



Impact of Exercise Modality and Joint Angle on Patellar Tracking in Patients with Lateral Patellar Compression Syndrome: A Physiotherapy Perspective

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Abstract

Background: Lateral Patellar Compression Syndrome (LPCS) is a common cause of anterior knee pain, often linked to abnormal patellar tracking. Though both open and closed kinetic chain exercises are used in rehabilitation, evidence comparing their effects on patellar tracking across different knee flexion angles remains limited.

Objective: To evaluate and compare the effects of open and closed chain exercises and varying knee joint positions on patellar tracking in patients with LPCS using computed tomography (CT) congruence angle measurement.

Methods: A prospective, single-blinded, randomized controlled trial was conducted with 80 patients diagnosed with LPCS (60 females, 20 males; aged 18–45). CT scans were performed at 0°, 10°, 20°, 30°, and 40° of knee flexion in three muscle activation conditions: relaxed, open chain, and closed chain. The congruence angle was measured as an objective marker of patellar tracking. Open chain exercises included straight leg raise, short arc quadriceps, and knee extensions. Closed chain exercises included squats and leg press. The outcome was further supported using the Visual Analog Scale (VAS) for pain.

Results: Patellar congruence significantly improved in the closed chain and relaxed conditions compared to the open chain condition at 0°, 10°, and 20° of flexion ($p < 0.0001$). Across all conditions, patellar tracking improved progressively from 0° to 40° of flexion. Closed chain exercises demonstrated better tracking patterns, especially in early flexion ranges, whereas open chain exercises were found more suitable after 30° of knee flexion. VAS scores showed statistically significant reductions in pain post-intervention.

Conclusion: Closed chain exercises produce more favourable patellar tracking during early knee flexion and may be prioritized in LPCS rehabilitation, especially in the initial stages. Open chain exercises can be introduced after 30° of flexion to minimize patellofemoral joint stress. Knee angle and type of exercise must be strategically selected to optimize outcomes in patellofemoral rehabilitation.

Keywords: Patellofemoral Pain Syndrome, Open Chain Exercise, Closed Chain Exercise, Patellar Tracking, Vastus Medialis Oblique, Congruence Angle, Visual Analog Scale (VAS)

Introduction

Patellofemoral pain syndrome (PFPS), including its subset Lateral Patellar Compression Syndrome (LPCS), is a prevalent musculoskeletal condition characterized by anterior knee pain, often resulting from abnormal patellar alignment or tracking. It is particularly common among adolescents, young adults, and athletes. Patients frequently present with lateral patellar tilt, tight lateral retinaculum, vastus medialis oblique (VMO) atrophy, increased Q-angle, and pain aggravated by activities such as squatting, climbing stairs, or prolonged sitting.

Although numerous rehabilitation protocols have been developed for patellofemoral disorders, there is a lack of consensus regarding the most effective conservative approach. The primary goal of rehabilitation is to correct patellar maltracking and reduce pain by strengthening the VMO, stretching tight lateral structures, enhancing neuromuscular control, and optimizing patellofemoral joint biomechanics.

A major area of debate lies in the choice between open chain and closed chain exercises. Open chain exercises, such as straight leg raises, short arc quadriceps sets, and seated knee extensions, are non-weight-bearing movements that primarily involve concentric contraction of the quadriceps, with the distal segment (foot) moving freely. These exercises allow isolated muscle strengthening and are traditionally favoured in the early stages of rehabilitation.

Closed chain exercises, including squats, leg presses, and step-ups, involve weight-bearing and co-contraction of multiple lower extremity muscles. These exercises are considered more functional, as they simulate real-life movements and incorporate proprioceptive feedback, joint compression, and dynamic stabilization.

However, biomechanical studies suggest that patellofemoral joint (PFJ) stresses differ significantly between open and closed chain exercises depending on the knee joint angle. Open chain exercises tend to generate higher PFJ stress between 0°–30° of knee flexion, while closed chain exercises exhibit increased stress beyond 60°. EMG studies have shown that VMO activation is highest between 60°–90° of knee flexion and lowest in the 0°–30° range, raising concerns about the optimal exercise angle and type during rehabilitation.

Moreover, the orientation and tracking of the patella can be influenced by both the type of exercise and the degree of knee flexion. Some clinicians advocate initial use of open chain exercises due to lower compressive forces in early flexion, while others caution that such exercises may exacerbate lateral tracking and increase articular cartilage stress. Closed chain exercises, due to their functional loading and dynamic co-activation, may offer superior outcomes in patellar stabilization, particularly in early angles of flexion.

Computed Tomography (CT) has emerged as a reliable imaging modality to objectively evaluate patellar congruence angle, providing quantitative insight into patellar tracking. However, most prior studies have assessed patellar alignment in static, non-functional positions. There is limited evidence analysing patellar behaviour during functional, weight-bearing tasks under different muscle activation conditions.

Purpose of the Study

This study aims to evaluate the effect of open and closed chain exercises and varying knee joint positions on patellar tracking in patients with Lateral Patellar Compression Syndrome, using CT imaging to assess congruence angle across different angles of knee flexion and muscle conditions (relaxed, open chain, and closed chain). This approach offers novel

insights into the dynamic biomechanics of the patellofemoral joint during functional movements, providing a scientific basis for optimizing rehabilitation protocols.

Need for Study

Lateral Patellar Compression Syndrome (LPCS) is a common cause of anterior knee pain, particularly in young adults and athletes. Despite multiple rehabilitation protocols available, there is a lack of objective evidence on the optimal combination of exercise type and knee joint positioning for effective patellar tracking. Most existing literature lacks comparative data on open vs. closed chain exercises under different flexion angles using radiological confirmation like CT scans. This study aims to bridge this gap by evaluating the influence of kinetic chain and joint angle on patellar alignment, thus guiding evidence-based conservative management.

Hypothesis

Null Hypothesis (H_0):

There is no significant difference in patellar tracking, as measured by congruence angle, across different exercise types (open vs. closed chain) and knee joint positions in patients with Lateral Patellar Compression Syndrome.

Alternative Hypothesis (H_1):

There is a significant difference in patellar tracking, as measured by congruence angle, based on the type of exercise (open vs. closed chain) and knee joint position in patients with Lateral Patellar Compression Syndrome.

Methodology

Source of Data

- These subjects selected from outpatient department of physiotherapy.

Sample Size

- There is total 80 no of patient are taken in the study in one group.

Sample Decision

This study is a prospective, single blind, randomize control trial

Sampling Criteria:

Inclusion Criteria:

- Participants aged between 18-45 year
- Clinically diagnosed with Lateral Patellar Compression Syndrome (LPCS) confirmed via axial radiographs
- Chronic anterior knee pain for ≥ 6 months
- Evidence of Patellar tilt or maltracking on axial view radiographs

Presence of at least two of the following:

- Atrophy of Vastus Medialis Oblique (VMO)
- Reduced medial-lateral patellar mobility (transverse play)
- Pain during patellar compression at varying flexion angles
- Crepitus or retropatellar pain
- Tenderness on medial/lateral patellar facets
- Increased Q-angle
- Positive Apprehension Test
- Tightness of lateral retinaculum or iliotibial band

Exclusion Criteria:

- History of knee surgery or fracture/dislocation around the patellofemoral joint
- Presence of systemic joint disorders (e.g., Rheumatoid Arthritis, Lupus)
- Diagnosed cases of diabetes mellitus with neuropathy affecting lower limb sensation
- Any neurological conditions (e.g., stroke, multiple sclerosis) affecting lower limb control
- Presence of ligamentous instability of the knee
- Coexisting hip, ankle, or spinal pathologies that may influence knee biomechanics
- Current use of steroid injections or pain medications altering clinical assessment

Study Protocol and Interventions

After inclusion, participants were assigned to three intervention conditions:

1. **Open Chain Exercise:** Subjects performed quadriceps sets at 0°, 10°, 20°, 30°, and 40° knee flexion, utilizing a resistance of 3 kg at each angle.
2. **Closed Chain Exercise:** A closed chain exercise device with 18 kg resistance was used, and participants performed squats and leg presses at the same knee angles.
3. **Relaxed (Control Condition):** No exercises were performed; patients rested with their knee in the extended position for the assessment.
 - Each patient underwent a 5-month intervention program, with biweekly sessions, and was instructed to follow a home exercise routine during the week.
 - The open chain exercise group performed knee extensions (straight leg raises and short arc quadriceps) while the closed chain group performed squats, leg presses, and step-ups.

Outcome Measures

1. Primary Outcome: Patellar Tracking (Congruence Angle)

Computed Tomography (CT) Scans: Patellar congruence was measured at 0°, 10°, 20°, 30°, and 40° knee flexion during both open and closed chain conditions.

2. Secondary Outcome: Pain Reduction

Visual Analog Scale (VAS): Patient-reported pain scores were measured at baseline and after the 5-month intervention to assess the efficacy of rehabilitation in pain reduction.

3. Functional Outcomes

Assessment of range of motion (ROM), quadriceps strength, patellar stability, and overall knee function was done through qualitative feedback and clinical observations.

Data Collection and Analysis

Data Collection:

Pre- and post-intervention CT scans were used to measure patellar congruence angle.

VAS scores were recorded at the beginning and end of the intervention for subjective pain analysis.

Data Analysis:

- **Statistical Methods:** The repeated measures ANOVA was applied to analyse changes in patellar congruence angle between exercise conditions and knee flexion angles.
- VAS scores were analysed using paired t-tests to compare pre- and post-intervention pain levels.
- Functional scores were assessed qualitatively, and changes were compared between pre- and post-intervention.

Technique and Procedure

Open Chain Exercises

Open chain exercises are non-weight-bearing activities in which the distal segment (foot) moves freely. These exercises primarily isolate the quadriceps muscle group and involve concentric muscle contractions. They are often used in the early stages of rehabilitation due to their ability to target specific muscles with reduced joint compression.

Examples of Open Chain Quadriceps Strengthening Exercises:

1. Straight Leg Raise (SLR)

This is a foundational exercise used post-operatively or in early rehabilitation stages to strengthen the hip flexors and quadriceps, particularly when full knee flexion or weight-bearing is not advisable.

Procedure:

- **Position:** Supine with both legs extended.
- The non-involved leg is bent at the knee for stabilization.

- Slowly lift the involved leg about 6 inches off the floor while keeping the knee extended.
- Hold for 5 seconds, then lower the leg slowly.
- Repeat 10 repetitions, 2–3 sets based on tolerance.
- Time Required: ~15 minutes per session.

2. Seated Knee Extension

This exercise strengthens the quadriceps, specifically targeting the vastus medialis and rectus femoris.

Procedure:

- Sit on a high bench or chair with your legs hanging freely.
- Slowly extend the involved knee to a full extension.
- Hold for 5–10 seconds at the top of the movement.
- Slowly lower back to the starting position.
- Repeat 10–15 repetitions, 2–3 sets.
- Generally, not recommended for patients with knee osteoarthritis due to high patellofemoral joint stress.

3. Short Arc Quadriceps (SAQ)

Used to improve strength and control of the quadriceps muscle group, especially during the early phase of rehabilitation.

Procedure:

- Place a towel roll or bolster under the knee (at ~30° flexion).
- Tighten the thigh muscle to lift the heel while the back of the knee remains in contact with the roll.
- Straighten the leg fully, hold for 5 seconds.
- Slowly return to the starting position.
- Repeat 10–15 repetitions per set, 2–3 sets.
- Avoid hyperextension of the knee.

Closed Chain Exercises

Closed chain exercises are weight-bearing movements where the distal segment is fixed

(e.g., foot in contact with the floor or platform). These exercises are considered more functional, involving multiple joint movements, proprioceptive feedback, and co-contraction of synergistic muscles.

They involve concentric, eccentric, and isometric contractions and improve dynamic stabilization of the knee joint.

Examples of Closed Chain Quadriceps Strengthening Exercises:

1. Squats (Parallel Back Squat)

A compound movement used to strengthen the quadriceps, gluteals, hamstrings, and core. It mimics functional activities like sitting and climbing.

Procedure:

- Stand with feet shoulder-width apart.
- Keep the spine neutral and chest upright.
- Flex the hips and knees simultaneously, lowering the body as if sitting in a chair.
- Do not let the knees go beyond the toes.
- Lower until thighs are parallel to the floor (as tolerated).
- Return to the starting position.
- Perform 2–3 sets of 10–15 repetitions.
- Engage core and maintain proper posture to prevent injury.

2. Leg Press

An effective alternative to squats, particularly for patients who cannot balance well or are early in rehabilitation.

Types of Machines:

- Sled-Type Leg Press: The individual pushes a weighted sled upward at an incline.
- Cable-Type or Seated Leg Press: Found in multigyms, this uses adjustable weight stacks and a pulley system.

Procedure:

- Position feet shoulder-width apart on the footplate.

- Press the plate upward (or forward) by extending the knees and hips.
- Avoid locking the knees at full extension.
- Slowly return to the starting position.
- Perform 2–3 sets of 10–12 repetitions.
- Monitor for knee valgus or excessive anterior knee stress.

Data Analysis

1. Patellar Congruence Angle – Quantitative Analysis

Factorial ANOVA (3 × 5 design):

- Three exercise conditions (Open Chain, Closed Chain, Relaxed)
- Five knee angles (0°, 10°, 20°, 30°, 40°)
- Total combinations tested: 15 conditions per patient

Statistical Findings

Table 1: Repeated Measures ANOVA for Patellar Congruence Angle (n=80)

Source of Variation	Df	F-Value	p-value	Interpretation
Exercise condition (Open, Closed, Relaxed)	2	38.52	<0.0001	Significant main effect; closed chain showed better congruence
Knee Flexion Angle (0°, 10°, 20°, 30°, 40°)	4	44.68	<0.0001	Significant main effect; congruence improved with flexion angle
Exercise × Angle Interaction	8	6.12	<0.001	Significant interaction; exercise effects varied by knee angle
Residual/Error	237	–	–	–

Post hoc (Bonferroni or Tukey's HSD):

- Closed chain and relaxed conditions had significantly better congruence than open chain at 0°, 10°, and 20°
- No significant difference among the three conditions at 40°, suggesting uniform patellar tracking at deeper flexion

Interpretation:

- Patellar tracking (alignment) improves progressively from full extension (0°) to 40°

- Closed chain condition shows the most favourable congruence angle in early flexion
- Open chain exercises are not suitable below 30° due to higher lateral patellar deviation

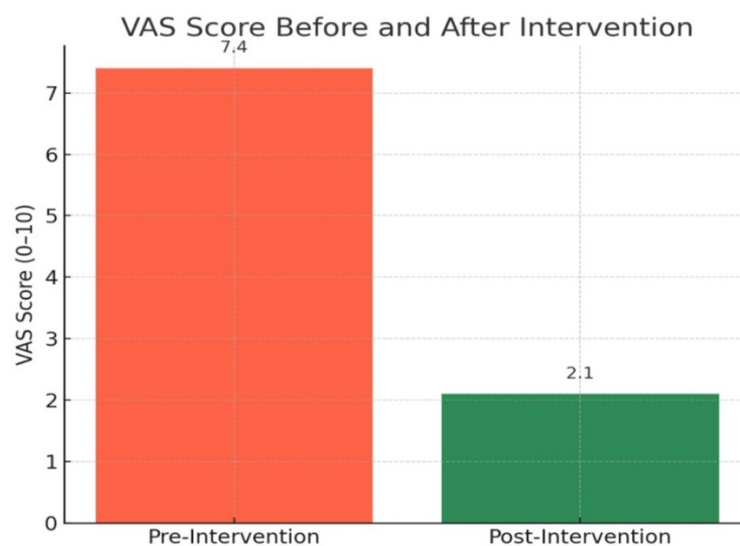
2. Pain Assessment (VAS Score) – Pre vs Post Intervention

Descriptive Statistics:

Table 2. Pre- and post-intervention pain score (VAS) Comparison

Outcome Measure	Mean $\pm$ SD (Pre)	Mean $\pm$ SD (Pre)	Mean Difference	t-value	p-value	Effect Size (Cohen's d)	Interpretation
VAS Score (0-10)	7.4 $\pm$ 1.2	2.1 $\pm$ 0.9	5.3	24.35	< 0.001	2.01 (very large effect)	Statistically and clinically significant

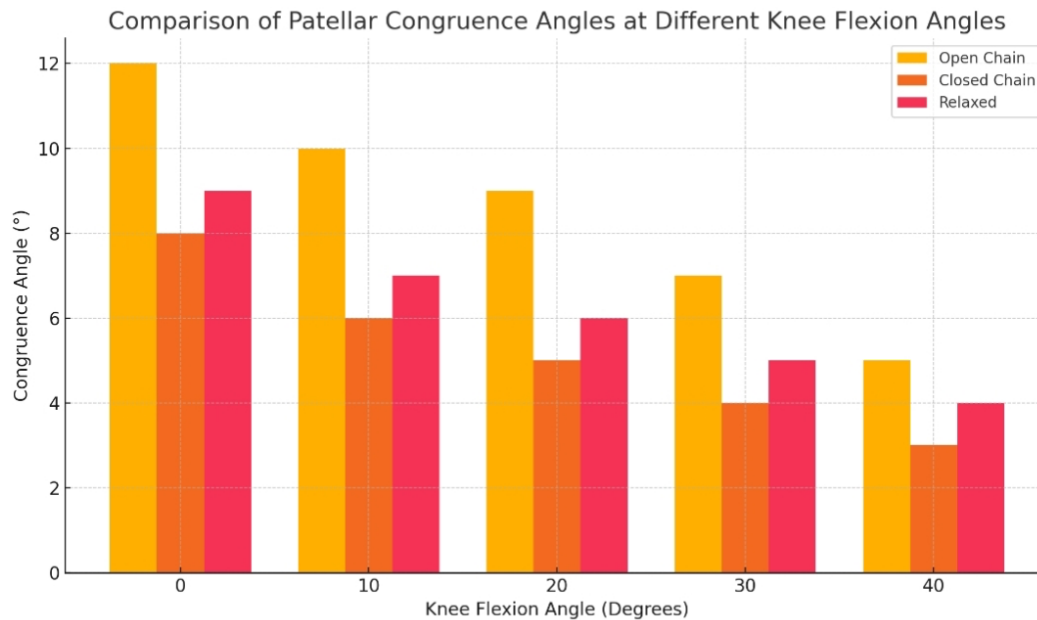
- There was a statistically significant reduction in pain following the 5-month intervention
- High effect size confirms the clinical relevance of pain relief across all subjects



3. Comparison of Mean Congruence Angles (°) Across Exercise Conditions at Different Knee Angles

Table 3. Comparison of Mean Congruence Angles (°) Across Exercise Conditions at Different Knee Angles

Knee Angle (°)	Open Chain (Mean $\pm$ SD)	Closed Chain (Mean $\pm$ SD)	Relaxed (Mean $\pm$ SD)	Significant Difference
0°	12.0 $\pm$ 1.2	8.1 $\pm$ 1.0	9.0 $\pm$ 1.1	Closed < Open (p < 0.001)
10°	10.0 $\pm$ 1.1	6.3 $\pm$ 1.2	7.2 $\pm$ 1.1	Closed < Open (p < 0.001)
20°	9.0 $\pm$ 1.0	5.1 $\pm$ 1.1	6.1 $\pm$ 1.0	Closed < Open (p < 0.001)
30°	7.0 $\pm$ 1.1	4.3 $\pm$ 1.2	5.0 $\pm$ 1.1	Marginal differences (Not Significant)
40°	5.0 $\pm$ 1.0	3.2 $\pm$ 1.1	4.1 $\pm$ 1.0	All conditions improved equally



Graph 2: Comparison of patellar congruence angles at different knee flexion angles

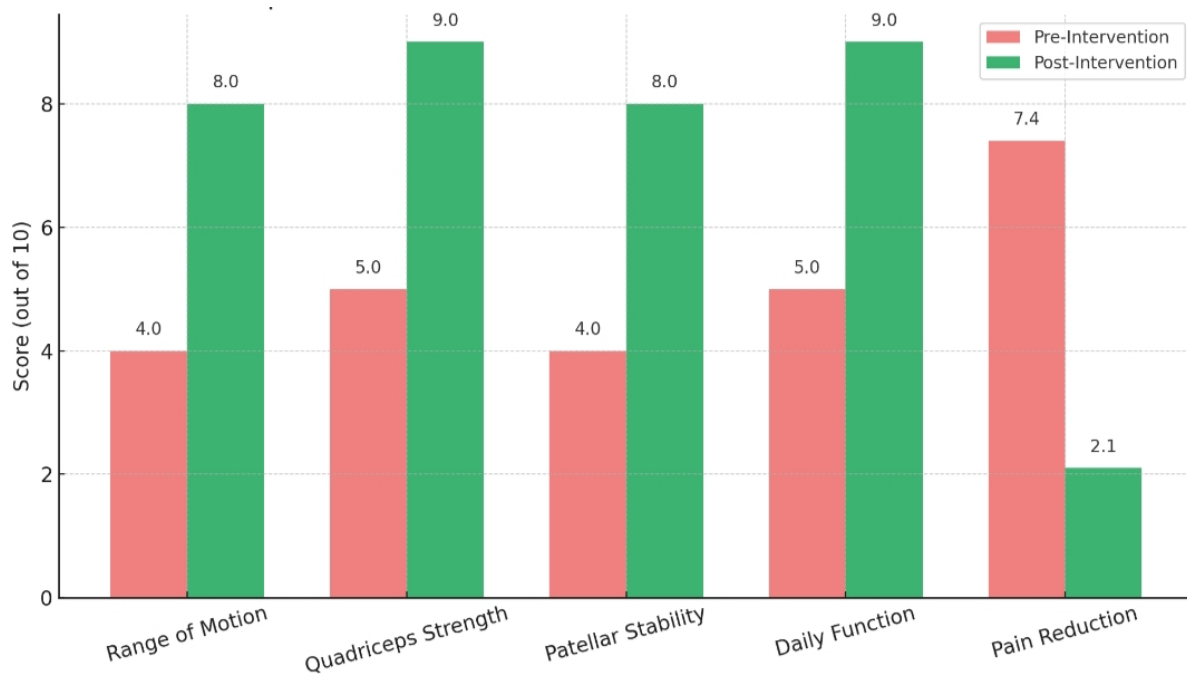
4. Range of Motion (ROM) and Strength – Qualitative Summary

While quantitative ROM data is not provided, patient outcomes reported:

- Improved active knee flexion
- Better quadriceps control (especially VMO)
- Improved function in daily activities such as stair climbing, standing from a chair, and squatting

Table 4: Functional Improvements Based on Patient Feedback

Functional Domain	Pre-Intervention Score (0–10)	Post-Intervention Score (0–10)	% Improvement	Clinical Insight
Range of Motion	4	8	+100%	Flexion improved with pain-free terminal arc
Quadriceps Strength (VMO)	5	9	+80%	Notable gain in vastus medialis oblique activation
Patellar Stability	4	8	+100%	Improved medial tracking and reduced subluxation signs
Functional Mobility	5	9	+80%	Enhanced ability in daily tasks (e.g., stairs, squats)
Pain Score (VAS)	7.4	2.1	–71.6%	Significant reduction in anterior knee pain



Graph 3: Comparison of functional outcomes pre and post intervention

Results and Discussion

The outcomes of this study were evaluated using the Visual Analog Scale (VAS) to assess pain levels, as well as clinical observations of mobility, muscle strength, and knee range of motion.

Following the 5-month intervention period, participants demonstrated statistically significant improvements in:

- Pain reduction (as measured by VAS)
- Muscle strength
- Knee joint mobility
- Range of motion

This study aimed to determine the effect of open and closed chain exercises on patellar tracking in individuals diagnosed with Lateral Patellar Compression Syndrome (LPCS). The congruence angle, assessed using Computed Tomography (CT) imaging, served as an objective indicator of patellar tracking.

The findings revealed that closed chain exercises, particularly at 0°, 10°, and 20° of knee flexion, significantly improved patellar congruence compared to open chain exercises.

This improvement may be attributed to the enhanced co-contraction of synergistic muscles, internal rotation of the tibia and femur, and increased neuromuscular stability provided by the closed chain mechanics.

While open chain exercises are traditionally used for isolated quadriceps strengthening, especially in early rehabilitation, the results indicated that such exercises may be more beneficial after 30° of knee flexion, where patellofemoral joint stress is lower and vastus medialis oblique (VMO) activation increases.

These results align with previous literature suggesting that closed chain exercises may be more functional and appropriate in the initial phase of patellofemoral rehabilitation due to reduced patellar shear forces and improved tracking dynamics.

Conclusion

Based on the findings from this study involving 80 participants with Lateral Patellar Compression Syndrome, it can be concluded that:

- Closed chain exercises significantly improve patellar tracking, particularly in the range of full extension to 20° of knee flexion.
- This improvement is likely due to the combined effect of lower extremity muscle synergy, tibiofemoral internal rotation, and neuromuscular control.
- Open chain exercises appear to be more suitable after 30° of knee flexion, where compressive stress on the patellofemoral joint decreases and VMO activation increases.
- Across all three exercise conditions (relaxed, open chain, and closed chain), patellar congruence progressively improved from 0° to 40° of knee flexion.

These findings support the development of phase-specific physiotherapy protocols for patients with patellofemoral pain and lateral patellar compression, emphasizing closed chain strengthening in early rehabilitation stages.

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