ankle weights, resistance bands, knee extension machines, bench/support surfaces, leg press Exercises: Stretching (hamstrings, plantar	No exercise intervention	- Pain (NPRS – ascending stairs): KHE group: $\downarrow$ 2.2 points (from 5.2 to 3.0), 95% CI $[-3.1, -1.3]$, $p < 0.001$ KE group: $\downarrow$ 1.5 points (from 4.9 to 3.4), 95% CI $[-2.2, -0.8]$, $p > 0.05$ (NS) CO group: $\uparrow$ 0.1 points (from 4.9 to 5.0), 95% CI $[-1.0, 0.3]$, $p > 0.05$ Between-group $\neq$: KHE vs CO: 2.3 points, $p < 0.05$; KE vs CO: 1.6 points, $p < 0.05$; KHE vs KE: 0.7 points, $p > 0.05$ (NS) - Pain (NPRS – descending stairs): KHE group: $\downarrow$ 2.6 points (from 4.9 to 2.3), 95% CI $[-3.5, -1.7]$, $p < 0.001$ KE group: $\downarrow$ 1.5 points (from 4.5 to 2.9), 95% CI

flexors, quadriceps, iliotibial band; 3 × 30s), seated knee extension (90°–45°), leg press (0°–45°), squats (0°–45°), single-leg calf raises, prone knee flexion, Standing hip abduction against resistance band, Sidelying hip abduction with weight, Sitting hip external rotation with resistance band, Side-stepping with elastic band.

[-1.9, -1.1], $p > 0.05$ (NS)

CO group: ↑ 0.1 points (from 4.1 to 4.2), 95% CI [-0.9, 0.3], $p > 0.05$ (NS)

Between-group #: KHE vs CO: 2.3 points, $p < 0.01$; KE vs CO: 0.7 points, $p > 0.05$ (NS); KHE vs KE: 1.6 points, $p < 0.05$

- Function (AKPS):

KHE group: ↑ 15.0 points (from 63.9 to 78.9), 95% CI [9.8, 20.2], $p < 0.01$

KE group: ↑ 10.2 points (from 70.4 to 80.6), 95% CI [5.4, 15.0], $p < 0.05$

CO group: ↑ 0.7 points (from 63.8 to 64.5), 95% CI [-3.2, 4.6], $p > 0.05$ (NS)

Between-group #: KHE vs CO: 14.3 points, $p < 0.01$; KE vs CO: 9.5 points, $p < 0.05$; KHE vs KE: 4.8 points, $p > 0.05$ (NS)

- Function (LEFS):

KHE group: ↑ 16.6 points (from 49.1 to 65.7), 95% CI [9.4, 23.8], $p < 0.01$

KE group: ↑ 10.0 points (from 55.6 to 65.6), 95% CI [5.7, 12.7], $p < 0.05$

CO group: ↑ 2.4 points (from 48.8 to 51.2), 95% CI [-0.6, 5.4], $p > 0.05$

Between-group #: KHE vs CO: 14.2 points, $p < 0.05$; KE vs CO: 7.6 points, $p < 0.05$; KHE vs KE: 6.6 points, $p > 0.05$ (NS)

Note RM = repetition maximum; VAS = Visual Analog Scale; AKPS = Anterior Knee Pain Scale; LEFS = Lower Extremity Functional Scale; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; SFEG = Short Foot Exercise Group; GRC = Global Rating of Change, reps = repetitions; ST = standard training; FST = functional stabilization training; NS = not significant; ITB = iliotibial band stretching; PLHG = Posterolateral Hip Group; AMHG = Anteromedial Hip Group; SJNWBE = Non-weight bearing single-joint exercises; MJWBE = Weight-bearing multiple-joint quadriceps exercise; ADL = Activities of daily living; KHE = knee and hip exercises; CO = control; KE = knee exercises; CKC = closed kinetic chain exercise; CKCH = closed kinetic chain exercises with hip exercise.

Whenever sufficient data were available, standardised effect size estimates were calculated to facilitate comparison across studies. However, several trials did not report dispersion measures (e.g., standard deviations or confidence intervals), limiting the ability to compute effect sizes consistently across all studies. Therefore, clinical relevance was interpreted based on reported between-group differences, magnitude of change, and statistical significance.

The primary outcomes of interest were pain and functional performance, as predefined in the review protocol. Secondary outcomes included muscle strength, kinematic variables, and, when available, quality-of-life or psychosocial measures. These secondary outcomes were analysed descriptively due to variability in reporting across studies.

The following is a summary of the results, separated by category of resistance-training strategy, for the treatment of pain and function in individuals with PFP (Table 7).

Quadriceps or hip-focused strengthening for patellofemoral pain treatment

The intervention category focused on quadriceps or hip strengthening included eight studies with a total of 507 participants, of whom 361 (71.2%) were women, with a mean age ranging from 22.6 ± 1.5 to 29.1 ± 7.4 years, and comprising individuals aged between 18 and 45 years old (Aghakeshizadeh et al., 2021; Almeida et al., 2021; Balci et al., 2009; Hansen et al., 2023; Herrington & Al-Sherhi, 2007; Ismail et al., 2013; Khayambashi et al., 2012; Saad et al., 2018). Participants were diagnosed with patellofemoral pain, with symptom duration ranging from more than 3 months to 60 months. They were mostly physically active or recreational athletes, with only one study including sedentary individuals or those engaged solely in activities of daily living (Khayambashi et al., 2012). The average body mass ranged from 55.4 ± 3.5 kg to 68.8 ± 10.5 kg, height from 159.7 ± 4.5 cm to 172.8 ± 9.6 cm, and BMI from 21.8 ± 1.6 to 25.5 ± 4.6 kg/m².

Intervention programs lasted 4 to 12 weeks, with 2 to 5 sessions per week, most commonly 3. Protocols included 2 to 4 sets per exercise, with 8 to 15 repetitions, or 10-second isometric contractions, with progression based on performance (e.g., achieving ≥ 14 repetitions) or the Rating of Perceived Exertion (RPE) scale. Training intensity ranged from 20–80% of 1RM, using bodyweight, elastic bands, and free weights. The exercises included knee extensions, squats, leg presses, step-ups, clamshells, hip abduction, and external and internal rotation. All studies in this category reported significant improvements in pain outcomes (assessed by VAS or NRS) and function (measured by Kujala, AKPS, or WOMAC) after the intervention ($p < 0.05$). In the study by Saad et al. (2018), which compared groups undergoing isolated quadriceps and hip exercises, both interventions produced similarly positive outcomes, with no statistically significant difference between them. Similarly, Hansen, Brushoj, Rathleff, Magnusson, and Henriksen (2023), through an equivalence design, confirmed that both hip and knee strengthening interventions were equally effective in reducing pain and improving function, with no evidence of superiority for either approach.

Quadriceps plus hip-focused strengthening for patellofemoral pain treatment

The combined intervention category targeting both hip and knee musculature encompassed six randomised controlled trials, totalling 305 participants, of whom 259 were women (84.9%) (Fukuda et al., 2012; Fukuda et al., 2010; Kamel et al., 2024; Kisacik et al., 2021; Sahin et al., 2016; Song et al., 2009). Participants ranged from 18 to 55 years of age, with mean ages varying from 21.9 ± 2.2 to 41.6 ± 8.3 years. The duration of patellofemoral pain symptoms ranged from six to 35.9 months. Three studies included sedentary individuals (Fukuda et al., 2012; Fukuda et al., 2010; Sahin et al., 2016) while the remaining three did not report participants' physical activity levels. Mean body mass ranged from 57.9 ± 9.9 kg to

71.3 ± 13.1 kg, height from 159.5 ± 2.0 cm to 170.5 ± 11.9 cm, and BMI from 21.8 ± 1.6 to 25.9 ± 3.9 kg/m².

The interventions lasted from 4 to 12 weeks, with frequencies ranging from 2 to 5 sessions per week. Protocols involved 2 to 5 sets of 8 to 20 repetitions, with or without isometric holds (up to 10 seconds), and progression criteria based on one-repetition maximum (1RM), performance benchmarks, or rating of perceived exertion (RPE). Training intensity ranged from 20–80% of 1RM or included bodyweight, elastic bands, progressive resistance, unstable surfaces, or weight machines. The exercise selection combined leg press, squats, knee extension, step-ups, straight-leg raises, clam shells, and hip abduction and rotation, as well as targeted strategies such as the Short Foot Exercise (SFE) (Kamel et al., 2024; Kisacik et al., 2021).

All included studies reported significant improvements in pain outcomes (measured by VAS or NPRS) and functional scores (measured by Kujala, AKPS, LEFS, or Lysholm). Fukuda et al. (2012) demonstrated the superiority of combined knee and hip exercises in reducing pain during stair ascent and descent ($\Delta = -3.2$ and -3.3 points on the NPRS, respectively), along with significant functional gains of up to +20.7 points on the LEFS and +15.8 on the AKPS. Similarly, Şahin, Ayhan, Borman, and Atasoy (2016) found the combined approach more effective than knee-only interventions, reporting reductions in pain ($\Delta = -1.2$ to -1.6 on the VAS) and functional improvements up to +7 points on the Kujala Score. Song et al. (2009) reported that the addition of hip adduction to the leg press significantly reduced pain ($\Delta = -2.5$ to -3.1) and improved function ($\Delta = +9.39$ on the Lysholm score).

Two studies (Kamel et al., 2024; Kisacik et al., 2021) incorporated the Short Foot Exercise (SFE) alongside the primary interventions to activate intrinsic foot musculature and enhance the functional stability of the kinetic chain. Kamel, Ghuiba, Abd Allah, Fayaz, and Abdelkader (2024) combined SFE with hip and knee strengthening, leading to significant

reductions in pain (up to -5.1 points on the VAS) and improvements in function (up to $+17$ points on the AKPS), with statistically significant differences compared to the control group ($p < 0.001$). Kısacık et al. (2021) used SFE as an adjunct to conventional strengthening. They observed superior functional outcomes (Kujala score) and pain relief during activities such as sitting and stair climbing compared with the control group.

Multicomponent interventions

The total sample comprised 324 participants, of whom 305 were female (94.1%), across seven randomised clinical trials investigating interventions primarily based on strengthening exercises targeting the quadriceps, hip, and core muscles, with variations including motor control, proprioceptive exercises, progressive instability techniques, and combinations with educational or functional strategies. Participant ages ranged from 18 to 45 years, with mean ages between 22.0 ± 2.9 and 28.5 ± 6.3 years. Six studies included only women (Baldon et al., 2014; da Silva Boitrigo et al., 2021; Foroughi et al., 2019; Pompeo et al., 2022; Rabelo et al., 2017; Silva et al., 2023), while one study also included men (Raju et al., 2024). Participants were classified as physically active in three studies (Foroughi et al., 2019; Pompeo et al., 2022; Silva et al., 2023), while two studies did not specify physical activity levels (Rabelo et al., 2017; Raju et al., 2024); one included recreational athletes (Baldon et al., 2014) and another included sedentary individuals (da Silva Boitrigo et al., 2021). Mean body mass ranged from 57.3 ± 7.3 kg to 64.6 ± 14.5 kg, height from 160.5 ± 3.5 cm to 164.0 ± 6.5 cm, and BMI from 21.5 ± 2.3 kg/m² to 24.1 ± 4.1 kg/m². Patellofemoral pain duration ranged from more than 3 months up to 47.7 months.

Interventions lasted between four and 12 weeks, with two to three sessions per week. Exercise volume ranged from 1 to 5 sets of 10 to 15 repetitions, with rest intervals from 30 seconds to 2 minutes. Intensity ranged from 50% to 75% of 1RM, with weekly progressions

based on strength testing and pain control. Sessions lasting 20 to 90 minutes included a warm-up (5 to 10 minutes), strengthening exercises, and, in some cases, neuromuscular, proprioceptive, or educational components.

The included studies addressed different strengthening strategies for treating patellofemoral pain, with variations in the inclusion of strengthening exercises targeting the hip, knee, core, as well as motor control and proprioception. Among the studies focused on hip and core strengthening, Baldon, Serrao, Scattone Silva, and Silva (2014) reported significant reductions in pain (VAS: -5.2 points) and improved function (LEFS: +18.9 points), with a significant between-group difference ($p < 0.05$) favouring the intervention group (Global Rating of Change: 100% vs 75% in the control group). Silva et al. (2023) compared two intervention groups: one performing strengthening exercises and the other performing the same exercises on unstable surfaces. Both groups showed significant improvements in pain (VAS: -2.2 and -1.7), function (AKPS: +16.5 and +16.7), and activities of daily living (ADLS: +15.3 and +16.9), with no significant between-group differences. Rabelo et al. (2017) combined strength training with motor control exercises, reporting reductions in pain (NPRS: -4.4 and -4.0) and functional gains (AKPS: +18.2 and +18.7), also without significant between-group differences.

In studies focusing on hip and knee strengthening, da Silva Boitrigo et al. (2021) found significant improvements in pain (NPRS: -5.0), function (AKPS: +18.2), and ADLs (ADLS: +23.8), with significant differences ($p < 0.05$) favoring the exercise group compared to a control group that received only a 60-minute educational session (Guidance Group) covering PFPS, healthy habits, chronic pain management, and biopsychosocial factors. Pompeo et al. (2022) observed improvements in pain (NPRS: -2.84 and -2.08) and function (AKPS: +9.6 and +5.36), with no significant between-group differences; both groups performed hip and lower-limb strengthening, with the DEG group adding foot/ankle exercises.

In studies that combined strengthening with motor control or proprioception, Raju et al. (2024) reported functional improvements (AKPS: +15.2 and +13.8), with experimental groups (hip strengthening and proprioceptive training) showing superiority over the control group ($p < 0.001$). Finally, Foroughi, Sobhani, Yoosefinejad, and Motealleh (2019) reported improvements in pain (NPRS: -4.2), function (AKPS: +12.2), and postural control (reduced CoP velocity: -11.0 mm/s), with significant differences across all variables ($p < 0.05$).

Technology-assisted or adjunct interventions

The total sample comprised 236 participants, including 151 females (64.0%), distributed across five randomised controlled trials that assessed the use of assisted or adjunct technologies combined with exercise programs for the treatment of patellofemoral pain (Albornoz-Cabello et al., 2024; Celik et al., 2020; Shadloo et al., 2021; Wu et al., 2022; Yip & Ng, 2006). Participants ranged in age from 18 to 55 years, with mean ages ranging from 27.4 to 42.0 ± 4.2 years. One study included only women (Shadloo et al., 2021), while the others featured mixed-gender samples. Two studies reported participants' physical activity levels: one included athletes engaged in regular sports practice (minimum of 2 h/day, 3 times/week) (Shadloo et al., 2021), and the other used the IPAQ classification, ranging from low to high activity levels (Wu et al., 2022). Regarding anthropometric characteristics, body weight ranged from 69.6 ± 3.8 kg to 78.3 ± 14.8 kg, height from 164.2 ± 7.4 cm to 176.8 ± 4.1 cm, and BMI from 22.0 ± 3.9 to 28.2 ± 4.9 kg/m². Symptom duration exceeded 6 months in all studies.

The strategies involving assisted technologies varied among studies. Intervention duration ranged from 3 to 8 weeks, with training frequencies from 3 to 7 sessions per week. Technological modalities included whole-body vibration platforms (WBV) (Shadloo et al., 2021; Wu et al., 2022), neuromuscular electrical stimulation (NMES) (Celik et al., 2020),

radiofrequency diathermy (Albornoz-Cabello et al., 2024) and electromyographic biofeedback (EMG) (Yip & Ng, 2006). Technical parameters and intensities were clearly reported, such as vibration at 30 Hz with a 3 mm displacement or NMES at 50 Hz with a 400 μ s pulse width. Some interventions included progressive increases in load or time, particularly the WBV combined with progressive strengthening, while others maintained constant intensity. In all cases, the technological resources were integrated with therapeutic exercises targeting the lower limbs, focusing on strengthening, motor control, stretching, and proprioception.

In studies using assisted or adjunct technologies, Shadloo, Kamali, and Salehi Dehno (2021) compared WBVT with conventional exercises and found significant improvements in pain (VAS: -5.53) and function (Kujala: +25.6 and +24.1), with no significant between-group differences. Wu et al. (2022) reported greater pain reduction in the combined WBVT and strengthening group (WHK) compared to strengthening alone (VAS: -14.3 vs -8.2; $p = 0.014$), although no significant differences were observed in function (AKPS: +5.8 vs +4.0) or quality of life (SF-36; $p > 0.05$). Celik, Argut, Turker, and Kilicoglu (2020) found functional improvement in both groups treated with NMES and strengthening (Kujala: +12.6 and +14.1; Lysholm: +18.1 and +4.9), without significant differences. Albornoz-Cabello et al. (2024) reported superior results for the group receiving radiofrequency diathermy, with greater reductions in pain (VAS: -48.4 mm vs -14.2 mm), functional improvements (Kujala: +19 vs +4), and increased functional capacity (LEFS: +17 vs +5), all with statistical significance ($p < 0.001$). Lastly, Yip and Ng (2006) evaluated EMG biofeedback combined with quadriceps training and observed pain improvement in both groups (PFPS: -6.7 and -9.8), with no significant between-group differences.

Core/trunk-focused interventions

The total sample consisted of 366 participants, 217 of whom were female (59.3%), distributed across four randomised clinical trials that investigated interventions focused on trunk and core, with or without educational programs, in the treatment of patellofemoral pain (Esculier et al., 2018; Ferber et al., 2015; Hong et al., 2023; Sheikhi et al., 2024). The age range was 18-45 years, with mean ages of 29.7 ± 7.1 and 32.1 ± 6.3 years. Two studies specified the level of physical activity, with one including runners (Esculier et al., 2018) and another recreationally active participants (≥ 3 times/week for ≥ 30 minutes) (Ferber et al., 2015). Regarding morphological characteristics, body weight ranged from 67.5 ± 14.0 kg to 72.5 ± 10.7 kg; height from 169.8 ± 8.9 cm to 171.3 ± 8.5 cm; and BMI from 23.2 ± 4.2 to 24.7 ± 3.3 kg/m². The mean reported duration of pain symptoms was approximately 43.8 months.

Core/trunk-focused interventions included four studies lasting 6-8 weeks, with session frequencies ranging from 3 to 6 per week and average session durations of 20-60 minutes. Intensity was self-regulated using the OMNI scale (RPE 6–7) in one study (Hong et al., 2023), while the others did not explicitly report it. Sheikhi, Rabiei, Letafatkar, and Rossettin (2024) and Hong et al. (2023) integrated educational interventions with physical exercises. Sheikhi et al. (2024) delivered in-person educational sessions combined with a supervised progressive strengthening protocol for trunk and hip, including motor control, overload, and mirror use. Similarly, Hong et al. (2023) combined health education with a home-based strengthening program for core, hip, and quadriceps, with biweekly adjustments by physiotherapists. Esculier et al. (2018) and Ferber, Bolgla, Earl-Boehm, Emery, and Hamstra-Wright (2015) focused on comparisons between strengthening strategies, assessing the effects of education alone, core/lower limb strengthening, and load-controlled gait retraining (Esculier et al., 2018), or comparing hip/core exercises with knee exercises and stability tasks on unstable surfaces (Ferber et al., 2015).

The results reported among the core/trunk-focused interventions showed positive effects on pain and function outcomes, with variations in the impact on psychosocial measures. Sheikhi et al. (2024) observed significant reductions in pain (-2.99 cm, $p < 0.001$) and improvements in function ($+11.46$ points on the KOS-ADL, $p < 0.001$), with superiority in pain, pain catastrophizing, and kinesiophobia scores compared to the control group. Hong et al. (2023) also reported improvements in the experimental groups in pain (-21.1 mm to -25.3 mm) and function ($+10.8$ points on the AKPS), with statistically significant differences compared with the control groups. Esculier et al. (2018) reported similar gains across exercise, gait retraining, and education groups, with no statistically significant differences between approaches in pain or function, and Ferber et al. (2015) directly compared HIP and KNEE groups and found equivalent improvements in pain (-3.11 vs -2.98 cm) and function ($+12.58$ vs $+12.90$ on the AKPS), with no significant differences between groups.

DISCUSSION

This systematic review was conducted to synthesise evidence from randomised controlled trials on the effectiveness of resistance training in reducing pain and improving function in individuals with PFPS. To this end, 30 studies were analysed, encompassing a total of 1,733 participants with PFPS, with an overall mean age of 28.8 ± 5.5 years (range: 18-55), predominantly female participants ($n = 1,288$; 74.3%). Overall, most resistance-based interventions reported positive effects on pain and functional outcomes in the medium- and long-term. However, the magnitude of these effects varied across protocols and study designs.

The main findings of this systematic review, which aimed to synthesise the results of randomised clinical trials using resistance exercise to reduce patellofemoral pain, include four distinct categories of benefits observed following training. First, strengthening isolated structures, such as the hip or quadriceps muscles, was effective in reducing pain and

improving function, with no superiority demonstrated in studies comparing these interventions. Specifically, the study conducted by Hansen et al. (2023) aimed to confirm the equivalence of the two isolated interventions, and the findings indicated no superiority of either intervention, thus being equivalent. Second, combined interventions (hip plus quadriceps) tended to show more consistent improvements than isolated interventions or control conditions, although not all studies reported statistically significant superiority. Although multicomponent strategies incorporating postural control and neuromuscular exercises yielded similar results, some studies did not show superiority in improvements in pain and function compared with those without these strategies (Baldon et al., 2014; Foroughi et al., 2019; Rabelo et al., 2017; Silva et al., 2023). Third, the use of assistive technologies such as whole-body vibration platforms (WBV), neuromuscular electrical stimulation (NMES), and electromyographic biofeedback (EMG) also produced positive effects in interventions, without demonstrating superiority in reducing pain and improving functionality compared with groups that used only strengthening exercises. Only the study by Albornoz-Cabello et al. (2024), which used radiofrequency diathermy, showed superior results for pain and functional variables compared with strengthening alone. The fourth category identified core/trunk-centred interventions, whether isolated (Esculier et al., 2018; Ferber et al., 2015) or combined with educational components (Hong et al., 2023; Sheikhi et al., 2024), as effective in improving pain, function, and psychosocial factors in patellofemoral pain. When an educational approach was associated with exercise, the intervention was superior in these groups, whereas other approaches directed to the knee (Ferber et al., 2015) or multicomponent strategies (Esculier et al., 2018) did not show superiority.

The findings of a systematic review with meta-analysis, including 14 randomized clinical trials and 673 participants, which examined the effectiveness of hip strengthening, with or without knee strengthening, in reducing pain and improving activity in individuals with

patellofemoral pain, demonstrated that this strategy is superior to isolated knee strengthening for reducing pain (mean difference: -3.3 ; 95% CI: -5.6 to -1.1) and improving function (standardized mean difference: 1.4 ; 95% CI: 0.3 to 2.8), especially in activities that demand load. In addition, combined strengthening was also superior to isolated hip strengthening for reducing pain (mean difference: -1.5 ; 95% CI: -2.3 to -0.8) and improving function (standardised mean difference: 0.7 ; 95% CI: 0.2 to 1.3), with benefits maintained beyond the intervention period (Nascimento, Teixeira-Salmela, Souza, & Resende, 2018).

Another more recent systematic review and meta-analysis compared exercise programs for hip and knee, hip only, and knee only in individuals with patellofemoral pain (Manojlović, Kozinc, & Šarabon, 2021). The results indicated that combined programs (hip + knee) and programs focused solely on the hip were equally effective in reducing pain (mean difference = -1.71 ; 95% CI: -3.11 to -0.30 ; $p = 0.02$) and improving function (standardized mean difference = 1.28 ; 95% CI: 0.45 to 2.12 ; $p = 0.003$), both superior to programs focused only on the knee. However, the subgroup analysis did not identify significant differences between the combined protocols and those focused exclusively on the hip, suggesting similar effectiveness between these two approaches.

These findings are generally consistent with the results reported in the present review, in which interventions combining hip and knee exercises frequently demonstrated greater reductions in pain and functional improvements than protocols targeting a single muscle group. However, given the heterogeneity of study designs and comparator conditions, these conclusions should be interpreted cautiously. As observed by Manojlović, Kozinc, and Šarabon (2021), our data indicate that including hip strengthening enhances the clinical effects of training, possibly by improving lower-limb kinematic control and patellofemoral stability. However, unlike the previous review, our study incorporated a larger number of recent clinical trials, expanding the analysis to other complementary approaches, such as

assistive technologies, multicomponent exercises, and core/trunk-focused interventions, thereby providing a more comprehensive view of the available therapeutic strategies.

The effects of core training on pain and function in individuals with patellofemoral pain have also been increasingly explored in recent years. Wang et al. (2024) identified low-quality evidence supporting the effectiveness of core training for short-term pain reduction (standardised mean difference = -0.60 ; 95% CI: -0.95 to -0.25) and high-quality evidence for functional improvement (weighted mean difference = 3.61 ; 95% CI: 1.44 to 5.78). These findings are consistent with the results observed in the present review, in which trunk-focused (core) interventions demonstrated significant reductions in pain and functional gains (Esculier et al., 2018; Ferber et al., 2015; Hong et al., 2023; Sheikhi et al., 2023). Furthermore, both Wang et al. (2024) and the results summarised here suggest that combined core and lower-limb training (particularly of the hip and knee) tends to produce more significant effects than isolated core training. Such results suggest that combining trunk-focused strengthening with specific lower limb exercises may enhance clinical outcomes, although further high-quality trials are required to confirm this potential additive effect.

In addition to conventional strengthening exercises, two studies in this review used whole-body vibration (WBV) platforms, with different training volumes (10 min/session) (Shadloo et al., 2021) and 40 min/session (Wu et al., 2022). In both studies, no consistent superiority of WBV over traditional exercises was observed for most pain and functional outcomes, except in the study by Wu et al. (2022), which reported greater pain reduction. These findings align with a systematic review and meta-analysis that included five studies with 180 participants investigating the use of WBV in the treatment of patellofemoral pain (Abdelhamed, Fahmy, Shahien, & Elaraby, 2023). The results showed that WBV did not produce significant differences compared to conventional exercises in pain outcomes (SMD = -0.93 ; 95% CI: -1.97 to 0.12 ; $p = 0.083$), knee function (SMD = -0.93 ; 95% CI: -0.11 to 0.12 ; $p = 0.083$), or

the mental component of quality of life (SMD = 0.26; 95% CI: -0.21 to 0.73; $p = 0.280$), with only a significant improvement observed in the physical component of quality of life (SMD = 0.64; 95% CI: 0.16 to 1.12; $p = 0.009$). Although WBV may offer some positive effects on quality of life, as also observed in our review (Wu et al., 2022), it does not consistently demonstrate clinically meaningful superiority compared to conventional strengthening interventions, which, combined with its higher cost and the need for specific equipment, may limit its adoption in clinical practice.

Some interventions included in this review also employed feedback strategies, both verbal (with internal and external focus) (Aghakeshizadeh et al., 2021) and visual, using mirrors (Sheikhi et al., 2024) or electromyographic (EMG) activity (Yip and Mg, 2006), to optimise motor performance during exercises, including as a tool for progression. Such strategies, when combined with therapeutic exercises, may enhance functional gains (AKPS), increase quadriceps strength, and reduce dynamic knee misalignments, in addition to improving muscle activation measured by EMG. They may act as facilitators of motor learning and neuromuscular control, as demonstrated by Ferlito et al. (2024), thereby potentiating the effects of rehabilitation programs for PFP. Although the evidence remains limited and heterogeneous, biofeedback methodologies may be an interesting addition to therapeutic protocols, with feedback types compatible with clinical practice that are easy to use, accessible, and cost-effective, such as mirror or verbal feedback.

In addition to the biomechanical effects already discussed, resistance exercises promote relevant neurophysiological adaptations that support the control and modulation of patellofemoral pain. Resistance exercise reduces patellofemoral pain through multiple neurophysiological mechanisms, including enhanced neuromuscular coordination, improved motor control patterns, increased muscle activation (particularly of the vastus medialis), and pain modulation through central nervous system adaptations, though the specific neural

pathways remain incompletely understood (Alaffari et al., 2025). These processes act together to break the cycle of muscle atrophy and pain, contributing to improved function and symptom relief in individuals with patellofemoral pain (Nie, Hu, Xiang, & Wang, 2023).

In addition to biomechanical adaptations, resistance exercise has been associated with neurophysiological changes that may contribute to pain modulation. However, it is important to emphasise that the randomised controlled trials included in this review did not directly assess neurophysiological outcomes, such as corticospinal excitability, central sensitisation, or descending pain modulation. Therefore, the following considerations should be interpreted as theoretical contextualization rather than direct findings of this review.

Neurophysiological evidence suggests that individuals with PFPS may exhibit alterations in corticospinal excitability, including increased motor threshold and reduced H-reflex amplitude in the vastus medialis, which are correlated with pain, chronicity, and lower knee extensor torque (Ho et al., 2022). In this context, it is plausible that resistance training, whether or not combined with feedback strategies, may influence neuromuscular activation patterns and motor control. Mechanisms related to exercise-induced hypoalgesia and descending pain modulation described in the literature (Lima, Abner, & Sluka, 2017) provide a potential explanatory framework for such adaptations.

Complementing these findings, Nicolini, Fahnestock, Gibala, and Nelson (2021) highlight that physical exercise can induce neuroplastic adaptations in cortical and descending motor system pathways, including changes in cortical excitability and motor map organisation. Although these mechanisms were not directly measured in the included trials, they may contribute to understanding the sustained reductions in pain and functional improvements observed following strengthening interventions. Nonetheless, future clinical trials incorporating direct neurophysiological measures are necessary to clarify the extent to which these central adaptations occur in individuals with PFPS undergoing resistance training.

These pieces of evidence on the central effects of resistance training reinforce the understanding of the results observed in the present systematic review. When analysing interventions that employed strengthening exercises, whether isolated or combined, we identified consistent reductions in pain and improvements in function among individuals with patellofemoral pain. The likely contribution of neuroplastic adaptations, in addition to already established peripheral effects, may help explain the sustained benefits observed even after the interventions end, particularly in protocols involving multiple muscle groups or incorporating motor feedback strategies.

Limitations

This review presents some limitations that should be considered when interpreting the results. First, the studies analysed exhibited high variability in program duration (3 to 12 weeks), volume (number of repetitions, sets, or exercises), session length, and protocol type. This heterogeneity makes it difficult to formulate clear recommendations for an ideal protocol to follow, despite all included studies demonstrating positive effects on pain reduction, improved function, and quality of life. Therefore, additional research is needed to reduce this variability and determine the optimal duration and frequency of resistance training programs in clinical outcomes.

Additionally, the narrative synthesis approach, although justified by the substantial clinical and methodological heterogeneity observed, limits the ability to estimate pooled effect sizes and quantify the overall magnitude of treatment effects across studies.

Regarding the methodological quality of the included studies, 43.3% presented an overall low risk of bias, 23.3% were classified as having some concerns, and 33.3% as high risk. The main methodological weaknesses were observed in the domains “Measurement of the outcome” and “Selection of the reported result,” indicating potential flaws in outcome

measurement and the possibility of selective reporting. Additionally, some studies did not implement assessor blinding, increasing the risk of detection bias. It was also noted that some clinical trials were not registered in official platforms, compromising transparency and the control of publication bias. Part of the included studies were pilot trials with small sample sizes, which limits statistical robustness and the generalizability of the findings.

Finally, another limitation of this review was the exclusive inclusion of studies that evaluated interventions based solely on strengthening exercises. Although this choice enabled the compilation of specific evidence on resistance training programs, it is acknowledged that other therapeutic approaches, such as orthoses or taping, may also be effective in the treatment of PFPS and were not considered in this analysis.

CONCLUSIONS

This systematic review indicates that resistance training appears to be an effective strategy for reducing pain and improving function in individuals with PFPS. Interventions combining hip and knee strengthening demonstrated more consistent improvements across studies than isolated strategies; however, these findings should be interpreted with caution given protocol heterogeneity and variability in methodological quality. Complementary approaches, including assistive technologies, motor feedback, and trunk-focused interventions, also showed beneficial effects, although consistent superiority over conventional strengthening was not established. Overall, resistance exercise is a viable therapeutic option for managing PFPS. Future randomised controlled trials using standardised protocols, rigorous methodological designs, and, when possible, mechanistic outcome measures are needed to strengthen the evidence base and clarify optimal prescribing parameters.

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