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Development of a 12-week preventive exercise protocol for patellofemoral pain syndrome for healthy Hilly Runners

J.P.Darjee[1] , Jakir Hussain[2] , Dr Nitin Sahai[1]
Affiliations
1. Department of Bio-Medical Engineering, North Eastern Hill University, Shillong, Meghalaya, India. e-mail id: jppt@rediffmail.com
2 University of Science & Technology, Meghalaya, India. e-mail id: jakirhussain00369@gmail.com
Corresponding author
Name: Dr. Nitin Sahai
Affiliation: Assistant Professor, Department of Bio-Medical Engineering, North Eastern Hill University, Shillong, Meghalaya, India.
e-mail: nitinbiomedical@gmail.com

ABSTRACT
Objective: To develop an evidence-informed, 12-week preventive exercise protocol targeting key biomechanical risk factors for patellofemoral pain syndrome (PFPS) in healthy runners from hilly terrain.
Methods: An extensive literature search was conducted in PubMed, Scopus, Web of Science, Cochrane Library and Google Scholar, supplemented by manual screening of guidelines and reference lists. Studies (2010–2025) on preventive physiotherapy, strengthening, flexibility, neuromuscular control and load management for PFPS were screened, yielding 42 articles for qualitative synthesis and 17 for quantitative integration into frequency–intensity–time–type (FITT) prescriptions. Three prospectively identified modifiable risk variables—patellar tilt, iliotibial band (ITB) tightness and hip-flexor tightness—were used as primary targets.
Results: A 12-week, three-phase (foundation, integration, performance) preventive protocol was developed, combining patellar taping, hip and knee strengthening, flexibility training, neuromuscular control drills and terrain-specific single-leg functional tasks. FITT-based tables were created for each variable, and 12 core exercises were standardised using a pragmatic "10 × 10" dosage (10 sets × 10 repetitions or 10 × 10-s holds) to simplify recall while maintaining training volume. The protocol is designed for home- or field-based delivery using bodyweight, elastic loop bands and low-cost substitutes for foam rollers and weights.
Conclusion: The proposed protocol translates current PFPS evidence and consensus recommendations into a structured, context-specific preventive strategy for healthy hill runners, emphasising dynamic stability, single-leg control and feasible implementation in resource-limited environments.
Keywords: Patellofemoral pain syndrome; prevention; exercise therapy; biomechanics; neuromuscular training; hill running; FITT principle.

INTRODUCTION
Patellofemoral pain syndrome (PFPS) is one of the most common causes of anterior knee pain in physically active individuals and young adults. It is associated with impaired knee function, reduced quality of life and an increased risk of early patellofemoral osteoarthritis (1), which is higher in prevalence than tibiofemoral compartment osteoarthritis (2). There is no definitive treatment or slowing of its progression, and knee osteoarthritis is a leading cause of disability worldwide (3).
PFPS is among the most common overuse injuries among physically active people, especially runners and athletes who live and exercise in steep or uneven terrain (4). Despite advances in rehabilitation strategies, a significant portion of recurrences may be linked to unaddressed underlying risk factors and a lack of structured preventive measures (5). The preceding chapters have highlighted the critical significance of muscle imbalances—especially in the hip and quadriceps groups—and iliotibial band tightness, abnormal patellar tracking, as the modifiable risk factors for PFPS. These results are in line with current biomechanical models that link poor neuromuscular control along the lower limb kinetic chain to excessive patellofemoral joint stress (6). Systematic reviews from the last ten years robustly support the idea that addressing these risk factors through targeted physiotherapeutic interventions can reduce both the frequency and recurrence of PFPS episodes, and importantly, mitigate the progression toward chronicity and osteoarthritis (7).
Biomechanical research and clinical outcome studies collectively emphasise that poor neuromuscular control along the kinetic chain—a cascade linked to excessive patellofemoral joint stress—underpins much of the symptom burden in affected individuals (8). Therefore, any effective preventive strategy must transcend mere relief of discomfort and aim to restore optimal alignment, load distribution and movement efficiency through structured, planned exercise interventions. This concept is strongly supported by recent meta-analyses, which advocate the translation of biomechanical insight into tangible clinical practice, enabling evidence-based protocols for prevention(9). In addition to isolated hip flexor and iliotibial band stretching regimens, this entails the development of certain exercise components that target muscle groups that affect patellofemoral joint stability, such as the quadriceps, hip abductors, external rotators and core stabilisers (10).
The creation of a thorough preventive plan for PFPS, therefore, involves methodological attention to each relevant aspect documented in previous analyses. The protocol presents a preventive paradigm not only for acute care and long-term symptom management but also for enhancing performance and minimising risk among runners and physically active individuals. Preventive approaches are further supported by education on activity load management, appropriate progression of physical activities and pre-participation screening to identify individuals at higher risk for patellofemoral pain (11). As underscored by recent reviews of global research trends and systematic outcome meta-analyses, the translation of current biomechanical and clinical evidence into practical, longitudinal prevention programs is vital for curbing PFPS and its consequences (12). Critically, such a plan must address each patient's unique profile through tailored interventions that begin with pre-participation screening, risk factor modification and education regarding activity progression and load management.
The proposed plan leverages multifactorial insights from the literature review to develop a physiotherapy protocol for the significant variables obtained from a prior objective that may actively reduce the occurrence of PFPS for runners of hilly terrain, Northeast India and beyond (13).

MATERIALS AND METHODS
Study design
This protocol-development study synthesised literature evidence and prior prospective findings in healthy runners from hilly terrain to construct a structured, preventive exercise programme for PFPS. The process included (1) a systematic literature search, (2) evidence extraction and grading, (3) FITT-based tabulation of interventions for each risk variable and (4) integration of components into a unified 12-week, three-phase protocol.

Literature search strategy
Electronic searches were conducted in PubMed, Scopus, Web of Science, Cochrane Library and Google Scholar using combinations of the terms "patellofemoral pain syndrome," "prevention," "exercise therapy," "biomechanics," "IT band tightness," "neuromuscular control", and "stretching," resulting in the identification of 324 records relevant to the topic. In addition, 18 more records were found through manual searches of reference lists and guidelines from organisations such as the American College of Sports Medicine (ACSM), International Olympic Committee (IOC) and Patellofemoral Pain Syndrome Research Retreats. This brought the total to 342 and finalised to 17 articles in the PRISMA method (Figure 1).

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Following duplicate removal, 298 unique records remained. Titles and abstracts of these 298 records were screened for relevance to PFPS prevention and management. Of these, 182 records were excluded as they focused on unrelated domains such as pharmacological management, surgical procedures or imaging studies. Subsequently, 116 full-text articles were assessed for eligibility. Inclusion criteria required that studies be randomised controlled trials, systematic reviews, or consensus statements published between 2010 and 2025, specifically addressing preventive physiotherapy, strengthening, flexibility, neuromuscular control, and load management. Of these, 74 were excluded due to insufficient preventive focus and lack of quantitative data.

The final review incorporated 42 studies into the qualitative synthesis, which includes 11 randomised controlled trials (RCTs), 9 systematic reviews and meta-analyses, 5 consensus statements/clinical guidelines, 10 narrative, cohort or case studies and 7 grey literature or clinical resources providing narrative and thematic insights. Finally, 17 studies were included in the quantitative synthesis for meta-analytic purposes and for informing tables and FITT-based protocol development for PFPS.

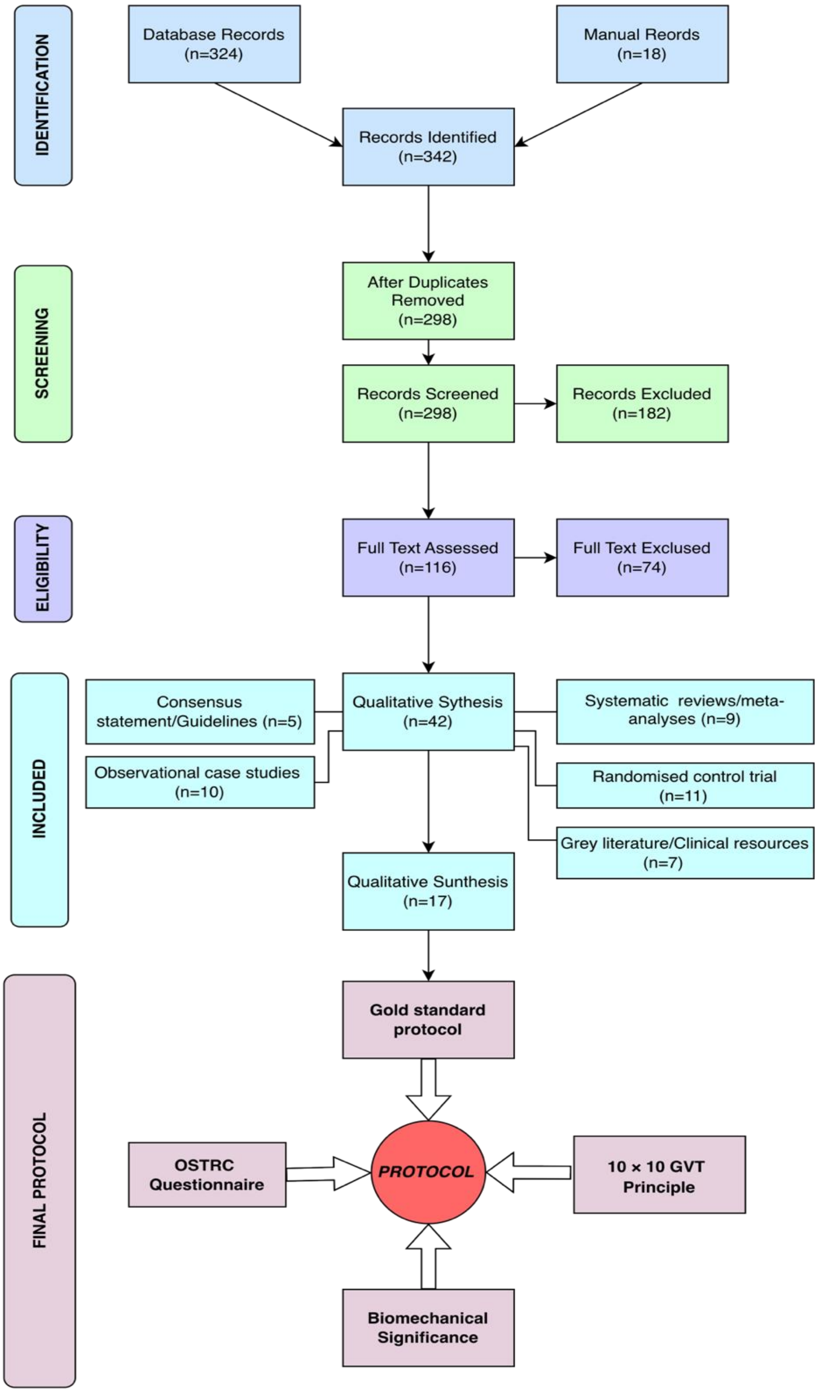

Figure 1: PRISMA 2020 flow diagram of literature review for protocol development.

Evidence integration and target variables

Findings from the systematic review, supplemented by targeted evidence, were then used to design the preventive protocol. For the development of the protocol, a total of 39 sources were integrated. This included 3 sources that specifically supported the use of patellar taping, 5 sources that provided evidence for IT band stretching, and 7 sources emphasising the value of hip flexor stretching. In addition, 5 recent studies focused on telerehabilitation and home-based physiotherapy protocols were included, highlighting modern delivery approaches. Finally, 13 other biomechanical or epidemiological background studies were utilised to provide a comprehensive scientific foundation for the protocol development of the prevention of PFPS for the three significant variables obtained from objective 2, i.e. patellar tilt, hip flexors and hamstring tightness.

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FITT-based protocol development

Using evidence from the final 13 studies, a 12-week preventive protocol was organised into three progressive stages and summarised in Table 4. The resulting programme consists of 35 distinct exercises, each accompanied by specific sets and repetition prescriptions. While comprehensive, this level of complexity increases participants' cognitive load and consequently elevates the risk of recall bias and reduced adherence. To mitigate these challenges, an additional literature search identified German Volume Training (GVT)—characterised by a standardised 10 × 10 loading framework—as a potential strategy for simplifying exercise prescription without compromising total training volume. Although only a limited number of studies have rigorously examined GVT or comparable high-volume 10 × 10 protocols, the investigation by Amirthalingam et al. (2017) has accrued over 100 citations, reflecting sustained academic interest. Notably, this approach has not yet been applied to patellofemoral pain syndrome. Integrating the underlying principles of GVT may therefore offer a pragmatic, evidence-informed method to enhance the feasibility, consistency and memorability of the current PFPS preventive protocol.

Equipment and implementation context

The developed exercise protocol uses primarily free-hand exercises in addition to simple, low-cost models. They are a resistance band loop (Figure 3a), a water bottle (Figure 3b) as a feasible alternative to a foam roller and a dumbbell.

[Figure 3. (a) The resistance loop band used in the study. (b) Water bottle.]

Resistance band loop

The American College of Sports Medicine (ACSM) (14) supports the use of elastic resistance bands as a practical substitute for free weights and resistance machines, especially in on-field-based settings, and acknowledges resistance training as a crucial part of all-encompassing fitness and injury-prevention programs. Resistance bands closely resemble the physiological strength curve of muscle activity by offering changing resistance across the range of motion. These are especially useful for lower-limb training and neuromuscular control workouts targeted at improving patellofemoral joint mechanics because of this characteristic, which permits progressive loading while reducing excessive joint stress (15). American Heart Association Science Advisory states that it improves muscular strength, endurance and joint stability while maintaining a favourable safety profile when appropriately prescribed (16). The gradual increase in resistance with elongation facilitates controlled eccentric and concentric muscle activation (17), which is essential in runners exposed to repetitive loading, especially in hilly terrain. Previous literature demonstrates that elastic resistance devices are capable of eliciting muscle activation levels comparable to traditional resistance modalities, while offering greater versatility and ease of progression (14,18). Elastic bands provide variable resistance that increases as the band is stretched, allowing functional, multiplanar loading of the hip and knee through the full range of motion in exercises such as clamshells, side-lying abduction, bridges, lateral walks and step-downs (19).Based on these considerations, elastic mini loop resistance bands were deemed appropriate for implementing a standardised, progressive and safe preventive exercise strategy in our study, in accordance with internationally accepted resistance training principles and clinical exercise prescription guidelines. As all subjects are novice we have selected the light resistance (7–10 Kg) loop resistance for all the exercises that are resistive.

Foam roller alternatives

To promote accessibility and cost-effectiveness in this field-based preventive trial conducted in Shillong, Meghalaya—where commercial foam rollers may not be readily available or affordable for all participants—subjects unable to procure one were suggested and instructed on practical household alternatives for the ITB "search and destroy" self-myofascial release technique (exercise code: 2d, Table 8). These included a wooden rolling pin wrapped in a thin towel or a firm, full 1–2 L water bottle (unfrozen due to local climate), both providing sustained pressure on tender trigger points along the lateral thigh comparable to foam rolling, as supported by studies showing equivalent effects of rigid substitutes and balls on flexibility and recovery (20–24). The non-frozen filled rigid water bottle was particularly emphasised as a versatile, dual-purpose tool, also serving as a safe dumbbell alternative (weighing ~1–1.5 kg when full) for the single-leg deadlift (2b) across the protocol, ensuring methodological consistency without additional equipment costs while maintaining intervention fidelity.

RESULTS

Overview of the developed protocol

A 12-week onfield preventive exercise protocol principle was finalised, to target three modifiable biomechanical risk variables for patellofemoral pain syndrome (PFPS) previously identified in healthy runners from the hilly terrain of Meghalaya: patellar tilt, iliotibial band (ITB) tightness and hip-flexor tightness, which can also be added to the warm-up session of the participants on field for application to a fresh batch of healthy runners to study its efficacy in the objective 4. The protocol was designed based on a phased frequency–intensity–time–type (FITT) principle on current evidence, keeping in mind that running injuries results from dynamic instability and motor control deficits rather than muscle length alone, and that functional, single-leg exercises mimicking the demands of running in residents of hilly terrain are superior to non-weight-bearing, isolated movements for injury prevention and performance(25).

Protocol for patellar tilt

Evidence regarding the role of patellar taping—especially McConnell taping (26) demonstrates that tailored medial patellar tilt interventions reduce pain and improve functional capacity, particularly during the initial weeks of rehabilitation or preventive exercise. Randomised controlled trials highlighted in several reviews show that the combination of patellar taping and exercise yields additive benefits in pain modulation and task performance compared to exercise alone, at least in the short term. Some longitudinal studies, however, warn of limited sustained benefit from prolonged taping, emphasising its role as an adjunct for early engagement and for facilitating pain-free exercise participation. Consequently, its strategic, protocolized use in home programs is recommended (13).

Table 1: Gold standard Protocols for Patellar tilt Based on FITT Principles and International Guidelines

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Variable	Frequency	Intensity	Time	Type	Monitoring	References
Patellar Tilt	Daily for 3 weeks	50% stretch	Till it comes out on its own	McConnell/Grelsamer taping (Kinesio-tape)	skin integrity; tape adherence	Soligard (27); Crossley 2016 (28); ACSM 2021(25)

Table 1 shows the protocol for patellar tilt and integrates evidence-based strategies for patellofemoral pain and related biomechanical conditions, reorganszed according to the FITT principles as recommended by the American College of Sports Medicine (ACSM, 2021), the International Olympic Committee (IOC Consensus Statement on Load in Sport, 2018) and the 2016 International Patellofemoral Pain Research Retreat Consensus Statement, and presented with supporting references.

Protocol for IT band tightness

Recent advances underscore the importance of direct interventions for IT band and hip flexor tightness as critical risk modifiers. RCTs and contemporary reviews identify that static stretching, proprioceptive neuromuscular facilitation (PNF), foam rolling and targeted flexibility training result in significant improvements in range, reduction in pain and improvements in running biomechanics among both adults and adolescents (29). Recent cohort analyses demonstrated that persistent ITB tightness, if not addressed early, results in altered gait and elevated lateral patellar stress—direct correlates of PFPS symptoms (30).

Table 2: Gold standard Protocols for IT band tightness Based on FITT Principles and International Guidelines

Variable	Frequency	Intensity	Time	Type	Monitoring	References
IT Band Tightness	3–5×/week for 6 weeks [20]	Mild-to-moderate stretch (no pain)	30–60 sec, 2–3 reptns	Static stretch (TFL, glutes), foam rolling, PNF	ITB flexibility; program adherence	Fredericson 2000 [19]; ACSM 2021 [14]; Witvrouw 2004 [21]

Table 2 shows that the protocol integrates evidence-based strategies for patellofemoral pain and related biomechanical conditions. It has been reorganised according to the FITT principles as recommended by the American College of Sports Medicine (25), the International Olympic Committee (27) and the 2016 International Patellofemoral Pain Research Retreat Consensus Statement (28). Each management approach is presented with supporting references.

Protocol for hip flexor tightness

For hip flexor stretching, daily lunge-based stretching and supplementary hip and core strengthening are recommended. These regimens, when included in preparticipation home programs, have reduced the development and recurrence rates of PFPS in athletic cohorts (6).

Table 3: Gold standard Protocols for Hip flexors tightness Based on FITT Principles and International Guidelines

Variable	Frequency	Intensity	Time	Type	Monitoring	References
Hip Flexor Tightness	Daily for 6 weeks [20]	Stretch to mild discomfort, not pain	30–45 sec, 2–3 repetn	Modified lunge stretch; VMO & hip abductor strengthening	Hip ROM (goniometer); function; adherence	Crossley 2016 [17]; ACSM 2021 [14]

Table 3 shows that the protocol—daily stretching of the hip flexors for six weeks, using 30–45 second holds for 2–3 repetitions per side, at an intensity that provokes mild discomfort (not pain), complemented by home-based modified lunge stretches and concurrent VMO & hip abductor strengthening—aligns closely with modern guidelines and the recommendations from multiple international expert consensus statements (25).

Developed preventive strategy protocol

Based on the knowledge of running biomechanics, musculoskeletal imbalances and their effectiveness on injury prevention, designed to address these three significant variables, emphasising dynamic stability, corrective exercise and functional movement, with reference support. This protocol is designed and structured (Figure 2) by focusing on dynamic neuromuscular control, targeted mobility and functional strength to replace traditional, often static, methods. This protocol provides a structured, progressive and evidence-informed approach to replace traditional methods.

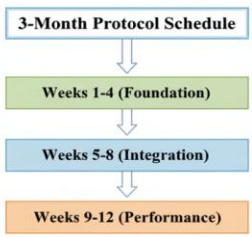

Figure 2. The structure for each developed protocol.

Concept of the protocol developed

The developed protocol targets the entire kinetic chain using multi-joint, functional movements rather than isolated muscle exercises, which is consistent with recommendations to train running-related tasks with integrated strength and control drills. Hill-running drills are included to challenge active control of braking and deceleration forces in a task-specific manner for runners. The 12-week programme is organised in progressive phases, with systematic increases in exercise load, complexity and neuromuscular demand approximately every 4 weeks, in line with resistance-training progression models. This structure also aligns with evidence that neuromuscular and strength adaptations consolidate over 8–12 weeks of consistent training(31,32) .Dynamic stretching and unilateral exercises such as the rear-foot elevated split squat are used to train the neuromuscular system to control the limb through a full range of motion, offering greater preparation for running than passive static stretching alone. This protocol is intended to develop a more resilient, biomechanically efficient runner by retraining fundamental movement patterns and improving load tolerance across the hip, pelvis, and knee, thereby serving as a preventive strategy for patellofemoral and iliotibial-band-related symptoms. In contrast to traditional programmes that rely heavily on static stretching or isolated open-chain exercises, the current approach emphasises dynamic neuromuscular control, targeted mobility and task-specific strength (33,34).

The principles for the developed protocol are based on the following key points:

- **Integration**: Many exercises simultaneously address more than one target (e.g., hip and trunk strength drills that also optimise patellar tracking mechanics and reduce iliotibial band tension), reflecting the interconnected nature of the kinetic chain (35,36).
- **Progressive overload**: Intensity is increased over time by adjusting sets, repetitions, hold durations, resistance and movement complexity roughly every 4 weeks, consistent with ACSM progression guidelines (37).
- **Consistency**: The protocol is prescribed at 3 sessions per week, with at least 1 rest day between sessions, which aligns with general strength-training recommendations and is feasible alongside a normal running schedule (38).

Table 4: Phase-wise summary of the protocol for each significant variable

Variable Targeted	Focus Area	Phase-I (Weeks 1-4) Foundation	Phase-II (Weeks 5-8) Integration	Phase-III (Weeks 9-12) Performance
Patellar Tilt	VMO/Medial Quad Strength & Hip Control	Isometric/Short-Arc Knee Ext., Clamshells (Low resistance, high reps)	Dynamic Lunges, Single-leg RDL (Light weight, control focused)	Weighted Step-Ups (Lateral & Forward), Lateral Band Walks (Fast tempo)
ITB Tightness	Gluteal Strength & TFL/Glute Max Length	Side-Lying Hip Abduction, Static Piriformis/Glute Stretch	Dynamic Hip Hinges, Foam Rolling (ITB & Glutes) with controlled pressure	Single-Leg Squat Variations (Focusing on knee-over-toe alignment), Cable/Band Hip Rotations
Hip-Flexor Tightness	Psoas/Rec Fem Lengthening & Core Stability	Modified Thomas Stretch, Supine Marching (Slow and controlled)	Dynamic Kneeling Hip Flexor Stretch, Plank with alternating leg lifts	Rear-Foot Elevated Split Squats, Standing Banded Hip Extension (Focus on glute activation)

Biomechanical significance of the protocol for patellar tilt prevention

The biomechanical significance of each phase of the developed protocol, summarised in Table 5, is explained below.

Patellar tilt is often a symptom of poor tracking, which is strongly influenced by weak VMO and poor control from the hip abductors (especially Gluteus Medius), promoting dynamic valgus and lateral patellar loading (39,40).

Table 5: Phase-wise summary of the protocol for the patellar tilt

Exercise	Phase-I (Weeks 1-4)	Phase-II (Weeks 5-8)	Phase-III (Weeks 9-12)
VMO Activation	Short-Arc Knee Extension: 3 sets x 15 reps. Focus on actively squeezing the inner quad.	Single-Leg Squat to Chair: 3 sets x 10 reps. Focus on keeping the knee tracking over the second toe.	Lateral Step-Downs: 3 sets x 12 reps. Slow and controlled lowering, ensure the knee does not collapse inwards.
Hip Control	Clamshells (Band): 3 sets x 20 reps (slow tempo).	Single-Leg Deadlift (RDL): 3 sets x 8 reps (light dumbbell). Focus on maintaining a level pelvis.	Pistol Squat Prep (to box/chair): 3 sets x 6 reps. Emphasize knee stability and hip engagement.

Phase I exercises were selected because hip and quadriceps strengthening address muscular imbalances and dynamic knee valgus, which perpetuate abnormal patellar tracking. Research demonstrates that strengthening the hip abductors and external rotators improves patellofemoral mechanics by controlling femoral internal rotation, the root biomechanical cause of lateral patellar deviation (30).

Phase II exercises, i.e. single-leg deadlifts, step-downs and controlled squats, force the runner to stabilise the hip and knee in weight-bearing positions, training the gluteus medius and minimus to control femoral internal rotation—the root biomechanical cause of patellar tilt—under conditions similar to running (25).Phase III targets single-leg control so the hip and knee stay aligned over the foot, limiting dynamic valgus and femoral internal rotation that increase lateral patellofemoral contact stress. Lateral step-downs are particularly sensitive for revealing and correcting abnormal lower-limb force lines in people with PFPS, making them ideal for high-demand tasks like hill running. Pistol-squat-type drills further train eccentric quadriceps and hip-abductor strength, which helps runners tolerate the greater patellofemoral joint loads seen during uphill and downhill running on hilly terrain. Together, these exercises retrain neuromuscular control in the exact single-leg stance positions that dominate trail and hill running, supporting both symptom reduction and load management(35).

Biomechanical significance of the protocol for iliotibial band (ITB) tightness prevention

The biomechanical significance of each phase of the above developed protocol, summarised in Table 6, is explained below variable-wise. While the ITB cannot truly be "stretched," the underlying issue is often weak hip stabilisers (Glutes) and a taut Tensor Fasciae Latae (TFL).

Table 6: Phase-wise summary of the protocol for the IT Band

Exercise	Phase-I (Weeks 1-4)	Phase-II (Weeks 5-8)	Phase-III (Weeks 9-12)
Gluteal/Hip Strength	Side-Lying Hip Abduction: 3 sets x 15 reps. Ensure foot is slightly behind the hip to isolate glute medius.	Bridge with March: 3 sets x 10 marches per leg. Maintain a neutral spine and stable pelvis.	Lateral Band Walks: 3 sets x 20 steps per direction (Medium resistance, faster pace).
Mobilization	Static Piriformis/Glute Stretch: 2-3 minutes per side. Hold tender spots for 30s.	Foam Rolling (ITB/TFL/Glutes): 2 minutes per area. Use a "search and destroy" technique.	Dynamic ITB/TFL Mobilization: Incorporate movements while foam rolling (e.g., knee flexion/extension).

Phase I emphasises side-lying hip abduction and foam rolling of the gluteal–ITB complex to improve gluteus medius activation and reduce lateral thigh stiffness, addressing early hip abductor fatigue that is linked to ITB problems in distance runners. For hilly-terrain runners, this builds baseline lateral hip strength and tissue tolerance before exposing them to long downhill loads, where ITB compression over the lateral femoral condyle is greatest (41–44).

Phase II progresses to bridge-with-march and more targeted foam rolling of ITB/TFL and glutes, combining proximal strengthening with myofascial mobilisation to reduce compensatory TFL dominance and ITB tension. This is biomechanically important on slopes, where contralateral pelvic drop and narrow step width increase hip adduction and knee varus moments, elevating tensile strain in the ITB during mid-stance (45–47).Phase III uses faster lateral band walks and dynamic ITB/TFL mobilisation to train endurance and rapid force production of the hip abductors under conditions closer to real trail running. Strong, fatigue-resistant gluteus medius and improved neuromuscular control help maintain pelvic stability and step width on prolonged ascents and descents, thereby limiting ITB compression and associated lateral knee and patellofemoral pain in hill runners (41,42,48).

Biomechanical significance of the protocol for hip-flexor tightness prevention

The biomechanical significance for each phase of the above developed protocol, summarised in Table 7, is explained below variable-wise.

Tight hip flexors (Psoas, Rectus Femoris) can limit hip extension, forcing compensatory anterior pelvic tilt during running, increasing load on the back and hamstrings (49).

Table 7: Phase-wise summary of the protocol for the Hip flexors

Exercise	Phase-I (Weeks 1-4)	Phase-II (Weeks 5-8)	Phase-III (Weeks 9-12)
Lengthening	Modified Thomas Stretch (Static): 3 sets x 60 second hold per leg. Focus on posterior pelvic tilt.	Kneeling Hip Flexor Stretch (Dynamic): 3 sets x 10 reps per leg (rocking back and forth).	Standing Dynamic Leg Swings (Forward/Backward): 3 sets x 15 swings per leg.
Core Stability	Plank: 3 sets x 45-60 second hold. Focus on drawing the navel to the spine to maintain a neutral pelvis.	Dead Bug: 3 sets x 10 reps per side (slow and controlled).	Rear-Foot Elevated Split Squat (RFESS): 3 sets x 8 reps per leg. This strengthens and stretches simultaneously.

Phase I uses the Modified Thomas stretch and plank to lengthen tight hip flexors while teaching a neutral pelvis, reducing anterior pelvic tilt that is linked to increased femoral internal rotation, patellar maltracking and higher patellofemoral joint stress. This is critical for runners because prolonged hill running in an anterior-tilt posture amplifies load on the anterior knee during stance (50–52) .
Phase II introduces a dynamic kneeling hip-flexor stretch and dead bug, integrating hip-flexor lengthening with active lumbopelvic control. Dead bug training improves core stability and control of the lumbopelvic complex, which helps runners maintain a neutral pelvis and better knee alignment when negotiating variable gradients and uneven terrain (53,54).
Phase III progresses to standing dynamic leg swings and rear-foot elevated split squats, which require hip extension strength and balance in a functional, single-leg position similar to running. The RFESS simultaneously strengthens gluteals and quadriceps while challenging pelvic and trunk control, improving the ability of hill runners to absorb and generate forces during uphill and downhill steps without reverting to hip-flexor–dominant, anterior-tilt mechanics that provoke patellofemoral pain (55–58) .

The implementation of the "10 × 10" principle

The structured exercise protocol comprises 12 distinct exercises, each originally prescribed with different sets, repetitions, positions and timings across the 3-month program. This complexity increases the risk that participants may forget the exact prescription for each exercise, potentially introducing recall bias despite the provision of printed handouts (supplementary material I). To enhance adherence and minimise this risk, the protocol was standardised using a 10 × 10 principle (10 sets × 10 repetitions or 10 × 10-second holds, depending on the task), which is supported by evidence from German Volume Training models (59). Recommendations to increase muscle size or lean body mass commonly emphasise higher training volumes, such as performing multiple sets of approximately 10 repetitions. Within this context, the German Volume Training model was introduced by strength coaches using a 10 sets × 10 repetitions structure to promote hypertrophy during general preparation phases (60). This high-volume configuration involves more sets per exercise than traditional hypertrophy prescriptions, yet has been shown to produce robust muscular and cardiovascular responses across different exercise modes (61–65).

Table 8: Compiled table presenting the complete protocol developed

Code	Exercises	Sets x Reps
Phase-I (Weeks 1-4)		
1a	Short-Arc Knee Extension	10 x 10
1b	Resisted Clamshell	10 x 10
1c	Resisted Side-Lying Hip Abduction	10 x 10
1d	Static Piriformis/Glute Stretch	10 x 10
1e	Static Modified Thomas Stretch	10 x 10
1f	Prone Plank	10 x 10
Follow-up: OSTRC Questionnaire		
Phase-II (Weeks 5-8)		
2a	Single-Leg Squat to Chair	10 x 10
2b	Single-Leg Deadlift (RDL) with light dumbbell	10 x 10
2c	Resisted Bridge with March	10 x 10
2d	Foam Rolling (ITB) "search and destroy" technique	10 x 10
2e	Dynamic Kneeling Hip Flexor Stretch	10 x 10
2f	Dead Bug	10 x 10
Follow-up: OSTRC Questionnaire		
Phase-III (Weeks 9-12)		
3a	Lateral Step-Down	10 x 10
3b	Pistol Squat Prep	10 x 10
3c	Lateral Band Walks (Medium resistance)	10 x 10
3d	Dynamic ITB/TFL Mobilization	10 x 10
3e	Standing Dynamic Leg Swing	10 x 10
3f	Rear-Foot Elevated Split Squat (RFESS)	10 x 10

Standardising exercise dosage, as mentioned in Table 8, simplifies recall without altering the specific positions or movement patterns of each exercise, thereby preserving their intended clinical and biomechanical significance within the preventive programme. Because modified GVT protocols may not always outperform moderate-volume approaches, they reliably elicit robust neuromuscular adaptations, confirming that a 10 × 10 prescription provides a potent and tolerable stimulus when appropriately supervised. Contemporary patellofemoral pain guidelines emphasise multi-joint hip and knee strengthening, neuromuscular retraining and progressive overload over 8–12 weeks as core components of rehabilitation (66). Therefore, adapting the GVT concept into a simplified 10 × 10 framework for key kinetic-chain exercises in this PFPS-prevention protocol offers an evidence-informed way to deliver sufficient training volume for strength, flexibility and neuromuscular control (52,67,68), while also providing a consistent and memorable structure that enhances adherence in runners.

DISCUSSION

The traditional approach to addressing tightness and alignment issues often relies on static stretching and isolated, non-functional strength training(40,69) . This protocol shifts focus to dynamic functional movement and neuromuscular control. The new protocol exercises were specifically chosen based on three biomechanical criteria designed to maximise functional carryover to running:

1. **Functional Specificity (Mimicking the Run Cycle):** The selected exercises directly mimic the single-leg stance phase of running or require similar stabilisation forces. For example, replacing seated VMO sets with Lateral Step-Downs and Single-Leg RDLs. These exercises force the runner to stabilise the hip and knee in a single-leg, weight-bearing position, training the glutes to control femoral rotation (the root cause of patellar tilt) under load.
2. **Integrated Stability and Mobility:** The protocol mandates integrating core stability with mobility work to ensure the newly gained range of motion is usable and sustainable during running, and for example, using the Rear-Foot Elevated Split Squat (RFESS) and the Dead Bug. The RFESS simultaneously stretches the hip flexor of the back leg while strengthening the glutes and core of the front leg. The Dead Bug specifically trains the core and pelvis to remain neutral while the limbs move, directly counteracting the tendency for anterior pelvic tilt caused by hip-flexor tightness.

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3. **Targeted Muscle Activation:** Exercises were chosen based on evidence demonstrating high activation of the specific stabilizing muscles necessary for each variable. For Patellar Tilt/ITB, it prioritized movements having high Gluteus Medius and Gluteus Minimus activation (e.g., Clamshells with resistance, Lateral Band Walks) to improve pelvic stability and reduce tension on the ITB. For hip flexor tightness, dynamic stretching (e.g., kneeling rocking) was used rather than static stretching because dynamic stretching prepares the muscle better and connective tissue for the rapid eccentric contractions required during running and enhances the "spring" mechanism crucial for efficient locomotion.

Rationale for 12-week duration

The 12-week intervention duration was selected based on multiple lines of evidence supporting sustained adaptations in strength, flexibility and neuromuscular control (70–74). The developed protocol aims to address the kinetic chain relation between the three variables (Figure 3).

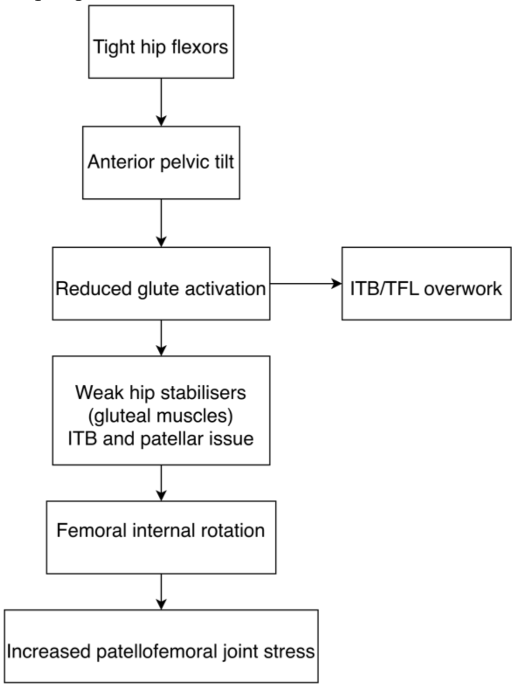

Figure 3. Kinetic chain interactions linking hip and pelvic dysfunction to ITB/TFL overwork and patellofemoral joint stress.

1. **Evidence from PFPS intervention trials (clinical timescale):** Research on progressive resistance training targeting proximal hip and pelvic musculature has demonstrated that 12 weeks is a sufficient timeframe for meaningful improvements in pain and functional capacity in individuals with PFPS (70). Randomised trials of hip and knee strengthening, as well as neuromuscular and sensorimotor training in PFPS, commonly employ programmes of around 12 weeks and report clinically important improvements in pain, function and strength (71–74). Together, these data support a 12-week window as clinically appropriate for capturing meaningful changes in patient-reported outcomes and lower-limb performance in PFPS populations.
2. **Neuromuscular and strength adaptations:** From a neurophysiological perspective, strength and motor-control adaptations, including neuromuscular recruitment patterns and muscle force production, require approximately 8–12 weeks of regular training for consolidation, after which gains can be maintained at lower exercise frequencies. Reviews of resistance-training physiology similarly report that neuromuscular and strength adaptations, including changes in motor-unit recruitment and force production, typically become evident over about 8–12 weeks of consistent loading(32).
3. **Flexibility and stretching time-course and maintenance:** Flexibility improvements in range of motion typically emerge within several weeks of consistent stretching, often within 3–6 weeks, but require ongoing maintenance to prevent regression(75). Chronic stretching interventions of 5–15 weeks produce substantial increases in range of motion, yet range of motion declines once stretching stops, indicating the need for continued, lower-frequency maintenance stretching to preserve gains (76).
4. **Alignment with ACSM exercise-training recommendations:** The American College of Sports Medicine (ACSM) guidelines emphasise that to achieve sustained improvements in muscle capacity, exercise prescriptions should follow evidence-based parameters for load progression, frequency and training duration, typically over multi-week cycles that allow for adaptation and consolidation (25). A 12-week intervention aligns with these guideline principles by providing adequate time for progressive overload, neuromuscular adaptation and transition into a maintenance phase (32).

The Integrated justification for a 12-week PFPS preventive protocol, taken together with evidence from PFPS-specific trials, neuromuscular physiology and stretching research, indicates that several weeks are required to realise flexibility gains, that strength and motor-control adaptations consolidate over 8–12 weeks, and that ongoing lower-frequency training is needed to maintain improvements. Therefore, a 12-week duration accommodates early neural adaptation (approximately the first 4–6 weeks) and subsequent consolidation (up to 12 weeks), while allowing for structured progression of load and integration of flexibility and neuromuscular training. This timeframe is consistent with preventive exercise protocols in the PFPS literature, facilitates comparison across studies and supports clinical translation of the proposed programme.

Comparison of traditional versus developed protocol

The core rationale for moving away from traditional methods outlined in Table 9 is based on the understanding that running injuries are typically problems of dynamic stability and motor control, not solely a lack of muscle length. Traditional exercises are often non-weight-bearing (e.g., a supine quad set). Hill running, especially in Meghalaya's terrain, demands high levels of single-leg stability under load. The proposed protocol uses exercises that mimic the single-leg stance phase of running (e.g., step-downs, RDLs) to train the muscles to fire when and how they are needed.

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Table 9: Traditional vs Functional Biomechanical Rehabilitation Protocols

Variable	Traditional/Established Protocol	Proposed Protocol	Key Difference & Rationale
Patellar Tilt	Isolated VMO Exercises (e.g., Quad sets with towel under knee) and Static Hamstring/Quad Stretches.	Functional Hip & Knee Control (e.g., Lateral Step-Downs, Single-Leg RDL, Pistol Prep).	Difference: Shift from isolated muscle activation to integrated biomechanical control. Rationale: Patellar tilt and tracking issues (often lateral deviation) are primarily caused by femoral internal rotation and hip adduction during the stance phase of running, not just a weak VMO. Strengthening the Gluteus Medius and Minimus (via RDLs and step-downs) controls the femur, which is the root cause of the tilt.
ITB Tightness	Aggressive Static ITB Stretching (e.g., Cross-leg standing stretch) and Intense/Painful Foam Rolling (often too fast).	Gluteal Strength & Dynamic Mobilization (e.g., Lateral Band Walks, Bridge with March, Controlled Foam Rolling).	Difference: Shift from attempting to lengthen an anatomically unstretchable structure to treating the cause of the tension. Rationale: The ITB is a dense fascia that acts as a passive stabilizer and has poor elastic properties, making static stretching largely ineffective. Tightness/pain is often due to the Gluteus Maximus and TFL overworking due to weak Gluteus Medius/Minimus. Strengthening the stabilizing glutes unloads the TFL/ITB and stabilizes the pelvis during running, which is key for hill runners.
Hip-Flexor Tightness	Prolonged Static Kneeling Hip Flexor Stretches (30-60 second holds) and Basic abdominal crunches for "core."	Dynamic Lengthening & Integrated Core Stability (e.g., Dynamic Kneeling Rocking, RFESS, Dead Bug).	Difference: Shift from passive range of motion to active, functional range of motion integrated with pelvic control. Rationale: While static stretching is not inherently bad, integrating mobility with stability (using dynamic stretching and exercises like the Dead Bug and RFESS) ensures the newly gained length is usable and held by the core muscles. This prevents the runner from reverting to an anterior pelvic tilt (which perpetuates hip flexor tightness) while running up or down hills. The focus is on motor control of the pelvis in functional positions.

Implementation considerations for hilly terrain

This protocol has been adapted for the specific context of healthy runners in the hilly terrain of Northeast India:

1. **Low-cost accessibility:** Emphasis on bodyweight exercises and minimal equipment (resistance bands, foam rollers, dumbbells) accessible in resource-limited settings.
2. **Home-based delivery:** Structured protocol suitable for implementation without access to specialised physiotherapy facilities. It is designed purely for on-field use.
3. **Terrain-specific training:** Incorporation of downhill walking, trail balance and uphill strides to build context-specific neuromuscular resilience.
4. **Cultural adaptation:** Exercise descriptions and cues adapted to local movement patterns and preferences of runners in the region.
5. **Easy to remember:** Using this clear 10 × 10 principle also makes it easy for participants to remember the required number of sets and repetitions, reducing errors in home or group sessions because the structure is simple and consistent (59). Printed handout of each exercise shall be easy to remember.

Future directions

Furthermore, emerging research in telerehabilitation shows that even web-based and remotely delivered physiotherapy programs can yield clinically meaningful reductions in pain and improvements in functional outcomes for PFPS, particularly helpful in increasing access for those in rural or remote environments such as Northeast India's mountainous regions. Supervised programs remain the gold standard, but digital interventions are a promising adjunct for scalable prevention (77).

CONCLUSION

The traditional approach to these variables—primarily using prolonged static stretching and non-functional, isolated strength work—has proven insufficient for preventing running injuries, particularly in runners navigating the challenging, uneven terrain of Meghalaya. The developed protocol is designed to replace the traditional methods, because running is a dynamic, single-leg activity and traditional static stretching fails to prepare the neuromusculoskeletal system for the high-impact, single-leg demands of running, especially on hilly terrain where greater stabilisation is required.

The developed protocol addresses the root cause of the aetiology. Patellar tilt, ITB tightness and hip-flexor tightness are not isolated issues; they are often symptoms of poor dynamic hip and pelvic control, known as the kinetic chain, which is explained in Figure 3, because tightness is often a neurological response to instability, not just a short muscle. We needed exercises that train the nervous system to actively control the joints through a full range of motion, which static stretches cannot achieve. Traditional methods only treat the symptom (e.g., trying to stretch the ITB) rather than strengthening the weak links (the hip abductors/external rotators).

This 12-week on-field preventive protocol synthesises contemporary evidence on PFPS management and translates it into a practical, phased intervention targeting three significant, modifiable biomechanical risk variables (patellar tilt, ITB tightness, hip-flexor tightness) identified from prior prospective epidemiological data in healthy runners. Structured according to FITT principles and international best-practice guidelines, the protocol integrates early pain management via taping with progressive flexibility, strength and neuromuscular training. The evidence-based rationale, standardised monitoring procedures and context-specific adaptations for hilly terrain position this protocol as a feasible and scientifically grounded intervention for PFPS prevention in active populations in Northeast India and similar environments.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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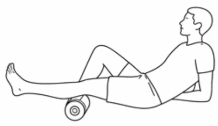
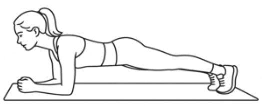
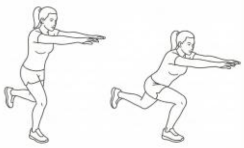
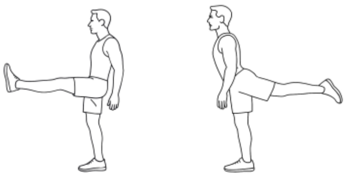
SUPPLEMENTARY MATERIAL

Supplementary Material I: Exercise illustrations for the 12-week protocol (codes 1a–3f)

Code	Exercise	Code	Exercise
1a		2d	
1b		2e	
1c		2f	
1d		3a	
1e		3b	
1f		3c	
2a		3d	
2b		3e	
2c		3f