

A NARRATIVE REVIEW OF PATELLOFEMORAL PAIN AND ITS BIOMECHANICAL CONTRIBUTORS, NON-PHARMACOLOGICAL MANAGEMENT, AND PREVENTION STRATEGIES RELEVANT TO RUNNERS

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ABSTRACT

Background: Patellofemoral pain (PFP), historically termed patellofemoral pain syndrome (PFPS), is a common and often persistent musculoskeletal condition among physically active individuals and runners. Its development is multifactorial, involving interactions between lower-limb biomechanics, muscle function, training exposure, and environmental demands. Runners exposed to uphill and downhill terrain may experience altered patellofemoral joint loading; however, evidence specifically addressing prevention in hilly-terrain running populations remains limited.

Objective: This narrative review synthesised evidence on biomechanical contributors to PFP, non-pharmacological management approaches, and prevention strategies relevant to runners.

Methods: Literature was identified through database searches and reference list screening. Searches addressed PFP/PFPS and related terms, biomechanical and aetiological factors, running, and non-pharmacological prevention and management. Of 81 identified records, 39 duplicates were removed, and 42 records underwent title and abstract screening. Eighteen full-text reports were sought, of which 13 were assessed for eligibility; 12 studies were included in the final narrative synthesis. Evidence was interpreted with attention to study design, diagnostic definitions, population characteristics, intervention components, outcome measures, follow-up duration, and applicability to runners.

Results: Biomechanical factors associated with PFP include impaired hip and knee muscle function, altered frontal- and transverse-plane lower-limb mechanics, reduced knee flexion during running or functional tasks, and foot-related factors such as increased pronation or rearfoot eversion. These factors should be interpreted cautiously because much of the evidence is cross-sectional and therefore does not establish causality. Exercise therapy and patient education represent the principal components of non-pharmacological management. Hip- and knee-targeted strengthening, combined interventions, patellar taping, foot orthoses, gait retraining, and lower-quadrant manual therapy may provide benefit for selected individuals; however, adjunctive treatments should be tailored to the patient's clinical presentation. Prevention evidence remains limited. Supervised lower-limb exercise programmes, patellofemoral bracing in selected high-risk populations, and running-technique retraining show potential preventive benefit, whereas evidence for foot orthoses, stretching, footwear modification, and education alone is inconsistent or of low certainty.

Conclusion: PFP in runners should be understood as a multifactorial condition rather than the consequence of a single biomechanical abnormality. Individualised exercise-based management and education are the most consistently supported approaches, with adjunctive interventions selected according to patient presentation and running-related demands. High-quality prospective studies are required to establish modifiable causal risk factors and to evaluate feasible, context-specific prevention programmes, particularly for runners exposed to sustained uphill and downhill terrain.

KEYWORDS: Patellofemoral pain; patellofemoral pain syndrome; runners; biomechanics; exercise therapy; injury prevention; gait retraining; foot orthoses; non-pharmacological management.

1. INTRODUCTION

1.1. Patellofemoral Pain and Its Relevance to Runners

Sports are beneficial to health, but also cause injuries [1]. Due to its low cost, running is the most popular form of sport. Twenty years ago, and even now, patellofemoral pain syndrome (PFPS) is the most frequent overuse running ailment, with the highest prevalence of 68% among Indian marathon runners [2]. The recurrent or chronic symptoms affect 70% to 90% of the Patellofemoral Pain (PFP) population, in some cases for up to 20 years, which may precede the onset of patellofemoral osteoarthritis (PFOA), the more prevalent than tibiofemoral osteoarthritis [3],[4] and has no cure [5]. As per the World Health Organisation (WHO) report published on 14th July'2023, "In 2019, about 528 million people were living with osteoarthritis (OA) worldwide, which is an increase of 113% since 1990", and it is the most common musculoskeletal illness and the primary source of chronic pain and disability[6],[7]. Residents of hilly terrain may be more susceptible to PFPS because it is typically triggered by loading of the knee extensor mechanism [3], such as climbing or descending stairs or slopes, squatting, kneeling, cycling, running, or prolonged sitting with flexed knees [2]. Therefore, we consider them a high-risk population for this condition, given the limited research on this topic.

In 2011, "The Patellofemoral Pain (PFP) Consensus Statement" advocated for a longitudinal, prospective study to establish a cause-and-effect relationship in PFPS [8]. The possible components of PFPS aetiology (Table 2.1) include genetic, environmental, and training factors [9].

1.2 Diagnostic Terminology and Differential Diagnosis

Anterior knee pain is a symptom rather than a specific diagnosis and may arise from several conditions affecting the patellofemoral region. Table 1 summarises the principal differential diagnoses, their distinguishing clinical features, and commonly associated clinical findings.

Table 1: Differential diagnosis of the conditions that cause Anterior Knee Pain.

Sl.No.	Diagnosis	Distinguishing symptoms	Clinical findings
1.	Patellar tendinopathy	Patellar tendon pain, exacerbated by squatting	Tenderness along the inferior pole of the patella. Pain aggravated by resisted quadriceps contraction
2.	Quadriceps tendinopathy	Pain in the upper area of the knee	Tenderness along the superior margin of the patella. Pain aggravated by resisted quadriceps contraction.
3.	Fat pad impingement (Hoffa's disease)	H/o hyperextension injury. Sudden onset of pain.	Tenderness deep to the patellar tendon (in the fat pad region)
4.	Patellar instability	History of recurrent buckling of the knee	Patella alta (High riding patella)
5.	Synovial plica	Complaint of sharp pain in any of the three compartments of the knee, and clicking associated with pain	Palpable and tender plica with positive Stutter test and the Hughston test, both.
6.	Prepatellar bursitis	Swelling in front of the patella h/o repeated kneeling activities	Cystic localised mobile swelling in front of the patella
7.	Infrapatellar bursitis	Swelling in front of the patella h/o repeated kneeling activities	Tenderness deep to the distal end of the patellar ligament
8.	Pes anserinus bursitis	Pain at the anteromedial part of the knee.	Tenderness (and sometimes a diffuse swelling) at the medial part of the proximal tibia

1.3 Patello-Femoral Pain VS Anterior Knee Pain

As many authors have used the term “overuse anterior knee pain (AKP), synonymous with patellofemoral pain syndrome (PFPS), we did an individual study search with the keywords of patellofemoral pain/ overuse anterior knee pain/prevention/runners, which is summarised below one by one.

Coppack et al. (2011) conducted a cluster RCT with 1502 UK Army recruits to test an exercise prevention program for overuse anterior knee pain (AKP/PFPS). The intervention group (n=759) performed 8 targeted exercises (quadriceps/gluteal strengthening + stretching) 7x/week during 14-week basic training, while controls (n=743) followed standard warm-ups. The program reduced AKP incidence by 75% (4.8% in the control vs 1.3% in the intervention; HR 0.25, p<0.001) and medical discharges by 88%, with 91% compliance under supervision. This demonstrates that simple supervised lower-limb exercises effectively prevent PFPS in high-risk populations undergoing intense physical conditioning [10].

Alexander et al. (2022) reviewed 18 RCTs for preventing running-related knee injuries: gait retraining ("run softer") significantly reduced risk by 66% (RR 0.32, low-certainty). Minimalist/traditional shoes (RR 0.73), soft/hard midsoles (RR 0.81), online programs (RR 0.89), and foot strengthening showed no effect (low/very low-certainty). Graduated programs and education are also ineffective [11].

Crossley et al. (2019) reviewed RCTs (mostly on military recruits) for PFPS prevention. Patellofemoral braces reduced risk by 50-74% (2 RCTs). Lower limb strengthening/stretching mixed: 75% ↓ in one RCT, no effect in others. Foot orthoses/footwear showed no significant benefit (3 RCTs). Quadriceps weakness is the primary modifiable risk factor [12].

Faller et al.'s (2021) Commentary advocates integrating Eccentric Exercise (EE) into prevention programs for patellofemoral pain (PFP/PFPS) in high-volume runners, citing EE's benefits, including greater force production, hypertrophy, and neural adaptations that build tissue capacity to withstand the demands of running. It reviews PFP risk factors (e.g., quadriceps/hip eccentric weakness) and proposes exercises such as single-leg squats and hip hikes, despite limited direct evidence for prevention. Authors call for prospective studies to validate EE's role, especially among military recruits[13].

Joseph et al. (2016) conducted surveys of 150 university athletes on their knowledge of how to prevent various sports injuries, including Runner's Knee/Patellofemoral Pain Syndrome (PFPS) and shin splints (SS), to slow ageing through fitness. Athletes showed strong PFPS awareness (significant t=4.87, p<0.05) compared to other sports injuries, such as Achilles tendinitis and shin injuries. Recommends seminars, workshops, and screenings for improved prevention strategies [14].

Grant et al. (2021), in their systematic review/meta-analysis of 56 studies, warn that methodological heterogeneity (task type, joint position, imaging modality) prevents a universal definition of patellar maltracking in PFPS. Greater lateral patellar shift (SMD=0.54) and tilt (SMD=0.71) were observed in PFPS vs controls, but confounding factors (age, sex, instability history) explained 30-50% of the variance. Patients with instability showed 2x greater maltracking than those with isolated PFPS (SMD shift=0.71, tilt=1.38), calling maltracking's causal role into question. Calls for standardised kinematic protocols to clarify PFPS aetiology beyond current inconsistent evidence[15].

There is a very limited review directly focusing on the prevention of PFPS with varying degrees of evidence certainty. Several systematic reviews have reported that the incidence of patellofemoral pain among the general population and

runners may be reduced by addressing modifiable biomechanical factors, establishing targeted exercise programs, and altering running mechanics (e.g., technique retraining). Pre-season, mechanism-based preventive interventions for runners are justified [11], [16], [17], [18].

Our previous narrative review examined distal biomechanical influences on knee pain and non-pharmacological management, including applications of three-dimensional printing [19]. The present review focuses specifically on patellofemoral pain relevant to runners, integrating evidence on biomechanical contributors, management, and prevention. Particular attention is given to distinguishing treatment outcomes in symptomatic individuals from evidence supporting the prevention of first-onset patellofemoral pain.

2. METHODOLOGY

2.1. Review design and objectives

This article was developed as a narrative review to critically synthesise the literature on the aetiology, biomechanical contributors, and non-pharmacological prevention and management of patellofemoral pain (PFP), also described as patellofemoral pain syndrome (PFPS). Particular attention was given to evidence relevant to runners and other physically active populations, as well as the potential implications of uphill and downhill running. The review addressed three principal questions: (1) which intrinsic and extrinsic factors are associated with PFP or prospectively associated with its development; (2) which non-pharmacological interventions have been investigated for its prevention and management; and (3) what evidence gaps remain regarding preventive interventions for runners exposed to hilly terrain?

A narrative approach was selected to integrate evidence from diverse study designs and to distinguish clinical intervention findings from epidemiological associations and proposed biomechanical mechanisms. The review was not designed to provide an exhaustive systematic identification of all eligible studies or to generate pooled effect estimates.

2.2. Information sources and literature search

The literature search was conducted using [retain only the sources actually searched: PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library]. Google Scholar was used as a supplementary source [if applicable]. Searches were performed between [insert search dates], with the final search completed on [insert date]. The publication period covered [insert the actual date range or state “database inception to the final search date”].

Search terms were organised into three complementary domains: PFP and its associated terminology; aetiological and biomechanical factors; and preventive or therapeutic interventions. Terms within each domain were combined using the Boolean operator “OR”, and relevant domains were combined using “AND”. Controlled vocabulary and free-text terms were used where supported by the database.

The search terminology included “patellofemoral pain”, “patellofemoral pain syndrome”, “anterior knee pain”, and “runner’s knee”, together with combinations of “risk factor”, “aetiology”, “etiology”, “biomechanics”, “patellar tilt”, “patellar tracking”, “hip strength”, “hip flexor tightness”, “iliotibial band”, “foot pronation”, “prevention”, “exercise therapy”, “strengthening”, “stretching”, “neuromuscular training”, “gait retraining”, “foot orthoses”, “taping”, and “bracing”. Additional searches incorporating “running”, “runner”, “trail running”, “uphill”, “downhill”, and “incline” were undertaken to identify literature relevant to running and terrain-related loading [retain only terms and additional searches actually used].

Searches addressing aetiology and risk factors were performed separately from searches addressing prevention and management to avoid restricting the evidence base to intervention studies. Reference lists of relevant articles and reviews were examined to identify additional publications [if performed]. Textbooks were consulted for anatomical and clinical background [if applicable], but were not treated as primary evidence of intervention effectiveness.

The database-specific search strategies, search dates, and applied restrictions are provided in [insert supplementary material identifier, if prepared].

2.3. Eligibility criteria

English-language publications with accessible full texts were considered for inclusion when they addressed at least one of the following:

- The epidemiology, aetiology, or factors associated with PFP.
- Lower-limb biomechanics or neuromuscular characteristics relevant to patellofemoral loading.
- Non-pharmacological interventions intended to prevent PFP or reduce its incidence.
- Non-pharmacological interventions intended to improve pain, function, or activity participation in individuals with established PFP.
- Running-related or terrain-related loading mechanisms with a clearly stated relevance to PFP.

Eligible evidence included randomised controlled trials, prospective and retrospective observational studies, cross-sectional and case-control studies, laboratory biomechanical investigations, systematic reviews, meta-analyses, and clinical consensus or practice guidance. Relevant narrative reviews and commentaries were considered for conceptual background and identification of research gaps, rather than as direct evidence of preventive efficacy.

Studies involving runners were prioritised. Research involving other physically active populations, adolescents, adults, and military recruits was considered where relevant to PFP, with differences in population and training exposure taken into account during interpretation. Investigations involving healthy participants or individuals with patellofemoral osteoarthritis were considered only as supplementary mechanistic or contextual evidence and were not treated as direct evidence of PFP prevention.

Publications were excluded when they addressed unrelated knee conditions without a clear connection to PFP, investigated pharmacological or surgical treatment alone, or did not provide sufficient information to interpret the relevant methods and findings. Duplicate records and overlapping reports were handled by [describe the procedure actually used]. Any additional restrictions concerning publication type, participant age, or publication period were [insert actual restrictions].

2.4. Article selection and diagnostic classification

Article selection involved assessing titles and abstracts, followed by examining potentially relevant full texts. Selection was undertaken by [insert the actual number of reviewers and their roles]. Where more than one reviewer participated, disagreements were resolved by [insert the procedure actually used]. Records were managed using [insert software or state that records were managed manually].

During full-text assessment, the diagnostic terminology and case definition used in each study were examined. Studies reporting “anterior knee pain” were not automatically classified as studies of PFP. Instead, their diagnostic criteria and exclusion procedures were reviewed to determine whether the findings could reasonably be interpreted as PFP-specific evidence. Where the diagnosis remained unclear, the study was described using its original terminology, and this uncertainty was considered during synthesis.

Prevention studies involving participants without PFP at baseline were distinguished from treatment studies involving participants with established symptoms. Studies assessing recurrence or secondary prevention were identified separately where applicable.

2.5. Data extraction and critical interpretation

Information from the selected publications was summarised using [insert the actual extraction approach: a structured extraction form, spreadsheet, or evidence table]. The information recorded included author and publication year, study design, population characteristics, sample size, diagnostic criteria, exposure or intervention, comparator, intervention duration, follow-up period, outcome measures, principal findings, and reported limitations.

For aetiological and risk-factor studies, particular attention was given to whether the proposed exposure was measured before the onset of PFP. Findings from prospective studies were distinguished from cross-sectional associations, and characteristics measured after symptom onset were not interpreted as established causal risk factors.

For intervention studies, the extracted information included exercise or treatment components, frequency, intensity, duration, progression, supervision, adherence, and adverse events where reported. Clinical outcomes included PFP or anterior knee pain incidence, pain intensity, functional scores, activity participation, and recurrence. Biomechanical outcomes included joint kinematics, kinetics, muscle activation, strength, flexibility, and measures of patellar alignment or tracking.

Critical interpretation considered study design, sample size, diagnostic clarity, comparator suitability, follow-up duration, precision of reported estimates, and applicability to runners. [Insert the actual appraisal procedure. If no formal appraisal was performed, state: “No formal risk-of-bias tool or evidence-certainty grading framework was applied; methodological limitations were considered qualitatively.”]

2.6. Narrative synthesis

The evidence was synthesised narratively under the following thematic domains: aetiology and associated factors; running and lower-limb biomechanics; non-pharmacological management; preventive interventions; and implications for runners exposed to hilly terrain.

Within each domain, findings were compared according to study design, population, diagnostic definition, intervention characteristics, outcome measures, and follow-up duration. Direct clinical evidence was distinguished from mechanistic findings and theoretical explanations. Improvements in pain or function among symptomatic participants were not interpreted as proof that an intervention prevents first-onset PFP. Similarly, changes in biomechanical measurements were not assumed to demonstrate a reduction in injury incidence unless this outcome was assessed.

Where systematic reviews and primary studies addressed overlapping evidence, their findings were interpreted together without treating repeated reports of the same trial as independent confirmation. Effect estimates and confidence intervals were reported where available, with uncertainty and inconsistencies considered alongside the direction and magnitude of findings.

No new meta-analysis was undertaken. Published pooled estimates were attributed to the original systematic reviews. Implications for hilly-terrain runners were described as direct findings only when studies specifically examined that population or exposure; otherwise, they were presented as extrapolations requiring further investigation.

2.7. Study Identification and Selection

The literature search identified 81 records: 63 from database searches and 18 from reference-list screening. After removing 39 duplicate records, 42 records were screened by title and abstract. Twenty-four records were excluded at this stage, and 18 full-text reports were sought for retrieval. Five reports could not be retrieved; therefore, 13 full-text reports were assessed for eligibility. One report was excluded following full-text assessment, and 12 studies were included in the final narrative synthesis.

3. Aetiology and risk factors of Patellofemoral pain

Patellofemoral pain syndrome (PFPS) arises from a multifactorial aetiology, including biomechanical malalignments. Table 2 provides a chronological review of early literature that elucidates these etiological insights and risk profiles, thereby informing targeted prevention and rehabilitation.

Table 2: Early work on the aetiology and risk factors of PFPS.

Sl. No.	Author and Year	Aetiology and Risk Factors
1	D. M. Pretorius et al. (1986) [20]	a. Foot Pronation b. Running Mileage c. Hill Running d. Shoe Type
2	S. P. Messier et.al (1990) [21]	a. Running Mileage b. Q-angle

		c. Knee extensor strength
3	E. Witvrouw et al. (2000) [22]	a. Quadriceps Inflexibility b. Hypermobility Patella c. Gastrocnemius Flexibility
4	M. J. Duffey et al. (2000) [9]	a. Pronation b. Arch index c. Shoe mileage d. Quadriceps Strength
5	J. E. Taunton et al. (2002)[23]	a. 30 years of age b. Knee Varus c. Femoral Anteversion d. Inexperience
6	V. Lun et al. (2004)[24]	a. Ankle Dorsiflexion b. Knee Genu Varum c. Forefoot Varus d. Static Alignment
7	G. R. Waryasz et al. (2008)[25]	a. Weakness In Functional Testing b. Gastrocnemius Tightness c. Hamstring Tightness d. Quadriceps Tightness e. Iliotibial (IT) Band Tightness f. Generalised Ligamentous Laxity g. Hamstring Weakness h. Quadriceps Weakness i. Hip musculature weakness
8	E. S. Chumanov et al. (2008) [3]	a. Female b. Hip abductor weakness
9	M. C. Boling et al. (2009) [4]	a. Reduced knee flexion angle b. Increased navicular drop c. Increased hip internal rotation angle
10	R. J. Coppack et al. (2011) [10]	Intrinsic risk factors
11	B. Noehren et al. (2012) [26]	Greater Hip adduction
12	B. Noehren et al. (2012)[27]	a. Greater Hip Adduction b. Hip Internal Rotation c. Tibial Internal Rotation
13	N. E. Lankhorst et al. (2013) [28]	a. Larger Q-Angle b. Sulcus Angle c. Patellar Tilt Angle d. Vastus Medialis Obliquus Wasting e. Quadriceps Weakness f. Hip Abductor Weakness g. Hip External Rotator Weakness

Recent research has advanced understanding of PFPS aetiology beyond traditional biomechanics, emphasising proximal muscle deficits, foot mechanics, and psychosocial factors via prospective cohorts and systematic reviews. Table 3 below summarises recent literature on aetiology and risk factors, with a focus on high-quality prospective designs that inform prevention.

Table 3: Recent work on the aetiology and risk factors of PFPS.

1	V. Middelkoop et al. (2014)	Greater Q-angles, greater sulcus angles, larger patellar tilt angles, lower hip abduction strength (as a percentage of body weight), and lower knee extension strength (peak torque) are all associated with PFP, according to a systematic review of factors associated with the condition. In a prospective cohort study design, more research is needed in high- risk populations, such as sports and military recruits [28].
2	M.M. Haque et al. (2015)	According to a study on the prevalence of OA in ethnic people living in hilly areas of Bangladesh, the knee was the most commonly affected joint. Climbing hills could aggravate it. According to the current survey, 54% of respondents engaged in strenuous hill climbing[29].
3	R. Shroff et al. (2016)	PFP and lower-extremity function were studied in an adolescent Indian population; the prevalence was 87.5%, and 75% of participants reported running impairments, with a gender prevalence of 40% in males and 60% in females. The adolescent growth spurt could be to blame [30].

4	G. Gharote et al. (2016)	PFPS is common in weightlifters, according to a study in Maharashtra, India. It was noted that the patellar grinding test identified PFPS in 80% of those reporting anterior knee discomfort. In an interview, Kujala Score revealed that 18% of lifters had fair results, 46% had good results, and 36% had exceptional results. Additionally, it was noted that 22% of the bilateral limbs were damaged, with the unilateral limb being more afflicted.
5	A. Manoharan et al. (2016)	A study on the prevalence of PFPS in Tamil Nadu, India, which included participants from a range of socioeconomic backgrounds, physical activities, and illnesses, found that almost one-third of the population in the 20–40 age range suffer from PFP, which is concerning. It may be possible to reduce disability and boost productivity by raising awareness of the etiological variables and providing health education to prevent its incidence [31].
6	C. T. Viljoen et al. (2020)	The most frequently injured body part was the knee (26.5%) in a retrospective study of trial runners, with 1 in 4 runners reporting at least 1 Running-Related Injury (RRI) in the past 12 months. Future research should concentrate on prospective cohort study designs with regular follow-up to limit recall bias and establish injury risk factors, which will ultimately lead to the development of specific injury prevention strategies [32].
7	R. Gajardo-Burgos et al. (2021)	There are no differences in age, sex, Body Mass Index (BMI), or competition distance between injured and non-injured runners, according to a study on the prevalence of illness and injury in the final four weeks leading up to a trail-running tournament. One in four athletes said their injuries developed gradually. The author proposed different approaches to preventing injuries, such as learning about the mechanisms and risk factors for injuries, implementing a preventive intervention, and evaluating its efficacy [25].
8	K. Cloosterman et al. (2021)	An online injury prevention program using 10 steps to escape from injuries found no effect on the prevention of RRI in non- professional runners [34].
9	C. N. Fick et al. (2022)	A study examining the impact of demographic factors on PFP found that body weight is a modifiable risk factor affecting both patellar flexion and shift. Losing weight may help individuals who are overweight and have PFP by lowering joint stress and maltracking. According to this study future research should assess the impact of certain factors on PFP, including lower limb strength, pain onset age and the level of physical activity [27].
10	A. Tiwari et al. (2023)	Middle-aged recreational athletes may have higher PFP due to lifestyle variables and the existence of underlying musculoskeletal disorders, according to a survey conducted on runners using the Kujala Score .
11	J. R. De Souza Júnior et al.(2024)	A study using a classification and regression tree model on rearfoot strike runners identified the influence of multiple factors associated with PFP. Subsequent investigations could elucidate whether modifying parameters could potentially mitigate this type of harm [35].
12	Neal et al. (2025)	Analysed biomechanical and biopsychosocial contributors to PFPS, identifying weak hip external rotators, excessive knee valgus, and foot pronation as primary modifiable risk factors across proximal, knee, and distal kinetic chain levels [36]

4. Research Progression on Patellofemoral Pain and Biomechanical Interventions

Zhang et al. (2025): Advances in biomechanical interventions for patellofemoral pain by employing statistical parametric mapping (SPM) to analyse patellofemoral joint (PFJ) loading during stair climbing under varied methods. These findings reveal distinct spatiotemporal PFJ stress patterns (e.g., peak contact forces of 4–6x body weight in deep flexion), highlighting stair ascent as a high-risk task for PFPS exacerbation and underscoring the need for targeted gait retraining/orthotic strategies [37].

Xu et al. (2024): Employs bibliometric analysis on 2,194 PFPS publications (2000–2023), identifying research progression hotspots like biomechanics (e.g., foot orthoses, gait retraining; 15% papers) and interventions (exercise 22%, taping 8%). Key clusters reveal a rising focus on hip strengthening/orthotics for kinematic corrections, with high-citation works (Neal/Crossley) emphasising combined approaches; predict future trends in personalised biomechanics/AI modelling. This visualisation study contextualises biomechanical interventions amid 12.4% annual growth, guiding targeted research on PFPS loading mechanisms [38].

Rathleff's (2023): Doctoral thesis synthesises longitudinal data from adolescent PFPS cohorts and develops a self-management intervention emphasising biomechanical education (gait retraining, load monitoring) to enhance long-term prognosis beyond acute physio. Building on his 2012 cluster Randomised Controlled Trials (RCTs), the study integrates patient-reported barriers (compliance, fear-avoidance) with kinematic analyses and advocates for proximal strengthening/foot orthoses for persistent cases (with 6–24 months of follow-up, resulting in a 70% reduction in recurrence) [39].

Chen et al. (2022): Systematic review/meta-analysis synthesised 6 RCTs (n>300 PFPS patients) on foot orthoses vs. controls/shams, finding significant improvements in knee function (SMD = -0.45, p=0.002) and sport/recreation (SMD = -0.54, p=0.04). No effects on pain intensity/symptoms/quality of life, but additive benefit with exercise; supports orthoses as an adjunct biomechanical intervention despite heterogeneity [40].

Costello et al. (2021): Leverages the multicenter Osteoarthritis Study cohort (n=3,795 knees) to descriptively analyse Ground Reaction Force (GRF) waveforms, revealing higher vertical GRF peaks and prolonged loading in radiographic OA knees with pain versus asymptomatic. These biomechanical patterns suggest that aberrant load distribution precedes symptoms, informing early PFPS interventions, such as gait retraining, to mitigate the progression of PFJ stress from overuse. Large-scale prospective data underscore GRF normalisation via orthoses/strengthening as key targets [41].

Fukusawa et al. (2020): Compared footstrike patterns (heel/midfoot/forefoot) in 106 recreational runners with/without anterior knee pain, finding no significant distribution differences (p>0.05), challenging the hypothesis that rearfoot striking causes PFPS. This case-control gait analysis suggests that other biomechanical factors (e.g., hip control, cadence) drive pain, supporting interventions such as proximal strengthening over strike retraining alone in novice runners [42].

Solomonow-Avnon et al. (2019): Pilot-tested medio-lateral foot Centre-of-Pressure (CoP) shifts to shorten knee lever arm, reducing adduction moment by 12–18% (p<0.01, n=10 healthy) during gait via dynamic platforms. This mechanism elucidates orthotic interventions for PFPS that target varus loading associated with patellar maltracking in runners; it supports the use of custom insoles that shift CoP laterally [43].

Burston et al. (2018): Compared three-quarter-length and full-length standardised foot orthoses during walking/stair descent in 15 healthy + 15 PFPS patients, showing both reduce coronal knee moments to healthy levels (p<0.05, ~20% drop in PFP). Full-length superior for stairs, validating orthoses as a biomechanical intervention normalising aberrant loading in pronators, despite minor FPI mismatches [44].

Collins et al. (2017): Crossover RCT (n=18 PFOA) tested prefabricated orthoses vs. flat sham during step-down/squats, finding no significant immediate pain reduction (p>0.05, moderate ES 0.4–0.6). Despite biomechanical rationale, results question the use of orthoses for advanced PFJ pathology, favouring exercise for runners, which contrasts with acute PFP studies [45].

Ludwig et al. (2016): Examined peroneal pressure-point insoles vs. neutral in 20 healthy individuals during gait, showing increased tibialis anterior activation (20%, p<0.05) and peroneus longus decrease (15%, p=0.08) via EMG. Targeted pressure rebalances ankle evertor/invertor dynamics, potentially aiding PFPS pronation control and reducing Illo-Tibial (IT) Band /hip strain in runners [46].

Buldt et al. (2015): Assessed foot posture function by Foot Posture Index (FPI) and arch height correlations with knee kinematics/kinetics in 83 healthy barefoot walkers, finding trivial associations (r<0.2, p>0.05) for adduction moments/varus alignment. Challenges foot-knee coupling in asymptomatic individuals, suggesting pronation effects emerge in pathology (e.g., PFPS pronators); this limits the rationale to symptomatic loading. A robust cohort tempers expectations for biomechanical interventions [47].

Lack et al. (2014): Repeated-measures study (n=15 PFP) on anti-pronation orthoses during step-up found increased hip flexion (+5°, p<0.05), gluteus maximus activation (+12%, p=0.04), and reduced knee abduction moment (p<0.01). Immediate proximal compensations validate the use of orthoses for kinematic chain realignment during functional tasks, a core feature of PFPS progression in runners [48].

Riskowski et al. (2013): Framingham Foot Study (n=2,320 adults) linked pronated posture (FPI>4, OR=1.48 knee pain) and impaired function (e.g., claw toes) to knee/foot/ankle pain via multivariable models. Population-level evidence establishes that foot pronation is an independent risk factor for lower-extremity pain (including PFP), thereby justifying the use of preventive orthoses in high-risk runners [49].

Rathleff et al. (2012): Protocol details a pragmatic cluster RCT (n=102 adolescents with PFPS across 6 schools), comparing 3-month exercise + education vs self-management for pain/function at 3, 6, and 12 months. Multimodal early intervention targets biomechanical deficits (hip/knee control), addressing a poor prognosis (2–5 year persistence); a pragmatic design enhances translation [50].

5. Non-pharmacological Management of PFPS

Crossley et al. (2002): A randomised, double-blinded, placebo-controlled trial on the efficacy of standardised physiotherapy for PFPS. The intervention included a home exercise programme with patellofemoral joint manipulation and taping, compared with placebo treatment consisting of sham ultrasonography and placebo taping, over six weeks in 71 patients. The study demonstrated that physiotherapy was effective in treating PFPS. However, limitations included imperfect blinding between the physiotherapy and placebo groups, and the inability to blind the treating therapists in this physical therapy trial [51].

Piva et al. (2009): Investigated predictors of pain and function outcomes after rehabilitation in 74 patients diagnosed with patellofemoral pain syndrome. A standardised physical therapy exercise protocol was employed, with baseline measurements of self-reported function and pain, followed by re-measurements at 2 months post-treatment. A key finding was that patients with reduced fear avoidance beliefs had better function and less pain, suggesting that individuals with PFPS should be treated with a reduction in fear avoidance beliefs. Interestingly, there was no correlation between increases in muscle strength and length and the outcome, a surprising finding that warrants further investigation [52].

Van Tiggelen et al. (2011): Examined the intrinsic risk factors and the effects of prophylactic dynamic patellofemoral bracing on the development of PFPS in 169 male subjects. The dynamic patellofemoral brace consisted of knee patches with Velcro and a neoprene sleeve designed to correct patellar alignment. The study concluded that patellofemoral bracing may reduce the risk of PFPS in prone individuals with intrinsic risk factors. However, external validity was limited as the subjects were military officer trainees [53].

Selfe et al. (2011): Conducted a clinical study evaluating the biomechanics of step descent using different treatment modalities for PFPS in 13 patients. The study compared neutral patella taping, a Trupull Advance sleeve knee brace, and no intervention during stair descent. Results demonstrated improved knee control with neutral patella taping and the Trupull Advance sleeve knee brace compared to no intervention, with bracing showing better control than taping. Limitations included the need for a more detailed study on the relationship between biomechanical measurements and clinical evaluation [54].

Barton et al. (2011): Investigated whether greater peak rearfoot eversion predicts foot orthoses efficacy in 26 individuals with PFPS [5]. Prefabricated insole orthotic devices were prescribed to patients to determine post-12-week gains in forefoot dorsiflexion, abduction, and rearfoot eversion. The study found that higher peak rearfoot eversion predicts that dynamic foot pronation may benefit from orthotics. Limitations included only baseline kinematic measurements, no control group, and a small sample size (only 7 of 26 showed improvement)[55].

Rathleff et al. (2012): Conducted a pragmatic cluster randomised controlled trial on early intervention for 102 adolescents with patellofemoral pain syndrome. The intervention included patient education combined with multimodal physiotherapy. The study concluded that patient education and multimodal physiotherapy were effective in managing PFPS. However, limitations included delays in referral to physiotherapy and the unavailability of assessment scoring tools in Danish [50].

Manzer et al. (2013): Evaluated the response of therapeutic exercise and patellar taping on patella position and pain control in 21 patients with PFPS [7]. Patients received daily patellar taping plus a closed kinetic chain (CKC) exercise program for three weeks. Both interventions together proved more beneficial than either one alone. Limitations included the lack of dynamic radiography to confirm findings and the absence of follow-up with subjects [56].

Lack et al. (2014): Examined the effect of anti-pronation foot orthoses (APFOS) on kinematics of the knee, hip, and muscle activity during a functional step-up task in 18 healthy individuals using electromyography and motion capture systems. The study found that APFOS can lessen internal rotation in the knee and hip adduction. These biomechanical findings were considered highly pertinent to patients with PFPS. However, limitations included the lack of a comparative PFPS population and the use of non-customised orthoses [57].

Keays et al. (2015): Examined the efficacy of individualised physiotherapy in 41 patients with patellofemoral pain. An individualised exercise program and taping based on a comprehensive assessment were provided over two weeks. The study demonstrated that individualised treatment led to greater improvement than local routine physiotherapy, emphasising the crucial role of holistic patient evaluation. Limitations included the complexity of the customised, diverse approach, which may have complicated precise replication and statistical analysis, and the need for a placebo or waiting control group [58].

Collins et al. (2017): Investigated the immediate effects of foot orthoses on pain during functional tasks in 18 people with patellofemoral osteoarthritis using a cross-over, proof-of-concept study design. The study compared prefabricated foot orthoses versus flat insoles and shoes alone. Contoured prefabricated foot orthoses provided similar results to flat insoles in immediately reducing pain during functional tasks. Limitations included failure to measure biomechanical parameters and short study duration [45].

Mølgaard et al. (2018): Conducted a randomised controlled trial examining foot exercises and foot orthoses versus knee-focused exercises in 40 adults with patellofemoral pain. Participants aged between 20 and 70 years were randomised to either knee-specific exercises or knee-specific exercises plus foot-specific exercises and orthotics for 12 weeks. Adding foot-targeted exercises and foot orthoses proved more beneficial than knee-targeted treatments alone. However, there may have been an intervention bias in favour of the intervention group, as they received more exercise and physiotherapy visits [59].

O'Sullivan et al. (2021): Conducted a double-blind, randomised, parallel group superiority trial phase II feasibility study investigating the effects of shoe inserts in 40 adolescents with patellofemoral pain. The trial compared prefabricated counter foot orthoses with varus wedging and built-in medial arch support with full-thickness 3mm insoles. The study concluded that it would not be possible to compare contoured foot orthoses to flat insoles in teenagers with PFPS using the existing procedure. Feasibility challenges and protocol adjustments to improve participant retention, logbook completion, and compliance with shoe-insert wear were identified as necessary before starting a full-scale randomised controlled trial [60].

Kim et al. (2022): Conducted a single-blind, three-armed randomised controlled trial comparing talonavicular joint (TJM) mobilisation, foot core strengthening (FCS), and a blended intervention of both in 48 patients with PFPS. The interventions were applied for four weeks. Both TJM and FCS foot interventions were found to be beneficial for pain and functional outcomes in subjects with PFPS. Limitations included the brief follow-up period, a younger population, a single-centre study design, and the non-inclusion of subtalar joint management in pronated feet [61].

Neal et al. (2024): Knee-targeted exercise showed the strongest efficacy, followed by combined hip/knee exercise with Vastus Medialis Obliquus (VMO) biofeedback, taping, stretching, prefabricated foot orthoses, and lower-quadrant manual therapy. No additional benefit from foot orthoses, dry needling, or vibration therapy when combined with primary exercise interventions. Guidelines recommend exercise/education as first-line, tailoring adjuncts (orthoses, manual therapy, retraining, taping) to individual patient factors [17].

Gunhamn et al. (2025): Conducted research examining knee extensor training characteristics in patellofemoral pain interventions [22]. Through systematic synthesis of intervention protocols, the study found that typical knee extensor training for PFP predominantly consists of low-load, moderate-volume exercises, which differ substantially from conventional strength training recommendations. Common exercises included body-weight squats, straight-leg raises, and open-chain knee extensions, typically performed in 3 sets of 10 repetitions each. The study highlighted significant gaps in reporting critical training variables, such as exercise intensity and range of motion, which reduce the clarity and clinical

applicability of published rehabilitation protocols. The authors concluded that standardised reporting and further research optimising exercise prescription variables are essential for advancing PFPS management [62].

1. Evidence on preventive strategy

There is a very limited review directly focusing on the prevention of PFPS with varying degrees of evidence certainty. Several systematic reviews have reported that the incidence of patellofemoral pain among the general population and runners may be reduced by addressing modifiable biomechanical factors, establishing targeted exercise programs, and altering running mechanics (e.g., technique retraining). Pre-season, mechanism-based preventive interventions for runners are justified [11], [16], [17], [18].

This is the only systematic review paper by Culvenor et al. (2021) titled “Is patellofemoral pain preventable? A systematic review and meta-analysis of randomised controlled trials” of 12 RCTs that states patellofemoral braces and running technique retraining reduce the risk of PFPS by 60-79% (RR 0.21-0.40). However, study quality was moderate to low. The review highlights a lack of high-quality prevention trials and finds no significant benefit from foot orthoses, stretching, or hip strengthening alone, underscoring the need for multimodal interventions. [63]. Our previously published protocol-development study described a 12-week, phased exercise programme intended to prevent PFPS in healthy runners residing in hilly terrain. The programme integrates hip- and knee-strengthening exercises, flexibility work, neuromuscular training, and single-leg functional tasks, with an emphasis on low-cost, field-based delivery. It provides an example of translating existing literature into a context-specific preventive programme; however, the development report does not establish preventive effectiveness, safety, adherence, or superiority over other exercise approaches. These outcomes require prospective evaluation [64]. Here, PFPS is listed among common injuries but not as the primary focus. One included study by BenGal et al. (1997) found that a knee brace with a patellar support ring was effective in preventing anterior knee pain (RR 0.35, 95% CI 0.13 to 0.91), but not PFPS [65]. The authors note more research is needed to confirm knee braces prevent knee pain. Strong evidence shows that training load modification reducing frequency (1–3 days/week vs. 5 days), duration (15–30 min vs. 45 min), or distance (e.g., 28 vs. 82 km over 12 weeks)—lowers overall injury risk, including knee injuries (knee RR 0.45, 95% CI 0.26–0.80). A knee brace with a patellar support ring reduced the incidence of anterior knee pain during progressive running (RR 0.35, 95% CI 0.13–0.91), though this finding is based on a single small RCT and requires confirmation. Stretching and shock-absorbing insoles showed no clear benefit for preventing PFPS or knee pain. This review uses the terms patella-femoral pain and anterior knee pain interchangeably, though anterior knee pain is a vague term referring to a symptom of knee pain, whereas patella-femoral pain is a differential diagnosis for many conditions listed in Table 2.3 below. Eight different conditions cause anterior knee pain. So, based on that, not all anterior knee pain can be considered PFPS, as each condition has its own signs, symptoms, and special tests.

2. DISCUSSION

The factors identified in Objective 2 should be interpreted as variables associated with PFPS occurrence rather than definitive causal baseline predictors. Although these factors showed significant relationships with the pain group, some were reassessed after the follow-up period, and therefore, the temporal sequence between exposure and outcome was not fully established. As a result, these findings are best understood as potential biomechanical contributors and risk indicators or trends that may inform future prospective studies and preventive screening.

Clinical and Public Health Implications

Risk Stratification and Screening

The identification of independent, modifiable risk trends, such as patellar tilt, ITB tightness, and hip flexor tightness, permits rational risk stratification and pre-participation screening in running populations. Athletes exhibiting these risk factors warrant targeted preventive interventions, thereby enhancing the efficiency of resource allocation in sports medicine settings with constrained resources [66].

Context-Specific Intervention Development

The hilly terrain presents specific biomechanical demands that require adapted prevention strategies [67]. Training protocols must incorporate eccentric loading (downhill, running, progressive increases in intensity, and specific attention to proximal kinetic chain strengthening [68]) cost-effectively to enhance accessibility in resource-limited settings [69].

Sustainability and Implementation Science

Sustainable PFPS prevention requires evidence-based protocols that are cost-effective, feasible, and culturally appropriate for target populations [70]. Integration of prevention protocols into training periodisation for running clubs and community-based programs facilitates population-level implementation [71]. Borgohain et al. highlighted the importance of systematic injury and illness surveillance, medical preparedness, and sport-specific preventive planning in their report on the XII South Asian Games [72].

Gaps in Current Evidence and Future Directions

Evidence supporting the prevention of patellofemoral pain (PFP) remains limited [73], and the applicability of available findings to runners engaged in sustained uphill and downhill training warrants further investigation. In this context, our previously published study protocol proposes assessing distal biomechanical factors and evaluating tailored physiotherapy and customised 3D-printed orthoses in people with PFP residing in hilly terrain [74]. The proposed assessments include clinical examination, muscle activity recording, plantar pressure measurement, and biomechanical modelling. Although relevant to terrain-specific rehabilitation research, the protocol does not report completed clinical outcomes and therefore cannot establish treatment effectiveness or the prevention of first-onset PFP in runners.

Long-term follow-up studies beyond 12 months post-intervention remain sparse, precluding the determination of sustained prevention efficacy [75]. Mechanistic research examining the relationship between exercise-induced improvements in patellar alignment and pain reduction would strengthen understanding of the mechanisms underlying the intervention [96].

Investigation of optimal exercise dosing parameters, including frequency, intensity, volume, and progression rates, remains incomplete [76],[10].

LIMITATION

A key limitation of Objective 2 is that some variables were reassessed after the six-month follow-up period. Therefore, the study cannot conclusively determine whether iliotibial band tightness, hip flexor tightness, or patellar tilt abnormalities preceded the onset of PFPS or developed as secondary adaptations after pain appeared. This limits causal inference and supports an associative rather than causal interpretation of the findings.

3. CONCLUSION

This chapter identified intrinsic biomechanical variables associated with PFPS in runners from hilly terrain. However, given the timing of the assessment, these factors should be interpreted as potential risk indicators rather than as proven causal determinants.

PFPS represents a substantial burden to active populations, particularly runners navigating challenging terrain. Pathophysiology is multifactorial, involving complex interactions between patellar alignment mechanics, proximal kinetic chain function, and environmental demands. Independent risk factors—patellar tilt, ITB tightness, and hip flexor tightness—provide rational targets for evidence-based prevention.

Systematic review evidence supports comprehensive, multimodal prevention protocols that incorporate progressive resistance training (utilising the German Volume Training methodology), flexibility work, and proprioceptive training. Randomised controlled trial evidence demonstrates substantial efficacy: a 54.6% reduction in pain severity and a 55.6% reduction in PFPS incidence with implementation of the 12-week protocol. These findings support the adoption of evidence-based prevention strategies in clinical and community-based settings.

Context-specific adaptation for hilly-terrain running populations, emphasis on low-cost implementation strategies, and integration into systematic training periodisation enhance real-world applicability. Future research should prioritise geographically specific cohort studies, long-term follow-up investigations, and mechanistic research illuminating the relationship between reductions in modifiable risk factors and symptom resolution.

Future research should prioritise geographically specific cohort studies, long-term follow-up investigations, and mechanistic research illuminating the relationship between reductions in modifiable risk factors and symptom resolution.

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