

Thesis

**Exercise induced Hypoalgesia: the effects of quadriceps
and/or hip muscle training on patients with
patellofemoral pain syndrome**

submitted by
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Zusammenfassung

Hintergrund und Zielsetzung: Das patellofemorale Schmerzsyndrom (PFPS) ist eine häufige Ursache anteriorer Knieschmerzen, die den Alltag und sportliche Aktivitäten erheblich beeinträchtigt. Trotz der etablierten Kräftigungsübungen der Oberschenkel- und/oder Hüftmuskulatur ist die Evidenz zur optimalen Trainingsstrategie uneinheitlich. Ziel dieser Arbeit ist, die aktuelle Evidenz zur Wirksamkeit von Übungen zur Stärkung des Quadrizeps und/oder der Hüftmuskeln bei Personen mit patellofemoralem Schmerzsyndrom (PFPS) durch eine systematische Übersichtsarbeit und eine Metaanalyse darzulegen.

Methode: Diese systematische Übersichtsarbeit basiert auf einer umfassenden Literaturrecherche in mehreren elektronischen Datenbanken. Eingeschlossen wurden prospektive Studien, deren Schwerpunkt auf der Kräftigung der unteren Extremitäten, insbesondere der Hüft- und/oder Oberschenkelmuskulatur, lag. Studien, mit anderem Interventions-Fokus oder retrospektivem Design, wurden ausgeschlossen. Nach Screening und Risikobewertung erfolgte eine Netzwerk-Metaanalyse, um die primären Endpunkte Schmerz (VAS, NRS) und Funktion (AKPS) zu analysieren. Sekundäre Outcomes wie Funktion, Lebensqualität (z.B. KOOS-QoL, SF-36) und langfristige Auswirkungen auf Schmerz und Mobilität wurden qualitativ analysiert.

Ergebnisse: Alle muskulären Interventionen führten zu einer signifikanten Schmerzreduktion im Vergleich zur Kontrollgruppe. Die Kombination aus Hüft- und Quadrizepstraining zeigte hierbei die stärkste Wirkung. Hinsichtlich der funktionellen Verbesserung (AKPS) war nur die kombinierte Intervention statistisch signifikant überlegen. Aussagen zur Lebensqualität und zum Langzeiteffekt waren aufgrund heterogener Messinstrumente nur eingeschränkt möglich, zeigten aber insgesamt einen positiven Trend zugunsten der aktiven Trainingsinterventionen.

Schlussfolgerung: Gezieltes Krafttraining ist eine effektive Maßnahme zur Schmerzreduktion bei PFPS. Insbesondere kombinierte Interventionen aus Hüft- und Kniekräftigung sind besonders effektiv und sollten bevorzugt in Rehabilitationsprogramme integriert werden. Zukünftige Studien sollten sich auf individualisierte Trainingsparameter, Langzeitverläufe und biopsychosoziale Einflussfaktoren konzentrieren.

Abstract

Background and Aims: Patellofemoral Pain Syndrome is a common chronic condition causing anterior knee pain, with a significant impact on daily activities and athletic performance. The intensity of symptoms increases during activities such as descending stairs and squatting. PFPS is particularly common among adolescents and women and constitutes a substantial share of knee pain patients in both primary care and sports clinic. The pathophysiology involves anatomical and biomechanical factors of the patellofemoral joint, including patellar maltracking, muscle weakness and knee valgus. The aim was to evaluate the effectiveness of quadriceps and/or hip muscle strengthening exercises in individuals with PFPS through a systematic review and meta-analysis. The findings aim to provide updated evidence to support individualised, evidence-based rehabilitation strategies, guide clinical decision-making, and inform future conservative treatment approaches.

Methods: The present systematic review evaluated the effectiveness of muscle-strengthening therapies for patellofemoral pain syndrome (PFPS) based on a comprehensive search of electronic databases. Included were prospective trials focusing on strengthening of the quadriceps and/or hip muscles; studies targeting other muscle groups or with retrospective designs were excluded. Following a thorough screening process and a risk of bias assessment, a network meta-analysis was conducted to assess the efficacy of interventions on primary outcomes such as pain (VAS, NRS) and function (AKPS). Secondary outcomes, including functional ability, quality of life (as measured by KOOS-QoL and SF-36), and long-term effects on pain and mobility, were evaluated qualitatively.

Results: All strengthening interventions, whether targeting the hip, quadriceps, or both, led to a statistically significant reduction in pain compared to control groups. The most substantial pain reduction was observed in combined hip and knee strengthening protocols. Regarding the Anterior Knee Pain Scale only the combined approach demonstrated a statistically significant improvement, isolated hip or quadriceps training did not reach significance despite observable trends.

Conclusion: Targeted strengthening exercises have been shown to be an effective way to reduce pain in individuals with PFPS, with the most consistent benefits being seen when training both the hip and the quadriceps together. It was found that functional improvements were only significant when both muscle groups were addressed. These results support the integration of both proximal and local strengthening in PFPS rehabilitation. Future research should explore long-term adherence, gender-specific adaptations, and personalised exercise strategies.

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List of Abbreviations

AKPS: Kujala Anterior Knee Pain Scale

EIH: Exercise-induced Hypoalgesia

KOOS-QoL: Knee Injury and Osteoarthritis Outcome Score KOOS

LEFS: Lower Extremity Functional Scale

MeSH: Medical Subject Headings

NRS: Numeric Pain Scale

NSAID: Non-Steroidal Anti-Inflammatory Drug

OSF: Open Science Framework

OVID: Offshore Vessel Inspection Database

PE德罗: Physiotherapy Evidence Database -ro

PICOS: Population, Intervention, Comparison, Outcome, Study Design

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

QOL: Quality of Life

RCT: Randomised Controlled Trial

ROB2: Version 2 of the Cochrane risk-of-bias tool for randomised trials

ROBINS-I: Cochrane tool for Risk Of Bias In Non-randomised Studies - of Interventions

ROM: Range of Motion

SF-36: Short Form (36) Health Survey

SLHT: Single Leg Hop Test

VAS: Visual Analogue Scale

VMO: Vastus Medialis Oblique

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1. Introduction

1.1 Introduction to the Topic

Patellofemoral Pain Syndrome (PFPS) is a common chronic cause of anterior knee pain with a significant impact on daily activities. The main symptoms are characterised by pain around or behind the patella that increases with activities such as descending stairs, running or squatting.(1–3) Due to its high prevalence and potential to limit both recreational and occupational function, PFPS remains a clinically relevant concern in both general and athletic populations. The prevalence and incidence of patellofemoral pain syndrome (PFPS) vary due to population characteristics and diagnostic inconsistencies or differences.

1.1.1 Epidemiology and Risk Factors of PFPS

Patellofemoral pain syndrome (PFPS) has been found to account for 11–17% of knee pain cases in general practice and 25–40% of knee problems seen in sports injury clinics.(4)

The annual prevalence of PFP has been reported to be 22.7% in the general population, but is higher in adolescents, reaching up to 28.9%. (5) Gender is a significant risk factor, with research suggesting that women are 2.23 times more prone to develop PFPS than men. (6)

These epidemiological differences, mentioned above, highlight the importance of understanding the condition especially in the context of individual patient characteristics, including age, gender and the level of physical activity.

1.1.2 Biomechanical Background

In order to understand the pathophysiology of PFPS, it is important to highlight the anatomy of the patellofemoral joint and its biomechanical influence. The patellofemoral joint consists of the trochlear groove of the femur and the patella, which is embedded in the quadriceps tendon and plays a crucial role in knee extension. It is mainly stabilised by the patellar tendon, the quadriceps muscle, the medial patellofemoral and patellotibial ligaments, the medial and lateral retinacula, the patellotibial ligament and the epicondylopatellar ligaments.(1,7) The quadriceps is made up of the rectus femoris, vastus medialis (including the VMO), vastus intermedius and intermedius and provides the primary dynamic stabilising force of the patellofemoral joint. These muscles help to

maintain patellar alignment during knee flexion and extension, and also optimise mechanical leverage for knee extension. The VMO is especially crucial in resisting lateral patellar displacement. Weakness or underdevelopment of the VMO leads to lateral patellar maltracking, especially between 0° and 30° knee flexion, a range where restraints due to bone structures are minimal. Hip abductors and external rotators play a pivotal role in knee stabilisation through their control of femoral adduction and internal rotation during movement. Weak hip musculature may lead to excessive dynamic knee valgus, which in turn exerts stress on the patellofemoral joint. The issue under discussion is whether hip weakness is a cause or a consequence, with prospective studies yielding inconclusive results. However, cross-sectional data consistently demonstrates lower strength levels in patients with PFPS.(7,8)

Patellar instability and maltracking due to muscular weakness or imbalance, dynamic valgus, overuse or repetitive biomechanical stress from high-impact activities (e.g. running) contribute to the risk of developing PFPS.(1,7)

1.1.3 Diagnostic Approach

The diagnosis of PFPS is based on a detailed patient history, physical examination and functional performance testing, in particular assessment of lower limb biomechanics and muscle strength, especially quadriceps, hip and trunk musculature. The major diagnostic criteria and tests for PFPS are listed in the following table.(2,8)(Table 1)

Key Diagnostic Criteria for PFPS

Category	Details
Core Diagnostic Criteria	<ul style="list-style-type: none"> - Retropatellar or peripatellar pain - Pain provoked by activities that load the patellofemoral joint, such as squatting, stair use, prolonged sitting, or running - No other source of anterior knee pain (e.g. meniscal, tendon, or ligamentous pathology)
Functional and Performance Testing	<ul style="list-style-type: none"> - Squat test - Step-down test - Single-leg squat
Pain Provocation	<ul style="list-style-type: none"> - Pain reproduction during squatting, stair descent, or sitting with flexed knees - These tests are useful clinically but may vary in specificity
Palpation and Inspection	<ul style="list-style-type: none"> - Local tenderness - Quadriceps atrophy (especially of the vastus medialis obliquus) - Asymmetries in patellar mobility
Special Tests (low sensitivity, high specificity)	<ul style="list-style-type: none"> - Patellar tilt test - Patellar apprehension test
Clinically Validated Pain Scales	<ul style="list-style-type: none"> - Anterior Knee Pain Scale (AKPS) - KOOS-PF subscale - Visual Analog Scale (VAS) - Numeric Pain Rating Scale (NPRS)

Adapted from Willy et al. (2019) and Bump & Lewis (2023).

Table 1 - Key Diagnostic Criteria(2,8)

A meta-analysis of different tests for PFPS showed a lack of diagnostic consistency, highlighting the importance of taking a thorough patient history. In clinical practice, a combination of subjective reporting and functional assessment is essential to guide accurate diagnosis and appropriate intervention. As it is considered a diagnosis of exclusion, it is important to rule out other conditions that could present similar symptoms, for instance patellar tendinopathy, chondromalacia patellae, prepatellar bursitis or intra-articular pathology (Table 2). The overlap of symptoms with other anterior knee disorders further emphasizes the need for diagnostic caution and individualized assessment.(2,9–12)

Differential Diagnosis of Patellofemoral Pain Syndrome (PFPS)

Condition	Key Characteristics
Articular cartilage injury	History of trauma; mechanical symptoms may occur if loose body is present.
Bone tumors	Insidious onset of pain; may have tenderness of bony structures.
Chondromalacia patellae	Retropatellar pain, possible history of trauma; may present with effusion.
Hoffa disease	Pain and tenderness localized to the infrapatellar (Hoffa) fat pad.
Iliotibial band syndrome	Lateral pain; tenderness over lateral femoral epicondyle; common in runners.
Lateral patellar compression syndrome	Poor patellar alignment; tight lateral retinaculum; anterior knee pain.
Loose bodies	Intermittent sharp pain, locking, or effusion.
Osgood-Schlatter disease	Swelling/tenderness at tibial tubercle in adolescents; aggravated by activity.
Osteochondritis dissecans	Intermittent pain, swelling, or locking; may affect joint surface.
Patellar instability / subluxation	Instability sensation; swelling; positive apprehension test.
Patellar stress fracture	Focal tenderness directly over patella; stress-related onset.
Patellar tendinopathy	Inferior pole tenderness; thickened tendon if chronic; pain with jumping.
Patellofemoral osteoarthritis	Crepitus, effusion, stiffness; radiographic changes; older adults.
Patellofemoral pain syndrome	Diffuse anterior knee pain; worsens with stairs, squatting, prolonged sitting.
Pes anserine bursitis	Medial knee pain; tenderness over pes anserine bursa.
Plica syndrome	Medial or lateral peripatellar pain; snapping; tenderness on exam.
Prepatellar bursitis	Swelling over patella, typically following trauma or pressure.
Quadriceps tendinopathy	Tenderness over quadriceps tendon insertion; pain with resisted knee extension.
Saphenous neuritis	Poorly localized medial pain; possible history of surgical trauma.
Sinding-Larsen-Johansson syndrome	Pediatric condition; tenderness at inferior patellar pole.
Symptomatic bipartite patella	Tenderness at superolateral patella; radiographic confirmation.
Referred pain from lumbar spine or hip	Knee exam normal; symptoms depend on source; often with ROM limitations elsewhere.
Hip osteoarthritis or fracture	Referred pain to knee; reduced hip ROM; groin pain or limp.
Septic arthritis	Hot, swollen joint with fever and systemic symptoms; urgent referral needed.
Tumor / DVT / SCFE / fracture	Systemic red flags (e.g., night pain, weight loss); limp in children; urgent evaluation.
Neurovascular compromise	Motor/sensory deficits; diminished pulses; emergency referral indicated.

Source: Adapted from Dixit S, DiFiori JP, Burton M, Mines B. Management of patellofemoral pain syndrome. *Am Fam Physician.* 2007;75(2):194-202.

Table 2 - Differential Diagnosis of PFPS (12)

As structural damage is often minimal or absent in PFPS patients, it is essential to consider pain perception mechanisms that may contribute to symptom persistence.

1.1.4 Pain Perception and PFPS

Patients diagnosed with PFPS often experience persistent pain despite the absence of visible anatomical abnormalities on imaging. This may be explained from nociceptive inputs from structures like Hoffa's fat pad, the peripatellar synovium and retinacula, as well as increased joint reaction forces during deep knee flexion, which can exacerbate symptoms. Inflammatory mediators and neuromuscular dysfunction may contribute to the development of chronic pain, leading to persistent symptoms even in the absence of structural abnormalities.(1,7)

These mechanisms are closely linked to pain sensitization, reflected in lower pressure pain thresholds and enhanced temporal summation of pain. It is suggested by this that both peripheral and central mechanisms play a part in altered pain perception. Sensitization contributes to increased pain perception, fear of movement (kinesiophobia), pain-catastrophising and reduced self-efficacy. These factors have a detrimental effect on physical function and knee-related quality of life. Given the role of pain sensitization, exercise therapy has emerged as a key strategy to alleviate symptoms and restore function. (13,14)

1.1.5 Therapeutic Concepts of PFPS

The therapeutic approach for acute PFPS should be on pain relief, including relative rest, icing and short-term NSAIDs if necessary. However, the mainstay of treatment is physiotherapy, exercise therapy in particular, which should target the hip, knee and core muscles to improve long-term pain and function. Hip-specific exercises may be prioritised in the early stages of treatment, and therapy should be individualised to avoid aggravating movements while maintaining activity.(3)

Research indicates that exercise generally has a beneficial effect on chronic pain, with improvements often observed after just one session of physical activity, a phenomenon known as exercise-induced hypoalgesia (EIH). EIH is characterised by a transient

reduction in pain sensitivity and has been demonstrated following various forms of exercise, including aerobic, isometric and dynamic resistance training. This hypoalgesic response has been observed in individuals with and without chronic musculoskeletal pain, although the degree of effect may be blunted in some chronic pain populations, highlighting the need for individualised exercise interventions. Significant and clinically relevant reductions in pain are often reported after 8 to 12 weeks of consistent exercise therapy, reinforcing exercise as a central strategy in chronic pain management.

While the underlying mechanisms of EIH are not fully understood, current evidence suggests that endogenous opioid and endocannabinoid systems, as well as enhanced central pain inhibition all contribute to the modulation of pain during and after exercise. Given the variability in response, particularly in chronic pain patients, EIH represents both a promising target and a complex challenge in exercise-based pain management.(15,16)

The overall effectiveness of adjunctive treatments like taping and orthotics remains uncertain. Patellofemoral knee braces are not recommended as they provide no additional benefit. Other adjunctive interventions such as running gait retraining (e.g., increasing cadence, decreasing hip adduction) may be useful for runners with PFPS. Some passive therapies are not recommended due to a lack of proven effectiveness. Manual therapy and dry needling do not improve outcomes when used alone, and although acupuncture can be used with caution, its superiority over placebo remains unclear. Furthermore, biophysical techniques such as electrical stimulation, cryotherapy, and ultrasound are not advised. Surgical treatment should only be considered if conservative treatments fail and imaging supports a surgical indication, as conservative approaches provide better outcomes.(3) Participants demonstrating greater adherence to exercise regimens exhibited superior improvements in pain levels and psychological outcomes (e.g. reduced catastrophising, diminished fear). Consequently, imparting knowledge about the condition to patients is imperative for the effective management of PFPS. The development of innovative, accessible educational materials is crucial for empowering patients to manage their condition independently. When patients have a comprehensive understanding of their condition, including its aetiology, treatment options, and strategies for improvement, they are more likely to adhere to their treatment plan. Indeed, it is well-documented that patients who have a comprehensive understanding of their condition are more likely to take action,

remain active, and experience better outcomes, including reduced pain and accelerated recovery.(3,13,14)

1.1.6 Pain Scales

The VAS, NRS and AKPS pain scales are used in this review to compare patients' levels of pain.

The Visual Analogue Scale (VAS) is a commonly used tool to measure pain and assess the effectiveness of treatments in research settings. It consists of a horizontal or vertical line, typically 10 cm long, with one end representing no pain (0) and the other representing the worst pain imaginable (10 cm or 100 mm). Patients indicate their perceived pain intensity by marking a point on the line, providing a continuous and therefore more accurate quantification of pain severity. Its sensitivity and simplicity make it particularly useful in clinical trials evaluating the effects of treatment interventions.(17)

The Numeric Rating Scale (NRS) serves as an assessment tool to measure pain intensity. Although there are several variations, the 11-point version is used as it is the most common one. Patients indicate a number between 0 and 10 that best reflects their pain intensity, with 0 being no pain and 10 being the worst pain imaginable over the past 24 hours.(17)

The Anterior Knee Pain Scale (AKPS) is a valid and reliable 13-item questionnaire for patients with PFPS that focuses on different aspects of knee function, pain with physical activity, limitations in daily life and functional ability. Scores range from 0 to 100, with lower scores indicating greater functional limitations and higher pain levels. Having undergone extensive validation and reliability testing, it serves as a measure of pain severity and effectiveness of treatment interventions.(18,19)

Anterior Knee Pain Scale (Kujala Score)

Reference: Kujala UM, Jaakkola LH, Koskinen SK, Taimela S, Hurme M, Nelimarkka O.
Scoring of patellofemoral disorders. *Arthroscopy*. 1993;9(2):159-163.

Name: _____ Date: _____
Age: _____ Knee: L / R Symptoms Duration: _____ years _____ months

Instructions: Circle the letter corresponding to your current knee symptoms.

1. **Limp**
 - (a) None (5)
 - (b) Slight or periodical (3)
 - (c) Constant (0)
 - (d) Unable (0)
2. **Support**
 - (a) Full support without pain (5)
 - (b) Painful (3)
 - (c) Weight bearing impossible (0)
3. **Walking**
 - (a) Unlimited (5)
 - (b) More than 2 km (3)
 - (c) 1-2 km (2)
 - (d) Unable (0)
4. **Stairs**
 - (a) No difficulty (10)
 - (b) Slight pain when descending (8)
 - (c) Pain both when descending and ascending (5)
 - (d) Unable (0)
5. **Squatting**
 - (a) No difficulty (5)
 - (b) Repeated squatting painful (4)
 - (c) Painful each time (3)
 - (d) Possible with partial weight bearing (2)
 - (e) Unable (0)
6. **Running**
 - (a) No difficulty (10)
 - (b) Pain after more than 2 km (8)
 - (c) Slight pain from start (6)
 - (d) Severe pain (3)
 - (e) Unable (0)
7. **Jumping**
 - (a) No difficulty (10)
 - (b) Slight difficulty (7)
 - (c) Constant pain (2)
8. **Prolonged sitting with knees flexed**
 - (a) No difficulty (10)
 - (b) Pain after exercise (8)
 - (c) Constant pain (6)
 - (d) Pain forces extension temporarily (4)
 - (e) Unable (0)
9. **Pain**
 - (a) None (10)
 - (b) Slight and occasional (8)
 - (c) Interferes with sleep (6)
 - (d) Occasionally severe (3)
 - (e) Constant and severe (0)
10. **Swelling**
 - (a) None (10)
 - (b) After severe exertion (8)
 - (c) After daily activities (6)
 - (d) Every evening (4)
 - (e) Constant (0)
11. **Abnormal painful patellar movement (subluxation)**
 - (a) None (10)
 - (b) Occasionally during sports (6)
 - (c) Occasionally in daily activities (4)
 - (d) At least one documented dislocation (2)
 - (e) More than two dislocations (0)
12. **Thigh atrophy**
 - (a) None (5)
 - (b) Slight (3)
 - (c) Severe (0)
13. **Flexion deficiency**
 - (a) None (5)
 - (b) Slight (3)
 - (c) Severe (0)

Total Score: _____

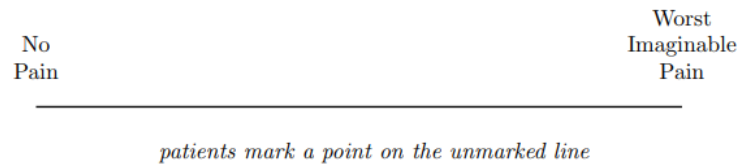
(Max: 100 points)

Figure 1 – AKPS (19)

VAS and NRS Pain Scales

Reference: Robinson CL, Phung A, Dominguez M, Remotti E, Ricciardelli R, Momah DU, et al. Pain Scales: What Are They and What Do They Mean. *Curr Pain Headache Rep.*

Visual Analogue Scale (VAS)



Numeric Rating Scale (NRS)

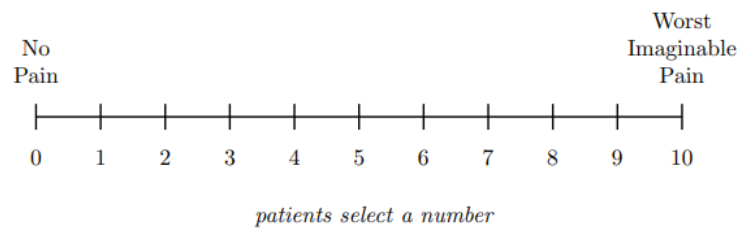


Figure 2 - VAS and NRS(17)

1.2 Identification of Knowledge and Research Gaps

A significant challenge in addressing PFPS is the absence of consensus regarding effective therapeutic modalities. A systematic review by Smith et al. highlights significant variability in the definition of PFPS across studies, complicating the synthesis of treatment outcomes.(5) This inconsistency is a contributing factor to the ongoing debate surrounding the appropriateness and effectiveness of interventions such as taping and specific strengthening exercises. For instance, some studies report positive effects of kinesio-taping on pain reduction in PFPS patients while others report that the long-term efficacy of traditional therapies such as quadriceps strengthening requires more rigorous validation.(20,21)

Given its potential role in mediating the pain-relieving effects of exercise, EIH represents a promising yet underexplored mechanism in PFPS therapy. Its clinical application, particularly in relation to individual variability in response, remains poorly understood and warrants further investigation.(15,16)

The majority of PFPS research has been conducted in younger, physically active populations, particularly males. This restriction limits the applicability of findings to older adults or females, who may exhibit divergent biomechanical and pain profiles.(22)

Furthermore Hott et al. emphasise the necessity to better understand the relative effects of different exercise strategies for PFPS. They highlight the current lack of consensus and the need for more systematic investigation into treatment specificity and variability.(23)

In addition, factors leading to a poor prognosis in PFPS, as outlined by Lankhorst et al, 2016 include prolonged pain duration and inadequate initial treatment. The authors emphasise that many patients continue to experience pain long after treatment, with a significant proportion still reporting symptoms 5 to 8 years after diagnosis. This highlights the critical need for longitudinal studies to identify predictive factors that contribute to persistent pain and functional impairment, thereby tailoring more effective, individualised treatment plans.(24)

In conclusion, the current management of PFPS is hindered by inconsistencies in treatment efficacy, limited standardisation of therapeutic protocols, limited investigation into the underlying pain mechanisms such as EIH, and insufficient consideration of individual and demographic variability. Addressing these research gaps through targeted studies will be essential to develop evidence-based, patient-centered treatment strategies.

1.3 Aims and Objectives

Patellofemoral pain syndrome (PFPS) remains one of the most common and complex conditions in both general and sports medicine. Its multifactorial aetiology, involving anatomical, biomechanical, neuromuscular and exercise-related variables, continues to challenge clinicians and researchers. Despite extensive research, the underlying mechanisms contributing to PFPS are not fully understood and its management remains inconsistent. Effective rehabilitation of PFPS typically involves exercise therapy as a central method, with quadriceps strengthening, specifically targeting the vastus medialis obliquus (VMO), long considered as the standard approach. However, recent biomechanical and clinical evidence has focused attention on the role of the proximal

kinetic chain, particularly hip muscle strength, as a key contributor to patellar tracking, knee joint loading and stability.(25–27)

Despite the prevalence of both hip- and knee-focused strengthening exercises in the management of PFPS, there is an absence of compelling evidence that favours one approach over another. A number of studies have indicated that hip-focused programmes may yield superior outcomes, including enhanced strength or kinematic parameters.(28) Conversely, other studies have failed to discern any substantial discrepancy in outcomes when comparing hip-focused programmes with knee-focused or combined interventions.(22,29)

Given this backdrop, it is necessary to determine whether the enhancement of interventions should focus on the hip, the quadriceps, or both. Consequently, a targeted investigation into the effects of hip and/or quadriceps strengthening is warranted. This targeted investigation could help resolve ongoing clinical uncertainty, inform evidence-based rehabilitation protocols, and ultimately contribute to more effective and individualized care for patients with PFPS.

The impact of PFPS on physical, emotional and social well-being is a multifaceted issue that warrants close examination. An important aspect of PFPS is its predominance among younger demographics, underscoring its relevance to the health and well-being of young individuals. It has the potential to limit participation in work, education, and physical activity, thereby reducing long-term well-being and opportunities. PFPS QoL scores have been found to be comparable to or even worse than those observed in some serious medical conditions, including knee osteoarthritis, particularly with regard to pain and sports function.(4)

The main objective of this thesis is to systematically evaluate the effectiveness of quadriceps and/or hip muscle strengthening in individuals diagnosed with PFPS. The present systematic review and meta-analysis aims to provide a structured and up-to-date synthesis of existing evidence. Beyond academic contribution, the findings of this study could have meaningful clinical impact. By clarifying the most effective strengthening

approach, it is anticipated that more efficient, individualised treatment strategies will be developed, reliance on pain medication will be reduced and the quality of life for individuals suffering from PFPS will be enhanced. Informed exercise prescriptions may also support a faster return to sport and activity, reduce chronification and enhance patient adherence by demonstrating clear, measurable outcomes.

The present study has two goals: first, to lay the groundwork for future conservative treatment strategies, and second, to help reduce the burden of chronic anterior knee pain.

2. Materials and Methods

2.1 Electronic bibliographic database searches

A comprehensive systematic search was conducted to identify prospective studies on the 14th of November 2023 evaluating the effects of muscle-strengthening interventions on patients with PFPS.

The search was carried out across the electronic scientific databases OVID, Web of Science and PEDro using a combination of MeSH terms and Boolean operators. The search strategy was developed to capture a broad range of therapeutic exercise interventions targeting the hip and/or knee muscles in individuals with PFPS.

The following combination of terms and keywords was used as a search strategy:

[(therapy OR exercise or strength* OR workout OR physical OR activity OR sports OR rehabilitation OR motion OR movement OR musculoskeletal) AND (hip OR gluteal OR gluteus OR iliopsoas OR external rotators) AND (patellofemoral OR peripatellar OR retropatellar OR anterior knee pain) AND pain AND (clinical OR controlled OR random* OR comparative OR cohort OR prospective OR follow-up OR "follow up" OR longitudinal)].

A structured approach using the PICOS framework was used to define inclusion and exclusion criteria, ensuring a clear and reproducible method of study selection.(30) (Table 3)

P (Population)	Male and female patients, 15 years or older, diagnosed with Patellofemoral Pain Syndrome (PFPS).
I (Intervention)	Quadriceps and/or hip muscle training (e.g., strength training or physiotherapy programs).
C (Comparison)	No intervention, placebo intervention, standard knee intervention, or before-and-after study.
O (Outcomes)	Primary Outcomes: Pain reduction (VAS, AKPS, NRS), Secondary Outcomes: functional improvements, quality of life.
S (Study Design)	Randomized controlled trials, non-randomised controlled trials, cohort studies, and prospective comparative studies.

Table 3 - PICOS Framework(30)

The search was limited to English-language publications and included studies published up to the definite search November 2023.

2.2 Study selection

The search results were imported into Rayyan.ai, an online tool designed to facilitate the systematic review process, after removing any duplicate entries.(31) Two reviewers independently screened the titles, abstracts and full texts of all retrieved studies using a set of predefined inclusion and exclusion criteria.

At the title screening stage, studies were included if they were prospective in design and investigated a lower extremity strengthening intervention in people diagnosed with patellofemoral pain syndrome (PFPS). At this early stage, acceptable comparators included another lower extremity muscle intervention, standard care, or a control group, which could be no intervention, placebo, or healthy participants. Trials were retained if they focused on adolescent or adult populations, as trials in very young children were not considered appropriate due to potential developmental differences.

At the abstract screening stage, a more refined classification of interventions was applied. At this stage, only trials that specifically focused on quadriceps and/or hip muscle training were retained for full-text review. Trials that investigated other muscle groups, such as foot muscles, core muscles or general exercise interventions, were excluded at this stage. The aim was to isolate the effect of targeted hip and/or knee muscle training as clearly as possible and to avoid confounding effects from other regions.

In addition to these content-related criteria, a number of methodological exclusion factors were consistently applied throughout the screening process. Studies were excluded if they reported an intervention duration of less than two weeks, as such a short timeframe was considered insufficient to produce measurable training effects. Furthermore, studies employing electrostimulation, taping, or other passive physiotherapeutic modalities as the primary intervention were excluded. Additionally, studies comparing different formats of rehabilitation delivery, such as telerehabilitation vs. face-to-face therapy, were excluded.

Lastly, all non-prospective study designs were excluded, including retrospective studies, case series, narrative reviews, and systematic reviews. Furthermore, studies were excluded if PFPS was not the sole diagnosis in the population under investigation, or if other knee pathologies such as osteoarthritis, patellar instability, or ligament injuries were also present.

The final inclusion criteria were that the full-text versions of the studies were available, that they had been published in English, and that they had undergone the peer-review process.

These criteria summarized in Table 4 were developed a priori to ensure consistency in the screening process and to maintain a high level of clinical relevance across the included trials. The age threshold of 15 years was chosen to include both adolescent and adult populations, while minimising heterogeneity due to developmental factors. Interventions had to include quadriceps and/or hip muscle strengthening, with comparators defined as control conditions such as standard care, placebo, or no intervention. With regard to the assessment of outcomes, studies were required to report pain outcomes using the Visual Analogue Scale (VAS) or the Numeric Rating Scale (NRS), both of which are validated tools for the assessment of pain intensity. Furthermore, functional outcomes were to be measured using the Anterior Knee Pain Scale (AKPS), a widely utilised and standardised instrument for the assessment of functional limitations in PFPS. In addition to the primary endpoints of pain reduction (VAS/NRS) and functional aspects (AKPS), secondary outcomes such as quality of life and long-term effects with regard to freedom from pain and mobility were also included in the analysis where reported. As the instruments used for this varied greatly (e.g. KOOS-QoL, SF-36, LEFS, SLHT), a quantitative synthesis was not carried out. Instead, a qualitative analysis of the corresponding study content was carried out. (Table 12)

The full texts of all potentially eligible studies were retrieved and reviewed in detail. In instances where a consensus could not be reached between the two reviewers concerning the inclusion of a particular study, a third reviewer was consulted to assist in resolving the disagreement and reaching a definitive decision.

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> • Prospective study design • Full-text available in English • Participants aged 15 years or older • Clinical diagnosis of patellofemoral pain syndrome (PFPS) • Intervention focused on quadriceps and/or hip muscle training • Control group: no intervention, placebo, standard care, or another lower extremity muscle intervention • Primary outcomes: pain (VAS or NRS), function (AKPS) 	<ul style="list-style-type: none"> • Non-prospective study types (e.g., retrospective, reviews, case series) • Mixed or multimodal interventions beyond hip/knee training • Interventions with duration > 2 weeks • Electrostimulation, taping, stretching or passive modalities as primary intervention • Comparisons of rehabilitation delivery formats (e.g., telerehab vs. in-person) • Studies involving comorbid conditions (e.g., osteoarthritis, patellar instability) • Non-English or non-full-text publications

Table 4 - Screening Criteria

2.3 Data Synthesis and Analysis

During the full-text screening one reviewer systematically extracted relevant data using a template that included study design, patient demographics, purpose of the study, inclusion and exclusion criteria, interventions and outcomes.(Table 4) The quality of randomised controlled trials (RCTs) included in this systematic review was evaluated using the Cochrane Risk of Bias Tool version 2 (ROB2) (Table 6), while the non-randomised studies were assessed using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool (Table 5). The implementation of these tools was guided by the overarching objective of this systematic review, which was to comprehensively examine potential biases in the included studies.

Risk of Bias Assessment - ROBINS-I

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Ali et al., 2021	moderate	low	low	low	low	low	low	moderate
Boling et al., 2006	moderate	moderate	low	low	low	low	low	moderate
Chiu et al., 2012	moderate	moderate	low	moderate	moderate	low	moderate	moderate
Greaves et al., 2021	low	low	low	moderate	moderate	low	low	low
Khayambashi et al., 2014	moderate	moderate	low	serious	low	low	moderate	moderate
Lack et al., 2023	moderate	moderate	low	low	moderate	low	low	moderate
Domain	Description							
D1	bias due to confounding							
D2	bias due to selection of participants							
D3	bias in classification of interventions							
D4	bias due to deviation from intended interventions							
D5	bias due to missing data							
D6	bias in measurement of outcomes							
D7	bias in selection of the reported results							

Table 5 - ROBINS I

Risk of Bias Assessment - RoB 2

Study (Year)	B1	B2	B3	B4	B5	Overall
Asif et al., 2022	some	some	low	low	low	low
Baldon et al., 2014	low	some	low	low	low	low
Crossley et al., 2002	low	some	low	low	low	low
da Silva Boitrago et al., 2021	low	some	low	low	low	low
Dolak et al., 2011	low	some	low	low	low	low
Emamvirdi et al., 2019	low	some	some	low	low	low
Ferber et al., 2015	low	some	low	low	low	low
Fukuda et al., 2012	low	some	low	low	low	low
Fukuda et al., 2010	low	some	low	low	low	low
Hansen et al., 2023	low	some	low	low	low	low
Hosseini et al., 2023	some	some	some	low	low	some
Hott et al., 2020	low	some	low	low	low	low
Ismail et al., 2013	low	some	low	low	low	low
Khayambashi et al., 2012	some	some	low	some	low	some
Monika et al., 2016	some	some	low	low	low	low
Nakagawa et al., 2008	low	some	low	low	low	low
Razeghi et al., 2010	some	some	low	low	low	low
Saad et al., 2018	low	some	low	low	low	low
Sahin et al., 2016	low	some	low	low	low	low
Sharif et al., 2020	some	some	low	low	low	low
Shetty et al., 2016	some	some	low	low	low	low
Song et al., 2009	low	some	low	low	low	low
van Linschoten et al., 2009	low	some	low	low	low	low
Zemadanis et al., 2015	some	some	low	low	low	low
B1	randomisation process					
B2	deviations from intended intervention					
B3	missing outcome data					
B4	measurement of the outcome					
B5	selection of the reported result					
Overall	overall assessment					

Table 6 - ROB2

The present review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The study selection process is presented in a PRISMA Flow Chart.(32)(Figure 3)

A network meta-analysis was conducted in order to synthesize both direct and indirect evidence across studies comparing multiple interventions. This approach allows the relative effects of all interventions to be estimated simultaneously, even in the absence of head-to-head trials. Consistency and transitivity assumptions were assessed through visual inspection of the network geometry and statistical measures of heterogeneity and inconsistency. The analysis focused on evaluating the effectiveness of the following intervention methods: knee-focused exercises, hip-focused exercises, combined knee-hip exercises and a control group.

As VAS and NRS scales have the same direction (e.g. 0 = no pain, 10 = maximum pain) and the outcomes were either standardised using the Standardised Mean Difference (SMD) or converted to a common scale (e.g. everything on 0-100), they are comparable in terms of content. Therefore, VAS and NRS were summarised as “pain” in this meta-analysis, which was one of the primary outcome measures, alongside the category for functional ability “AKPS”. They were analysed to estimate the overall effect size of hip and/or quadriceps muscle training on pain reduction in patients with patellofemoral pain syndrome (PFPS).

The pairwise meta-analyses were performed for all available direct comparisons. The network meta-analysis combined direct and indirect evidence to estimate the effect size between all interventions studied. The interventions were ranked according to their effectiveness. The analysis included both two-arm studies and multi-arm studies.

Although 30 studies were included in the preliminary selection (Figure 3), not every study showed all three AKPS, VAS and NRS pain scale data. Consequently, some of these studies were not included in some of the quantitative analysis. Please refer to the Tables in

the Appendix for details of the studies and subgroups that were used for the separate quantitative analyses.

All analyses were conducted using NMA Studio 2.0, an interactive tool for network meta-analysis.

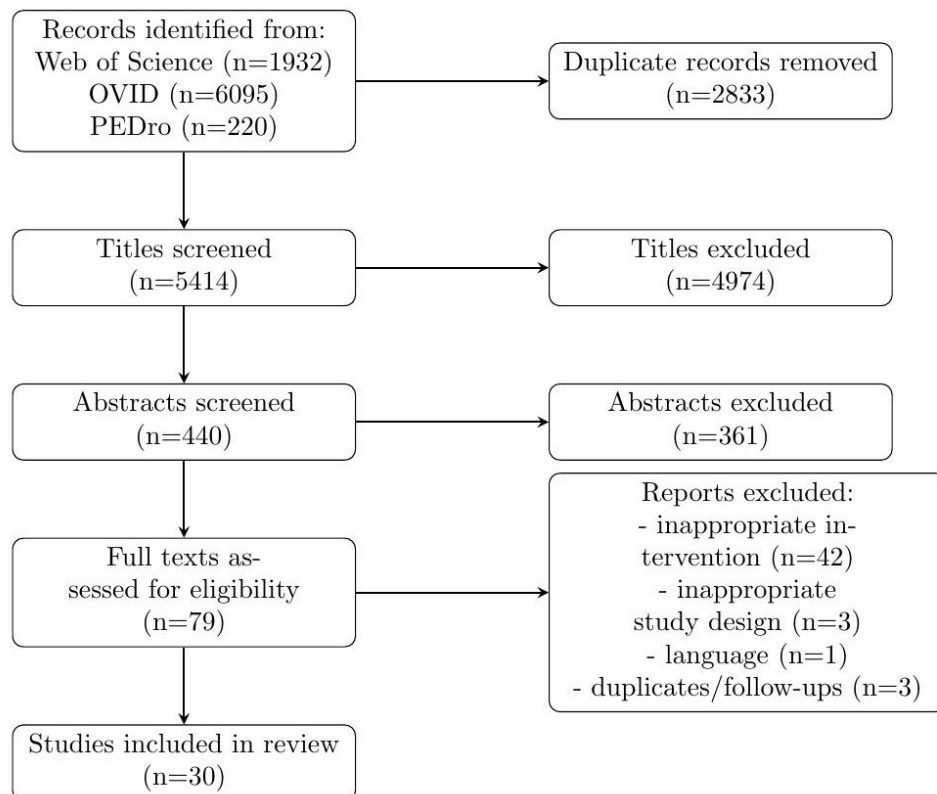


Figure 3 - PRISMA Flow Diagram(32)

3. Results / Findings with Graphical Representations

3.1 Descriptive Analysis:

3.1.1 Study type and Characteristics

A total of 30 trials from 16 different countries were included in this systematic review. The majority (23/30 trials) were RCTs, but 7 trials of other study types were also included.

In terms of population characteristics, a total of 1663 patients were included in these studies, with an average of 55.4 patients per study. All included trials reported their population size and details of age, inclusion and exclusion criteria and intervention. Three studies only reported vague or qualitative information such as “some dropouts”, which made precise classification difficult. Nevertheless, it should be noted that the other 27 studies systematically documented whether they had dropouts or not, which is important for the interpretation of the results, especially with regard to possible biases due to missing data.

Most studies focused on young to middle-aged adults, with only a few including participants over 40. The standard deviations suggest a moderate range of ages, typically indicating a fairly homogeneous group of participants within each study. The calculated mean age reported was 27.2 years.

3.1.2 Intervention Group Description

Typical interventions focusing on the muscles close to the knee joint were primarily aimed at strengthening the quadriceps, sometimes with a specific focus on the vastus medialis obliquus (VMO). Commonly used exercises included the leg press, squat variations, isometric quadriceps contractions and active or knee extension exercises - in some cases using resistance bands (e.g. TheraBand™). In many studies, the knee-centred intervention was referred to as the standard of care for PFPS. In some cases, it was also used as a control intervention to provide a baseline for comparison with hip or combined treatment strategies.

Interventions that focused on the hip muscles aimed to strengthen the gluteal muscles, hip abductors and external rotators. Typical exercises included 'side-lying hip abductions', targeted external rotation exercises with resistance (e.g. TheraBand™) and exercises in the supine or lateral position with additional weights. Sometimes these movements were also performed in a controlled and slow manner to improve neuromuscular control.

Many of the training protocols used a combined approach, working both the muscle groups close to the knee joint and those close to the hip joint. These programmes included squats, step-downs, isometric hip abductions and standing stabilisation exercises. Functional movement sequences were also often included to improve muscle control and power transmission throughout the lower limb. In some trials, the hip was trained first and then the knee.

3.1.3 Control Group Description

The control groups in the included trials were varied and not uniform. They ranged from no intervention or maintenance of daily activities to minimal care (e.g. health education, postural advice), passive modalities (e.g. heat, electrotherapy) and placebo treatments. In some of the included studies, standard quadriceps-focused interventions were used as comparators for hip-focused or combined training protocols. Although these interventions served as control conditions within the respective trials, they were classified as part of the "knee intervention group" in the network meta-analysis. All other control interventions, regardless of their intensity or content, were grouped under the umbrella term "control group" to ensure methodological consistency and allow for uniform statistical comparisons with the active muscle-strengthening interventions.

3.1.4 Intervention Duration, Frequency and Follow-Up Assessment

The duration of the intervention varied between 2 and 12 weeks in the included studies. The majority of the studies (n = 15) used a duration of 6 weeks, followed by 8 weeks in 7 studies. In 6 studies, the intervention was designed for 4 weeks, while one study investigated a shorter duration of 2 weeks or a longer duration of 12 weeks. Seventeen out

of the thirty studies included focused on a training programme consisting of three sessions per week.

One study stated the frequency as 'every other day', which corresponds to approximately three sessions per week and was therefore also assigned to this group. Five studies performed the exercises five times per week, one study reported six sessions per week. A total of 4 studies reported an intervention of 1 or 2 sessions per week. In two studies, no specific information was given on the training frequency.

A total of eleven studies reported follow-up data. The most frequent follow-up examinations took place after three or six months. Specifically, the follow-up took place in six studies after three months, in four studies after six months and in three studies after twelve months. In addition, a follow-up was conducted in two studies after six weeks and in one study after eight weeks.

3.1.5 Follow-Up Data of Interventions

The analysis of the follow-up times indicates that, in the majority of studies, effects were observed over a period of three to six months. Only a few studies including follow-up assessments at twelve months, while others used shorter periods of six to eight weeks.

For the purpose of conducting this qualitative analysis, the data obtained from the full-text analysis extractions were utilised, as illustrated in tables 7 and 8.

Author & Year	Country	Study type	Intervention/Control	calculated mean age	Pain Scales
Ali et al., 2021	Pakistan	quasi experimental trial	Hip vs. Knee	29.5	AKPS, VAS
Asif et al., 2022	Pakistan	RCT	Hip vs. Knee	23.43	AKPS, NRS
Baldon et al., 2014	Brazil	RCT	Hip vs. Knee	22.0	VAS
Boling et al., 2006	USA	non randomised pretest/posttest intervention study	Knee+Hip vs. X (no intervention or healthy)	23.5	VAS
Chui et al., 2012	China	prospective independent group comparison	Knee vs. X (no intervention or healthy)	33.08	AKPS, NPRS
Crossley et al., 2002	Australia	RCT	Knee+Hip vs X (no intervention or healthy)	27.5	AKPS, VAS
Da Silva Boitrago et al., 2021	Brazil	RCT	Knee+Hip vs. X (no intervention or healthy)	26.28	AKPS, NRS
Dolak et al., 2011	USA	RCT	Hip vs. Knee	25.5	VAS
Emamvirdi et al., 2019	Iran	randomized controlled laboratory study	Knee+Hip vs. X (no intervention or healthy)	22.6	VAS
Ferber et al., 2015	Canada, USA	RCT	Hip vs. Knee	29.0	AKPS, VAS
Fukuda et al., 2012	Brazil	RCT	Hip+Knee vs Knee	22.5	AKPS, NRS
Fukuda et al., 2010	Brazil	RCT	Hip+Knee vs Knee	24.67	AKPS, NRS
Greaves et al., 2021	UK	non blinded, non randomised observational study	hip+knee; before and after	30.8	AKPS, NRS
Hansen et al., 2023	Denmark	RCT	Hip vs. Knee	27.2	AKPS, NRS
Hossein et al., 2023	Iran	RCT	Hip+Knee vs Knee	26.06	VAS
Hott et al., 2020	Norway	RCT	Hip vs. Knee	27.53	AKPS, VAS
Ismail et al., 2013	Egypt	RCT	Hip+Knee vs Knee	21.0	AKPS, VAS
Khayambashi et al., 2014	Iran	comparative control trial	Hip vs. Knee	27.75	VAS
Khayambashi et al., 2012	Iran	RCT	Hip vs. X (no intervention or healthy)	29.7	VAS
Lack et al., 2023	UK	observational study	Hip; before and after	30.6	AKPS, VAS
Monika et al., 2016	India	RCT	Hip+Knee vs Knee	21.24	AKPS, NRS
Nakagawa et al., 2008	Brazil	RCT	Hip+Knee vs Knee	23.6	VAS
Razeghi et al., 2010	Iran	RCT	Hip+Knee vs Knee	22.62	VAS
Saad et al., 2018	Brazil	RCT	Hip vs. Knee vs. X (no intervention or healthy)	22.97	AKPS, VAS
Sahin et al., 2016	Turkey	RCT	Hip+Knee vs Knee	34.15	AKPS, VAS
Sharif et al., 2020	Pakistan	RCT	Hip+Knee vs Knee	34.03	AKPS, VAS
Shetty et al., 2016	India	RCT	Hip+Knee vs Knee	27.74	AKPS, NRS
Song et al., 2009	Taiwan	RCT	Hip+Knee vs. Knee vs. X (no intervention or healthy)	40.9	VAS
Van Linschoten et al., 2009	Netherlands	RCT	Hip+Knee vs. X (no intervention or healthy)	24.0	AKPS, VAS
Zemadani et al., 2015	Greece	RCT	Hip vs. Knee	28.3	VAS

Table 7 - Characteristics of included studies (1)

Author	Population	drop out	Duration and Training Intervals		Follow Up
Ali et al., 2021	30	x	6 wks	5x / wk	x
Asif et al., 2022	28	x	6 wks	3x / wk	x
Baldon et al., 2014	31	1	8 wks	3x / wk	3 mo
Boling et al., 2006	28	x	6 wks	3x / wk	x
Chui et al., 2012	15	x	8 wks	3x / wk	x
Crossley et al., 2002	71	4	6 wks	1x / wk	3 mo
Da Silva Boitrago et al., 2021	60	x	6 wks	1x / wk	6 wks
Dolak et al., 2011	33	6	4 wks	3x / wk	8 wks, 3 mo
Emamvirdi et al., 2019	64	x	6 wks	3x / wk	x
Ferber et al., 2015	199	54	6 wks	6x / wk	x
Fukuda et al., 2012	54	5	4 wks	3x / wk	3 mo, 6 mo, 12 mo
Fukuda et al., 2010	70	6	4 wks	3x / wk	x
Greaves et al., 2021	27	11	6 wks	no info	x
Hansen et al., 2023	200	some	12 wks	3x / wk	6 mo
Hosseini et al., 2023	35	x	8 wks	3x / wk	x
Hott et al., 2020	112	some	6 wks	3x / wk	12 mo
Ismail et al., 2013	32	x	6 wks	3x / wk	x
Khayambashi et al., 2014	36	x	8 wks	3x / wk	6 mo
Khayambashi et al., 2012	28	x	8 wks	3x / wk	6 mo
Lack et al., 2023	21	3	2 wks	5x / wk	x
Monika et al., 2016	30	x	4 wks	on alternate days	x
Nakagawa et al., 2008	14	x	6 wks	5x / wk	x
Razeghi et al., 2010	32	1	4 wks	no info	x
Saad et al., 2018	40	1	8 wks	2x / wk	x
Sahin et al., 2016	55	5	6 wks	5x / wk	12 wks
Sharif et al., 2020	30	x	6 wks	6x / wk	x
Shetty et al., 2016	30	x	4 wks	3x / wk	x
Song et al., 2009	89	8 - still analyzed	8 wks	3x / wk	x
Van Linschoten et al., 2009	131	some	6 wks	1-2x / wk	3 mo, 12 mo
Zemadani et al., 2015	38	2	6 wks	3x / wk	x
Abbreviations:					
wks	weeks				
x / wk	sessions per week				
mo	month				
x	no				

Table 8 - Characteristics of included studies (2)

3.1.6 Secondary Outcomes: Function, Quality of Life and Long-Term Effects

In addition to the primary outcomes of pain and function (measured by VAS/NRS and AKPS), several included studies reported additional secondary outcomes, including functional capacity, quality of life (QoL) and long-term effects on pain and mobility.

A variety of measurement tools were utilised to evaluate secondary outcomes beyond pain and AKPS, including the Lower Extremity Functional Scale (LEFS), the Functional Index

Questionnaire (FIQ) and the Single-Leg Hop Test (SLHT). In this analysis, functional outcomes were defined as either patient-reported measures of activity limitations (e.g. LEFS, FIQ, KOOS-Function, Kujala Score) or performance-based tests assessing real-life functional capacity, such as Step-Down Tests and Single-Leg Hop Tests. Of the 30 studies that were included in the analysis, 16 explicitly reported at least one secondary outcome related to functional capacity or quality of life. Of these, five studies utilised the LEFS, three each employed the KOOS-QoL subscale, the SLHT and the Step-Down Test. Two incorporated the FIQ.

By contrast, outcomes that were exclusively focused on muscle strength (e.g. handheld dynamometry, isokinetic testing) were not classified as functional, as they assess physical capacity rather than the ability to perform daily activities.

The assessment of quality of life (QoL) was less frequent and was typically conducted via the KOOS-QoL subscale, the Short Form-36 (SF-36), or the EQ-5D. Due to considerable variability in outcome measures and assessment time points, a pooled quantitative synthesis was not feasible. Consequently, a qualitative summary of the available evidence was conducted. (Table 9)

Across studies, a general trend towards functional improvement was observed, particularly in interventions combining hip and quadriceps strengthening. However, the evidence pertaining to quality of life was more limited. However, Greaves et al. reported a statistically significant improvement in the KOOS-QoL subscale (+23.44 points, $p = 0.002$) and additional positive trends in the SF-36. However, it should be noted that other studies either did not assess QoL or referenced it without detailed reporting or usage of predefined scales. Follow-up assessments ranging from 3 to 12 months were conducted in several studies, indicating that the benefits of exercise therapy may extend beyond the intervention period, particularly with regard to pain and function. Nevertheless, the long-term impact on quality of life remains inadequately documented. A comprehensive overview of the reported secondary outcomes can be found in Table 9.

Author, Year	Function / QoL measured	Significance + Details
Ali et al., 2021	KOOS	hip and hip core strengthening demonstrated superior KOOS improvement (35.26±13.98, p<0.05) compared to knee strengthening (24.80±3.12, p=0.25)
Baldon et al., 2014	LEFS, SLHT self report	LEFS showed significant improvements in both groups with no between-group differences, while only the Functional stabilisation group demonstrated significantly better SLHT performance at the end of intervention compared to baseline and compared to the Standard knee group
Boling et al., 2006	FIQ	significant improvement starting at week 2 of the rehabilitation program and continued improving through the remainder of the study, demonstrating enhanced functional performance in patients with patellofemoral pain syndrome
Crossley et al., 2002	FIQ, SF-36	no significant difference in the change in FIQ between the two treatment groups, no differences were found for changes in health-related quality of life (SF-36) between groups
Da Silva Boitrago et al., 2021	ADLS	significantly better functional outcomes in the exercise group (86.5) compared to the guidance-only group (60), demonstrating that combined resistance and proprioceptive exercises more effectively improved daily activity function in women with patellofemoral pain syndrome
Dolak et al., 2011	LEFS	significant improvement in LEFS scores for all participants, with both groups combined showing progressive increases from baseline (56.5 ± 12.2) to 4 weeks (63 ± 12.7) and further improvement at 8 weeks (67.6 ± 11.5), demonstrating a total improvement of 12 points which exceeded the clinically significant threshold of 8 points
Enamwirdi et al., 2019	SLHT	significant improvement in the experimental group with a 24.62% increase in performance after VCI exercises, showing a strong effect size of 0.676 and statistical significance (P = 0.003) compared to the control group
Fukuda et al., 2010	LEFS, SLHT	both LEFS and SLHT showed statistically significant improvements in the intervention groups compared to the control group (P < .05), with LEFS demonstrating clinically meaningful changes above the 9-point threshold in both treatment groups
Greaves et al., 2021	KOOS	clinically meaningful improvements after exercise intervention, with significant increases of 16.26 points in overall function and 23.44 points in quality of life (p=0.0001 and p=0.002 respectively)
Hansen et al., 2023	KOOS, EuroQoL/EG-5D-3L	both KOOS subscales and EuroQoL EQ-5D-3L showed modest improvements from baseline, with the KOOS quality of life demonstrating the largest change (15.7-19.2 points at 26 weeks), though there were no statistically significant differences between quadriceps and hip exercise groups for any of these outcomes
Hott et al., 2020	EQ-5D-5L, step-down	modest improvements in EQ-5D-5L scores over time, no significant between-group differences at 12 months in EQ-5D-5L measurements when comparing hip exercise, knee exercise or free physical activity groups - only the control (free physical activity) group showed a statistically significant improvement in EQ-5D-5L from baseline to 12 months - the other groups did not achieve statistical significance
Saad et al., 2018	step up&down	significant improvement in dynamic valgus control during step-down activities
Sahin et al., 2016	3-limb hop test, one leg squat, step down	the hip-and-knee exercise group showed significantly greater improvements in functional outcomes compared to the knee-only exercise group, with better scores in the Kujala functional index (P=0.002), one-leg squat test, and step-down tests at follow-up (P<0.017), along with higher gains in hip abductor and external rotator strength
Shetty et al., 2016	LEFS	the experimental group showed significantly greater improvement in LEFS scores (P<0.001) compared to the control group, with the experimental group increasing from 40.26±13.15 to 66.20±7.49 while the control group increased from 48.50±15.29 to 56.92±17.19
Song et al., 2009	Lysholm Score	both training groups improved; but no significant difference between leg-press and hip adduction+leg press group (hip adduction did not add extra value to function)
Zemadani et al., 2015	LEFS	both Groups A and B showed significantly improved LEFS scores after Mobilization-with-movement application and post-intervention compared to Group C (P < 0.001)

Table 9 - Analysis of Secondary Outcomes

3.2 Quantitative Synthesis / Meta Analysis

The quantitative synthesis was conducted separately for two outcome categories: Pain, assessed using VAS and NRS, and the AKPS score. For each outcome, both pairwise and network meta-analyses were performed to estimate comparative effects between interventions. The results are visualised using network diagrams, league tables and forest plots providing an overview of treatment rankings and effect estimates with corresponding confidence intervals.

3.2.1 “Pain”

The network meta-analysis for the “Pain” category included 27 studies/subgroups with a total of 1380 patients in four different interventions. There were six possible pairwise comparisons, all of which were supported by direct data. Further details on the network structure are shown in Table 10.

<u>Characteristic</u>	<u>Value</u>
Number of Interventions	4
Number of Studies/Subgroups	27
Total Number of Patients in Network	1380
Total Possible Pairwise Comparisons	6
Total Number of Pairwise Comparisons with Direct Data	6
Number of two-arm studies	23
Number of multi-arms studies	4

Table 10 - Characteristics table "Pain"

A network plot was created to visualise the structure of the available evidence. The nodes in the plot represent the 4 different groups: knee, hip, knee+hip and control.

The lines between them represent the direct comparisons from the included studies.

Network plot of all studies

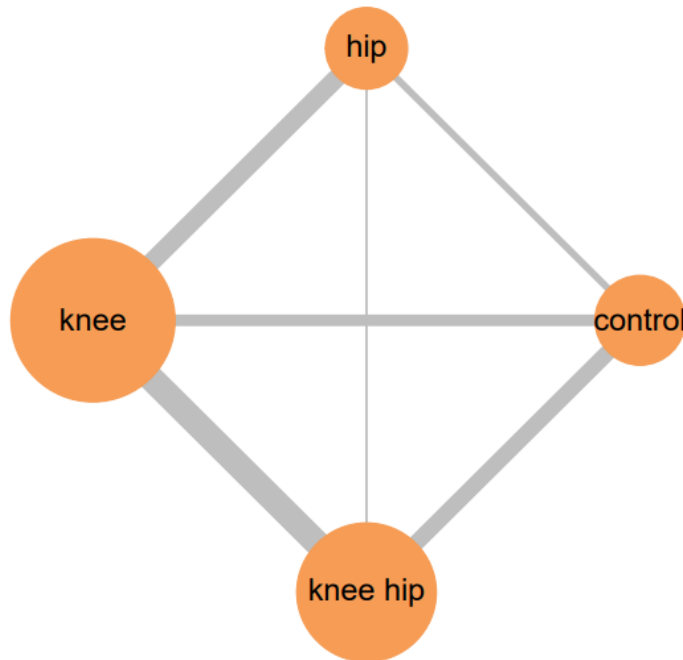


Figure 4 - Network Plot "Pain"

Figure 4 shows the network plot for the outcome “Pain”. The size of the nodes is proportionate to the number of subjects in each group, thus there are more subjects in the knee group than the knee+hip group, the control group, and the hip group. The thickness of the lines denotes the number of studies conducted for each comparison. A higher number of studies was identified for knee vs. knee+hip, followed by knee vs. hip. The least number of studies could be observed in knee vs. control, control vs. hip, and hip vs. knee+hip.

Overall, the network for “Pain” demonstrated a high level of connectivity, with all interventions being linked either directly or indirectly. However, the number of studies per comparison varied, with some treatment pairs being looked at more often than others, which could have an impact on the findings.

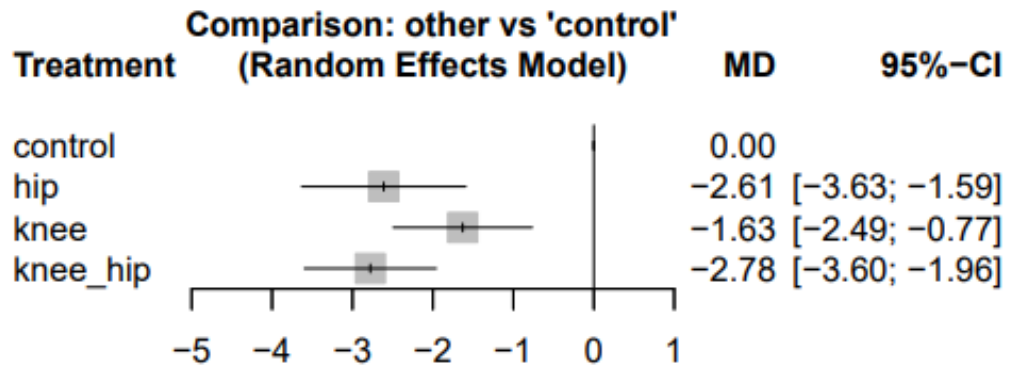


Figure 5 - "Pain" Forest Plot "Intervention VS Control"

The forest plot for the category “Pain” (Figure 5) illustrates the effects of the muscular interventions (knee, hip, knee+hip) compared to the control group.

The findings reveal a substantial reduction in pain symptoms across all three interventions when compared to the control group. The knee+hip group exhibited the most substantial effect (MD = -2.78, 95% CI -3.60 to -1.96), followed by the hip group (MD = -2.61, 95% CI -3.63 to -1.59) and the knee group (MD = -1.63, 95% CI -2.49 to -0.77).

knee&hip	0.30 [-2.00; 2.60]	-1.30 [-2.02; -0.58]	-2.39 [-3.37; -1.41]
-0.17 [-1.14; 0.80]	hip	-0.60 [-1.60; 0.40]	-2.71 [-4.10; -1.32]
-1.15 [-1.80; -0.50]	-0.98 [-1.86; -0.11]	knee	-2.01 [-3.22; -0.80]
-2.78 [-3.60; -1.96]	-2.61 [-3.63; -1.59]	-1.63 [-2.49; -0.77]	control

Table 11 - "Pain" League Table

Table 11 presents the league table for the outcome “Pain”, incorporating both direct comparisons (pairwise meta-analyses, blue cells) and the results of the network meta-analysis (yellow cells). The interventions are ordered along the leading diagonal, as

indicated by the grey cells, from those which are most effective (top left) to those which are least effective (bottom right) in reducing pain symptoms.

All three muscular interventions (knee, hip and knee+hip) showed a statistically significant reduction in pain compared to the control group. The combined knee+hip intervention presented the greatest mean difference in pain reduction (MD = -2.78, 95% CI -3.60 to -1.96), followed by the hip and knee groups. The control group showed the least change in pain outcomes.

3.2.2 “AKPS”

A total of 26 studies/subgroups with 1,356 patients were included in the network meta-analysis for the outcome "AKPS". The analysis covered four different interventions and allowed for six possible pairwise comparisons, all of which were based on direct evidence. An overview of the study characteristics is given in Table 12.

<u>Characteristic</u>	<u>Value</u>
Number of Interventions	4
Number of Studies/Subgroups	26
Total Number of Patients in Network	1356
Total Possible Pairwise Comparisons	6
Total Number of Pairwise Comparisons with Direct Data	6
Number of two-arm studies	22
Number of multi-arms studies	4

Table 12 - Characteristics table "AKPS"

As in the “Pain” analysis, we also performed a network plot for the AKPS category.

Network plot of all studies

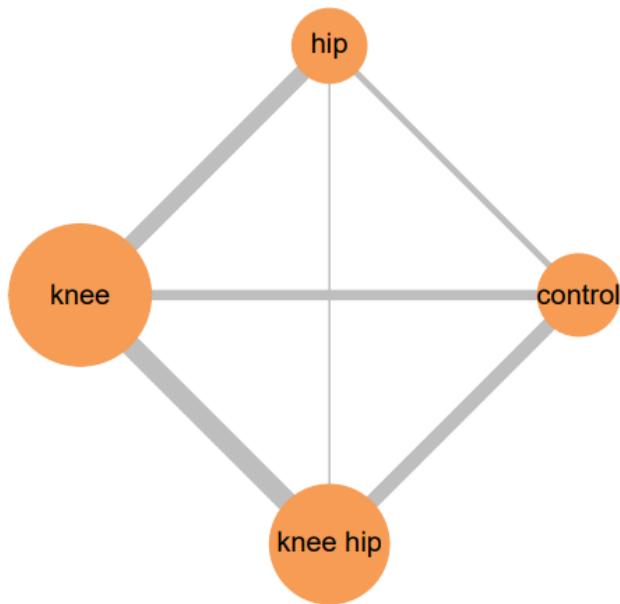


Figure 6 - Network plot "AKPS"

Figure 6 shows the network plot for the outcome parameter “AKPS”. The size of each node reflects the number of participants allocated to each intervention, indicating that the largest sample size was in the “knee” group, followed by “knee+hip”, “control” and “hip”. The thickness of the connecting lines is proportional to the number of studies contributing direct comparisons between each intervention. Therefore, the most commonly studied comparison was “knee” vs. “knee+hip”, followed by “knee” vs. “hip”, and “control” vs. “knee+hip”. Comparisons with fewer studies included “knee” vs. “control”, followed by “control” vs. “hip”, and the least common comparison was “hip” versus “knee+hip”.

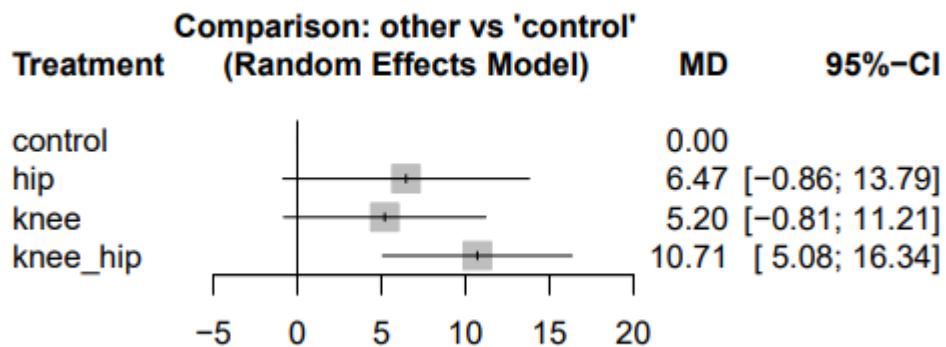


Figure 7 - „AKPS Forest Plot "Intervention VS Control"

The forest plot for the AKPS category (Figure 7) illustrates the comparative effects of the three intervention groups (hip, knee and knee+hip) against the control group. The mean difference (MD) represents the average improvement in AKPS scores, with higher values indicating better outcomes. The 95% confidence interval (CI) reflects the degree of uncertainty around the MD, results are considered statistically significant if the CI does not include zero.

Among the interventions, the “knee+hip” group showed the greatest improvement in AKPS scores compared to the “control” group (MD = 10.71, 95% CI 5.08 to 16.34), followed by the “hip” group (MD = 6.47, 95% CI -0.86 to 13.79) and the “knee” group (MD = 5.20, 95% CI -0.81 to 11.21). Of the three interventions, only the “knee+hip” group showed a statistically significant improvement, as the 95% confidence intervals for both “hip” and “knee” groups crossed zero and were therefore not significant.

knee&hip	-0.10 [-13.12; 12.92]	6.49 [1.38; 11.60]	9.84 [2.98; 16.70]
4.24 [-2.63; 11.10]	hip	0.25 [-7.33; 7.82]	4.92 [-4.77; 14.61]
5.51 [0.95; 10.07]	1.27 [-5.21; 7.75]	knee	8.44 [0.36; 16.52]
10.71 [5.08; 16.34]	6.47 [-0.86; 13.79]	5.20 [-0.81; 11.21]	control

Table 13 - League Table "AKPS"

The league table for AKPS outcomes (Table 13) highlights the combined “knee+hip” intervention as the most effective approach, with the highest improvement in functional scores compared to all other groups. This intervention significantly outperformed the control group (MD = 10.71, 95% CI 5.08 to 16.34) and also showed a meaningful difference compared with the knee group alone (MD = 5.51, 95% CI 0.95 to 10.07). In contrast, the hip and knee interventions alone did not show a statistically significant advantage over the control group, as their confidence intervals included zero. Of all treatment options, the knee+hip combination was the most consistently beneficial.

4. Discussion

4.1 Response to the Research Question and Interpretation of Results

The objective of this systematic review and network meta-analysis was to determine whether targeted strengthening of the quadriceps and/or hip muscles is effective in reducing pain and improving function in people with patellofemoral pain syndrome (PFPS) and to determine which intervention approach produced the most favourable results.

The results of this review clearly showed that all active exercise interventions, whether knee, hip or combined knee+hip, were superior to control conditions in reducing self-reported pain intensity, as measured by validated scales such as the Visual Analogue Scale (VAS) and the Numeric Rating Scale (NRS). Among these, the combined intervention group (hip+quadriceps strengthening) showed the largest and most statistically significant effect size for pain reduction, followed closely by hip strengthening alone. Quadriceps-only interventions, although effective, showed comparatively smaller improvements.

These findings are consistent with current theories emphasizing the role of muscular deficits in the pathophysiology of PFPS. It appears that combining hip and knee strengthening may offer a more comprehensive approach to improving lower limb alignment. By addressing both proximal and local stabilisers, such interventions could enhance overall neuromuscular control and reduce the probability of muscular imbalances. This integrated training strategy may optimise movement patterns during everyday and athletic tasks, potentially supporting long-term improvements in symptoms and lowering the risk of reoccurrence.(33–35)

In addition to biomechanical mechanisms, the observed pain reduction across all active interventions may also reflect the effects of exercise-induced hypoalgesia (EIH). This phenomenon describes a temporary decrease in pain sensitivity after physical activity, which is mediated by central and peripheral neurophysiological mechanisms. Recent findings indicate that EIH may play a role in alleviating symptoms associated with chronic musculoskeletal conditions, such as PFPS.(15,16)

While muscle-specific effects were important, the structure of the training protocols themselves, particularly regarding duration and frequency, may also have influenced the outcomes observed. The differences in the duration of intervention and frequency of sessions across studies offered different insights into the design of muscular rehabilitation programmes for PFPS. The fact that most studies used a six-week duration (15/30) and the majority used three training sessions per week (17/30) suggested that the researchers tended to follow established clinical recommendations. This consistency supported the external validity of the results and suggested that a 6-week protocol with three sessions per week was widely regarded as a standard regimen.

At the same time, the existence of studies of shorter (2 or 4 weeks) and longer (8 or 12 weeks) duration, as well as variations in session frequency (from 1-2 sessions to 6 sessions per week), illustrated the diversity of approaches to optimising treatment effects. These differences may have reflected different clinical goals, differences in patient populations or attempts to explore the dose-response relationship of training intensity. Although most studies followed a common protocol, the observed variations could have provided valuable insights into the minimum effective dose and potential benefits of more intensive interventions.

The AKPS analysis indicated that combined training programmes focusing on the hip and knee extensor muscles delivered superior outcomes in terms of function and pain management when compared to isolated interventions targeting only the hip or knee. It is interesting to note that all three intervention groups (hip training only, knee training only, combined) led to a significant reduction in pain on the VAS and NRS pain scales. However, it was the combined training that showed a significant improvement in the AKPS, which takes functional performance into account in addition to pain assessment.

One potential explanation for this could be found in the enhanced functionality of combined training forms. While isolated knee extension exercises, such as leg extensions, are effective in addressing specific muscle groups under controlled conditions, they do not fully reflect the complex, multi-joint requirements of everyday life or sporting activities. In contrast, combined exercises such as lunges engage active neuromuscular control and coordinated movements across multiple joints, therefore offering more realistic training stimuli.

Furthermore, these exercises contributed to enhanced stability and alignment of the leg axis, particularly in the frontal and sagittal planes. This was crucial for the prevention or correction of dynamic misalignments, such as valgus or varus deviations, which often contributed to the development or maintenance of patellofemoral pain syndrome. The simultaneous loading of the proximal (near the hip) and distal (near the knee) muscles stabilised the lower limb as a whole.(36)

Another relevant aspect to consider was the importance of balance between the muscle groups. The focus of strength training on the quadriceps, particularly the vastus medialis, without concurrent emphasis on the gluteal and ischiocrural muscles, resulted in a muscular imbalance. This may have resulted in increased tension on the kneecap, which is not sufficiently compensated for and could therefore could have caused new complaints. Conversely, combined training was shown to promote balanced activation of the entire leg musculature along the axis of movement.(37)

Several studies included in the review demonstrated positive trends with regard to patient-relevant endpoints, including quality of life and long-term pain relief. The mentioned effects were observed in studies with extended follow-up periods, thereby underscoring the significance of a sustainable training regime. The integration of knee and hip strengthening exercises appeared to play a role in the stabilisation of symptoms and the prevention of recurrences, particularly in the long term follow ups.

4.2 Critical Reflexion on Content and Methods

This work was subject to several limitations inherent to the methodology of systematic reviews. Firstly, it was based exclusively on previously published literature, which may have led to publication bias in favour of studies with positive results. Studies reporting negative or non-significant findings are less likely to be published, which can distort the true effect sizes presented in meta-analyses.

Secondly, the analysis was restricted to studies published in English, which may have introduced a potential language bias and limited the comprehensiveness of the evidence

base, particularly in a global context, where high-quality research from non-English-speaking countries may have been excluded, potentially omitting relevant data and reducing the generalisability of the findings.

Although the majority of the included studies were randomised controlled trials (RCTs), several were non-randomised or observational in nature, which inherently increased the risk of bias due to the absence of randomisation and potential influence of confounding factors. Even among the RCTs, there was considerable variability in blinding methods (e.g. open-label, single-blind), intervention durations, and follow-up periods, which may affect the consistency and comparability of outcomes. These methodological differences contributed to statistical and clinical heterogeneity, which should have been taken into account when interpreting the results.

When interpreting the findings of this review, it was important to consider several limitations regarding sample size and generalisability. A number of the included studies featured relatively small sample sizes, which may have reduced statistical power and increased the risk of type II errors. Such limited sample sizes can hinder the ability to detect subgroup effects and may have led to treatment efficacy being either over- or underestimated.

Furthermore, participant recruitment strategies varied widely across studies and were often restricted to specific settings such as university clinics, military populations or sports medicine centres. This may have resulted in the study populations not being fully representative of the broader PFPS population. Variability in lifestyle, cultural context, healthcare access and adherence to exercise regimens may have further influenced treatment outcomes and limited the generalisability of the findings.

Another important limitation was the potential influence of individual psychological and physiological characteristics, which were not consistently reported or controlled for across studies. Factors such as pain catastrophising, fear of movement beliefs, prior physical activity levels and baseline pain modulation capacity (e.g. central sensitization or impaired endogenous pain inhibition) may have affected both perceived pain intensity and

responsiveness to exercise therapy.(16)These individual differences introduced additional variability and may have helped explain the heterogeneity of outcomes observed between trials.

Consequently, future research should utilise methodologically comparable instruments to record quality of life, whilst also systematically documenting long-term progression. This approach was considered the most reliable method for evaluating the efficacy of sustainable therapy and the potential benefits of specific exercise programmes. Furthermore, it would be logical to place greater emphasis on psychosocial factors, as research demonstrated a correlation between these factors and the chronification of pain, as well as treatment outcomes in PFPS.(3)

An additional challenge was the variety of exercise interventions used in the studies. While all trials focused on strengthening the quadriceps and/or hip muscles, the exact type, frequency, intensity and supervision of exercises varied considerably. This lack of standardisation made it difficult to interpret effect sizes and limits the ability to draw specific conclusions about optimal training protocols. Furthermore, the incorporation of both direct and indirect comparisons in the network meta-analysis was predicated on the assumption of homogeneity, a prerequisite that may have not been fully satisfied given the heterogeneity of study designs and populations.

Therefore, limitations in study design, such as inadequate blinding, incomplete outcome data or unclear allocation procedures, may have introduced bias that could have affected the internal validity of individual studies and consequently, the strength and trustworthiness of the synthesized conclusions. The overall quality and reliability of the evidence were further influenced by the methodological rigor of the included trials, which was systematically assessed using the Cochrane Risk of Bias tools ROB2 for randomised studies and ROBINS-I for non-randomised studies.

4.3 Suggestions for Future Research

Although PFPS is one of the most commonly reported musculoskeletal complaints, particularly in adolescents and young adults who participate in sports, its exact aetiology is still not fully understood. A variety of intrinsic and extrinsic factors have been proposed, including biomechanical misalignment, muscular imbalance, overuse and psychological components. However, the interplay between these potential contributors remains poorly understood. This continuing uncertainty makes it difficult to develop targeted, evidence-based prevention strategies, which are essential to reduce the incidence and recurrence of PFPS.

Current research frequently treats patients suffering from PFPS as a homogeneous group, despite the acknowledged variability in the aetiology and response to treatment of this condition. Future research should prioritize the development and implementation of stratified or personalised approaches that consider individual biomechanical, psychosocial, and lifestyle factors.(23,28)

Epidemiological data shows that PFPS is more common in women than in men. Although several hypotheses have been proposed to explain this sex difference - such as anatomical characteristics (e.g. increased Q-angle), hormonal fluctuations and differences in neuromuscular control - none of these factors has been definitively established as a primary cause. Many studies have looked at the female population in isolation, which can provide useful insights into the sex-specific presentation. However, what appears to be largely lacking in the current literature is a systematic comparison between female and male patients with PFPS. Such comparative studies could help to clarify whether the underlying mechanisms truly differ between the sexes and whether these differences warrant different preventive or therapeutic approaches.(6,38)

Future research should aim to address this gap by explicitly designing studies that include both female and male participants and analysing sex differences in biomechanics, muscle activation patterns, treatment response and long-term outcomes. A better understanding of these variables could pave the way for the development of more individualised, gender-specific intervention strategies. Furthermore, the integration of multidisciplinary

approaches - including biomechanical, hormonal and neuromuscular assessments - may contribute to a more comprehensive understanding of PFPS and ultimately improve both prevention and treatment outcomes.

In this review, we focused on comparing exercise interventions targeting different muscle groups, such as the quadriceps and hip muscles. While this provides valuable insight into the relative effectiveness of proximal versus local muscle strengthening, future studies and systematic reviews should aim for a more refined and refined analysis of exercise modalities. This includes distinguishing not only the anatomical focus of the intervention, but also the specific characteristics of the exercises used such as type of movement, mode of muscle contraction (e.g. eccentric vs. concentric), training intensity, volume, frequency and progression strategies. A more detailed approach would allow a deeper understanding of the underlying mechanisms of action and support the development of more tailored, evidence-based rehabilitation protocols for people with PFPS.

An important perspective for the management of patellofemoral pain syndrome (PFPS) and a promising direction for future research is the consideration of the biopsychosocial model. While PFPS has traditionally been viewed through a biomechanical lens, there is increasing evidence that psychosocial factors influence pain perception and recovery. One such factor is kinesiophobia, the fear of movement due to pain or the risk of injury, which has been associated with greater disability and poorer outcomes.

This suggests that effective management of PFPS may require more than just physical therapy. Addressing psychological components, such as fear-avoidance behaviours, pain catastrophizing or low self-efficacy, may improve treatment adherence and long-term recovery. Future studies should therefore further explore the integration of psychological support into PFPS care, and investigate which patient subgroups may particularly benefit from a biopsychosocial approach.(39)

5. Conclusion

This systematic review and network meta-analysis confirms that targeted muscle strengthening significantly reduces pain in people with patellofemoral pain syndrome, with combined hip and quadriceps exercises showing the greatest overall effectiveness. While all active interventions outperformed control conditions in terms of pain reduction, only the combined approach resulted in significant improvements in pain and function as measured by the Anterior Knee Pain Scale. These findings support the integration of both proximal and local strengthening strategies into clinical rehabilitation protocols. Further research should continue to explore individualised training modalities and long-term outcomes to optimise therapeutic strategies for diverse PFPS populations.

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Appendix

Ethical Approval

No ethical approval was required as the study was based on retrospectively analysed data already published in the scientific literature.

Screening and Selection Process Using Rayyan

The initial screening of titles and abstracts and the selection of full texts was carried out using Rayyan (<https://rayyan.ai>), a web-based tool designed to facilitate the systematic review process. After removing duplicates, two independent reviewers screened all identified records for eligibility. Conflicts were resolved by discussion or by involving a third reviewer.

Rayyan allowed blinded screening and tagging of included and excluded studies, ensuring efficient collaboration and transparency in the selection process. Reasons for exclusion at the full-text stage were documented within the platform and are summarised in Table 4.

AI Tools

As a non-native speaker of English, I used the DeepL Write and Scribbr paraphrasing tools to assist with grammar and the reformulation of phrases to enhance comprehension and clarity. Therefore, some wording was improved and changed where necessary, but the content itself remained unchanged.

The reference management software Anara was used to verify and standardise citations and references.

I used ChatGPT to refine the LaTeX codes for formatting and optimising the tables included in this thesis.

Tables for Statistical Analysis

NMAStudio 2.0

studlab	intervention	N	TE	seTE	year	rob	age
Asif_2022	knee	14	2.28	1.54	2022	1	45.6
Asif_2022	knee&hip	14	1.71	1.06	2022	1	45.6
Baldon_2014	hip	15	1.4	1.4	2014	1	45.6
Baldon_2014	knee	16	3.1	3.2	2014	1	45.6

Crossley_2002	control	35	5.0	2.5	2002	1	45.6
Crossley_2002	knee&hip	36	3.0	2.0	2002	1	45.6
da_Silva_2021	control	30	6.07	2.2	2021	1	45.6
da_Silva_2021	knee&hip	30	1.9	1.8	2021	1	45.6
Dolak_2011	hip	17	2.4	2.0	2011	1	45.6
Dolak_2011	knee	16	4.1	2.5	2011	1	45.6
Emamviridi_2019	control	32	6.1	1.12	2019	1	45.6
Emamviridi_2019	knee&hip	32	3.1	1.61	2019	1	45.6
Ferber_2015	hip	111	1.96	1.92	2015	1	45.6
Ferber_2015	knee	88	1.99	2.05	2015	1	45.6
Fukuda_2012	knee	26	5.3	1.3	2012	1	45.6
Fukuda_2012	knee&hip	28	1.2	1.1	2012	1	45.6
Fukuda_2010	control	25	5.0	2.5	2010	1	45.6
Fukuda_2010	knee	22	3.4	2.3	2010	1	45.6
Fukuda_2010	knee&hip	21	3.0	1.8	2010	1	45.6
Hossein_2023	knee	12	3.41	0.43	2023	1	45.6
Hossein_2023	knee&hip	12	2.08	0.29	2023	1	45.6
Hott_2020	control	36	3.2	2.14	2020	1	45.6
Hott_2020	hip	39	2.9	1.75	2020	1	45.6
Hott_2020	knee	37	2.6	2.48	2020	1	45.6
Ismail_2013	hip	16	2.0	1.1	2013	1	45.6
Ismail_2013	knee&hip	16	2.3	1.1	2013	1	45.6
Khayambashi_2014	hip	18	2.11	1.6	2014	1	45.6
Khayambashi_2014	knee	18	3.27	2.19	2014	1	45.6
Khayambashi_2012	control	14	6.7	2.4	2012	1	45.6
Khayambashi_2012	hip	14	1.4	1.9	2012	1	45.6
Monika_2016	knee	15	5.53	0.63	2016	1	45.6
Monika_2016	knee&hip	15	3.66	1.04	2016	1	45.6
Nakagawa_2008	knee	7	4.0	2.6	2008	1	45.6
Nakagawa_2008	knee&hip	7	1.1	1.2	2008	1	45.6
Razeghi_2010	knee	16	4.81	1.79	2010	1	45.6
Razeghi_2010	knee&hip	17	3.37	1.50	2010	1	45.6
Saad_2018	control	10	3.69	0.6	2018	1	45.6
Saad_2018	hip	10	0.55	0.8	2018	1	45.6
Saad_2018	knee	10	0.56	0.89	2018	1	45.6
Sahin_2016	knee	27	2	1.11	2016	1	45.6
Sahin_2016	knee&hip	28	1	1	2016	1	45.6
Sharif_2020	knee	15	4.67	0.90	2020	1	45.6
Sharif_2020	knee&hip	15	3.67	1.45	2020	1	45.6
Shetty_2016	knee	15	2.50	1.40	2016	1	45.6
Shetty_2016	knee&hip	15	2.33	1.40	2016	1	45.6
Song_2009	control	30	4.8	2.55	2009	1	45.6
Song_2009	knee	30	2.26	2.20	2009	1	45.6
Song_2009	knee&hip	29	2.62	2.51	2009	1	45.6
van_Linschoten_2009	control	66	3.22	2.8	2009	1	45.6
van_Linschoten_2009	knee&hip	65	2.30	2.5	2009	1	45.6
Zemadanis_2015	hip	12	x	x	2015	1	45.6
Zemadanis_2015	knee	13	x	x	2015	1	45.6

Pain

Study	Intervention	n	Mean	SD
Ali 2020	knee	15	x	x
Ali 2020	hip	15	x	x
Asif 2022	knee	14	2.28	1.54
Asif 2022	knee&hip	14	1.71	1.06
Baldon 2014	hip	15	1.4	1.4
Baldon 2014	knee	16	3.1	3.2
Boling 2006	control	14	x	x
Boling 2006	knee&hip	14	x	x
Chiu 2012	control	6	x	x
Chiu 2012	knee	9	2.8	1.64
Crossley 2002	control	35	5.0	2.5
Crossley 2002	knee&hip	36	3.0	2.0
da Silva 2021	control	30	6.07	2.2
da Silva 2021	knee&hip	30	1.9	1.8
Dolak 2011	hip	17	2.4	2.0
Dolak 2011	knee	16	4.1	2.5
Emamvirdi 2019	control	32	6.1	1.12
Emamvirdi 2019	knee&hip	32	3.1	1.61
Ferber 2015	hip	111	1.96	1.92
Ferber 2015	knee	88	1.99	2.05
Fukuda 2012	knee	26	5.3	1.3
Fukuda 2012	knee&hip	28	1.2	1.1
Fukuda 2010	control	25	5.0	2.5
Fukuda 2010	knee	22	3.4	2.3
Fukuda 2010	knee&hip	21	3.0	1.8
Hossein 2023	knee	12	3.41	0.43
Hossein 2023	knee&hip	12	2.08	0.29
Hott 2020	control	36	3.2	2.14
Hott 2020	hip	39	2.9	1.75
Hott 2020	knee	37	2.6	2.48
Ismail 2013	hip	16	2.0	1.1
Ismail 2013	knee&hip	16	2.3	1.1
Khayambashi 2014	hip	18	2.11	1.6
Khayambashi 2014	knee	18	3.27	2.19
Khayambashi 2012	control	14	6.7	2.4
Khayambashi 2012	hip	14	1.4	1.9
Monika 2016	knee	15	5.53	0.63
Monika 2016	knee&hip	15	3.66	1.04
Nakagawa 2008	knee	7	4.0	2.6
Nakagawa 2008	knee&hip	7	1.1	1.2
Razeghi 2010	knee	16	4.81	1.79
Razeghi 2010	knee&hip	17	3.37	1.50

Saad 2018	control	10	3.69	0.6
Saad 2018	hip	10	0.55	0.8
Saad 2018	knee	10	0.56	0.89
Sahin 2016	knee	27	2	1.11
Sahin 2016	knee&hip	28	1	1
Sharif 2020	knee	15	4.67	0.90
Sharif 2020	knee&hip	15	3.67	1.45
Shetty 2016	knee	15	2.50	1.40
Shetty 2016	knee&hip	15	2.33	1.40
Song 2009	control	30	4.8	2.55
Song 2009	knee	30	2.26	2.20
Song 2009	knee&hip	29	2.62	2.51
van Linschoten 2009	control	66	3.22	2.8
van Linschoten 2009	knee&hip	65	2.30	2.5
Zemadani 2015	hip	12	x	x
Zemadani 2015	knee	13	x	x

AKPS

Study	Intervention	n	Mean	SD
Ali 2020	knee	15	x	x
Ali 2020	hip	15	x	x
Asif 2022	knee	14	91.57	7.65
Asif 2022	knee&hip	14	92.14	5.12
Baldon 2014	hip	15	x	x
Baldon 2014	knee	16	x	x
Boling 2006	control	14	x	x
Boling 2006	knee&hip	14	x	x
Chiu 2012	control	6	x	x
Chiu 2012	knee	9	83.8	7.01
Crossley 2002	control	35	78	12
Crossley 2002	knee&hip	36	86	9
da Silva 2021	control	30	71.83	11.8
da Silva 2021	knee&hip	30	85.8	12.3
Dolak 2011	hip	17	x	x
Dolak 2011	knee	16	x	x
Emamvirdi 2019	control	32	x	x
Emamvirdi 2019	knee&hip	32	x	x
Ferber 2015	hip	111	87.95	11.26
Ferber 2015	knee	88	87.67	10.53
Fukuda 2012	knee	26	64.6	10.2

Fukuda 2012	knee&hip	28	85.7	9.0
Fukuda 2010	control	25	64.5	11.1
Fukuda 2010	knee	22	80.6	13.9
Fukuda 2010	knee&hip	21	78.9	16.0
Hott 2020	control	36	73.1	15.0
Hott 2020	hip	39	73.1	11.47
Hott 2020	knee	37	74.4	14.28
Ismail 2013	hip	16	85.1	6.2
Ismail 2013	knee&hip	16	85.0	6.7
Khayambashi 2014	hip	18	x	x
Khayambashi 2014	knee	18	x	x
Khayambashi 2012	control	14	x	x
Khayambashi 2012	hip	14	x	x
Monika 2016	knee	15	66.2	4.8
Monika 2016	knee&hip	15	79.6	8.4
Nakagawa 2008	knee	7	x	x
Nakagawa 2008	knee&hip	7	x	x
Razeghi 2010	knee	16	x	x
Razeghi 2010	knee&hip	17	x	x
Saad 2018	control	10	81.9	8.41
Saad 2018	hip	10	91.8	5.67
Saad 2018	knee	10	90.11	6.11
Sahin 2016	knee	27	79.1	7.6
Sahin 2016	knee&hip	28	77.9	6.6
Sharif 2020	knee	15	49.20	8.41
Sharif 2020	knee&hip	15	58.23	7.73
Shetty 2016	knee	15	82.28	11.51
Shetty 2016	knee&hip	15	84.93	6.11
Song 2009	control	30	x	x
Song 2009	knee	30	x	x
Song 2009	knee&hip	29	x	x
van Linschoten 2009	control	66	74.9	17.6
van Linschoten 2009	knee&hip	65	78.8	15.5
Zemadani 2015	hip	12	1.4	5.8
Zemadani 2015	knee	13	x	x