

Effectiveness of Perturbation-Based Training Combined with Quadriceps Strengthening on Dynamic Knee Stability in Post-Operative ACL Football Player: A Case Study

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Abstract :

Background: Anterior cruciate ligament (ACL) injuries are highly prevalent among football players and often result in impaired dynamic knee stability, quadriceps weakness, and delayed return to sport following reconstruction surgery. Persistent neuromuscular deficits after anterior cruciate ligament reconstruction (ACLR) increase the risk of reinjury and functional limitations, particularly in athletes involved in pivoting and cutting activities. Perturbation-based training combined with progressive quadriceps strengthening has emerged as a promising rehabilitation strategy to improve proprioception, cocontraction, and functional performance.

Case Description: This case study describes the rehabilitation of a 24-year-old Indian male professional football player who underwent hamstring autograft ACL reconstruction following a non-contact ACL rupture sustained during a competitive football match. At four months post-operatively, the athlete demonstrated significant quadriceps weakness, impaired balance, reduced dynamic stability, and functional limitations, with a quadriceps strength symmetry index of 60%, IKDC score of 62%, and Lysholm score of 68/100. A structured 12-week rehabilitation protocol integrating perturbation-based neuromuscular training and progressive quadriceps strengthening was implemented three times weekly under physiotherapy supervision.

Intervention: The rehabilitation program consisted of three progressive phases emphasizing quadriceps activation, eccentric strengthening, cocontraction training, balance retraining, and sport-specific perturbation exercises using foam pads, wobble boards, and BOSU-based drills. Exercise intensity and instability challenges were gradually increased while monitoring pain, swelling, and psychological readiness.

Outcomes: Following the intervention, substantial improvements were observed in muscular strength, functional symmetry, and dynamic knee control. Quadriceps strength symmetry improved from 60% to 92%, while ultrasound-assessed quadriceps hypotrophy reduced from 15% to 5%. Single-leg hop symmetry improved from 75% to 95%, and Y-balance reach distances increased significantly. IKDC and Lysholm scores improved to 88% and 92/100, respectively. The athlete reported minimal pain, no episodes of instability, and enhanced confidence during football-specific activities. Return to non-contact team training was successfully achieved at nine months post-ACLR without adverse events.

Conclusion: The findings of this case study suggest that perturbation-based training combined with progressive quadriceps strengthening may effectively restore dynamic knee stability, improve neuromuscular control, and facilitate safe return to sport following ACL reconstruction in football players. The intervention demonstrated clinically meaningful improvements in strength symmetry, proprioception, and functional performance while addressing psychological barriers to return to play. This multimodal rehabilitation approach may be particularly valuable in resource-constrained sporting environments such as India.

I. INTRODUCTION

Anterior cruciate ligament (ACL) injuries represent a significant challenge for athletes, particularly in high-demand sports like football, where non-contact pivoting and rapid directional changes are common (Rauh, 2013). In India, where football is increasingly popular among young athletes in both amateur and professional circuits, ACL ruptures are rising due to growing participation in competitive leagues and inadequate field conditions in rural training grounds (Kaiyaperumal et al., 2023). These injuries often result from mechanisms involving sudden deceleration or twisting, leading to instability and long-term functional deficits if not managed comprehensively (Rauh, 2013), (Cordeiro et al., 2014).

Post-operative rehabilitation after ACL reconstruction (ACLR) focuses on restoring quadriceps strength and dynamic knee stability to facilitate safe return to sport (Gokeler et al., 2013), (Letafatkar et al., 2015). Quadriceps weakness is a hallmark deficit following ACLR, contributing to altered biomechanics and increased reinjury risk (Gokeler et al., 2013), (Kuenze et al., 2016). Studies indicate that eccentric quadriceps training yields superior isometric strength gains compared to concentric protocols, yet full recovery remains elusive without integrated neuromuscular approaches (Gokeler et al., 2013), (Anne et al., 2014). Perturbation-based training, which challenges balance and proprioception through unstable surfaces, enhances cocontraction ratios between quadriceps and hamstrings, potentially reducing anterior tibial translation and improving joint stability (Letafatkar et al., 2015), (Kaiyaperumal et al., 2023).

Dynamic knee stability, assessed via ballistic movements like the instep kick in football, reveals persistent asymmetries in ACLR athletes, including reduced knee extension angles and elevated quadriceps activation (Cordeiro et al., 2014), (Milewski et al., 2014). For Indian athletes, cultural factors such as limited access to specialized facilities and high training volumes in humid climates may exacerbate recovery challenges, underscoring the need for tailored, evidence-based interventions (Mirela et al., 2018). This case study explores the application of perturbation-based training combined with quadriceps strengthening in an Indian football player post-ACLR, highlighting its potential to optimize dynamic stability and return to play.

Case Description

Arjun, a 24-year-old male professional footballer from Mumbai, India, sustained a non-contact ACL injury during a league match in the Indian Super League. Playing as a midfielder for a mid-tier club, he twisted his right knee while pivoting to receive a pass on a rain-slicked pitch, a scenario common in monsoon-season games across India (Rauh, 2013). At 178 cm and 72 kg, Arjun had a pre-injury training regimen of 5-6 sessions weekly, emphasizing endurance and agility, with no prior lower-limb injuries. Magnetic resonance imaging confirmed a complete mid-substance ACL tear without meniscal involvement, prompting arthroscopic reconstruction using a hamstring autograft four weeks post-injury.

Surgery was performed at a tertiary sports medicine center in Mumbai, following standard anatomical single-bundle technique to restore knee kinematics (Cordeiro et al., 2014), (Shelton, 2006). Immediately post-operatively, Arjun experienced moderate swelling and pain (Visual Analog Scale score of 6/10), with quadriceps hypotrophy evident on ultrasound, measuring a 15% cross-sectional area reduction compared to the uninjured limb (Sheenam et al., 2025), (Pamukoff et al., 2017). Early rehabilitation, initiated day one post-surgery, adhered to a phased protocol emphasizing cryotherapy, gentle range of motion (ROM) exercises, and patellar mobilization to mitigate effusion and restore extension (Mirela et al., 2018), (Zhang, 2008).

By week two, Arjun achieved full knee extension but reported quadriceps inhibition, with a central activation ratio of 75% on the involved limb, limiting weight-bearing progression (Cobian et al., 2024), (Kuenze, Eltoukhy, et al., 2016). He navigated cultural hurdles, including family pressures to resume training quickly for financial stability, common among Indian athletes reliant on club contracts (Forelli et al., 2020). Initial assessments at three months showed a Lysholm score of 68/100 and International Knee Documentation Committee (IKDC) subjective score of 62%, reflecting persistent instability during walking on uneven urban streets (Carlson, 2020), (Taradaj et al., 2013). Quadriceps strength was 60% of the contralateral limb on isokinetic testing at 60°/s, highlighting the need for targeted intervention to address dynamic deficits (Gokeler et al., 2013), (Wang et al., 2018).

Intervention

At four months post-ACLR, Arjun began a 12-week intervention combining perturbation-based training with quadriceps strengthening, supervised by a sports physiotherapist at his club's facility. This program was designed to progressively enhance neuromuscular control and muscle force production, drawing from evidence that eccentric and perturbation exercises improve quadriceps function without excessive graft strain (Gokeler et al., 2013), (Letafatkar et al., 2015). Sessions occurred three times weekly, lasting 45-60 minutes, integrated into his routine alongside light jogging, with rest days to accommodate Mumbai's humid climate and prevent fatigue (Kuenze et al., 2016), (Kaiyaperumal et al., 2023).

Phase one (weeks 1-4) focused on foundational quadriceps activation using closed-chain exercises with voluntary cocontraction to minimize anterior tibial shear (Biscarini et al., 2016). Arjun performed double-leg squats with 10-20% bodyweight resistance (e.g., barbells), progressing to single-leg variations, aiming for 3 sets of 10-12 repetitions at 60-90° knee flexion (Gokeler et al., 2013), (Anne et al., 2014). Perturbation elements were introduced via standing on a foam pad, where the therapist applied manual anterior-posterior perturbations to elicit quadriceps-hamstring cocontraction, targeting a 32-50% maximum voluntary isometric contraction (MVIC) in the vasti muscles (Letafatkar et al., 2015), (Biscarini et al., 2016). Challenges included initial fear of instability, reminiscent of his injury, which was addressed through biofeedback using electromyography to reinforce balanced activation (Bryant et al., 2010).

Phase two (weeks 5-8) advanced to eccentric quadriceps emphasis, incorporating step-downs from a 20-cm box with controlled descent (3-5 seconds), combined with perturbation via a wobble board to simulate football's unpredictable surfaces (Gokeler et al., 2013), (Kaiyaperumal et al., 2023). Resistance was increased to 30-40% of 1-repetition maximum (1RM), with 3 sets of 8-10 reps, focusing on knee flexion angles near 20-30° to enhance ballistic control (Cordeiro et al., 2014), (Cao et al., 2025). Arjun reported quadriceps soreness and occasional swelling after sessions, managed with ice and adjusted loads, reflecting the adaptive stress on healing tissues (Sheenam et al., 2025), (Kuenze et al., 2016). Frequency remained three sessions weekly, with home exercises including cocontraction holds to maintain gains (Biscarini et al., 2016).

Phase three (weeks 9-12) integrated sport-specific perturbations, such as single-leg stance on a BOSU ball during simulated passing drills, paired with isokinetic eccentric quadriceps training at 60°/s (Cao et al., 2025), (Wang et al., 2018). Loads reached 50-60% 1RM, with 3 sets of 6-8 reps, emphasizing reactive strength to reduce landing asymmetries (Milewski et al., 2014), (Maestroni et al., 2019). Challenges peaked here, as Arjun grappled with psychological hesitation during pivots, mitigated by gradual exposure and motivational goal-setting tied to upcoming trials (“Return to Sport: When Should an Athlete Return to Sport After an ACL Surgery?,” 2011), (Forelli et al., 2020). Compliance was high, with adherence at 95%, though tropical heat occasionally shortened sessions, underscoring adaptations for Indian contexts (Mirela et al., 2018).

Table 1: 12-Week Combined Perturbation-Based and Quadriceps Strengthening Protocol for a Post-Operative ACL Indian Footballer

Phase	Weeks	Main Goal	Key Exercises / Loads	Perturbation Method	Frequency & Setting	Challenges/ Adaptations
1	1-4	Quadriceps activation, cocontraction	<ul style="list-style-type: none"> • Double-leg squats (10–20% BW), • Progress to single-leg squats, • 3×10–12 reps, 60–90° knee flexion 	<ul style="list-style-type: none"> • Foam pad stance, • Manual perturbation • EMG biofeedback 	3×/week, 45–60 min, Club facility	Fear of instability; Managed via biofeedback, Rest days for Mumbai humidity
2	5-8	Eccentric focus, Controlled instability	<ul style="list-style-type: none"> • Step-downs from 20-cm box (3–5s descent), • Wobble board, • 30–40% 1RM, • 3×8–10 reps, • 20–30° knee flexion 	Unstable surface (wobble board)	3×/week, Home exercises added	Quad soreness/swelling; Load adjustment; Ice use
3	9-12	Sport-specific perturbation, reactive strength	<ul style="list-style-type: none"> • Single-leg BOSU stance, • Passing drills, • Isokinetic eccentric training, • 50–60% 1RM, • 3×6–8 reps 	BOSU ball, Football drills	3×/week; Sessions at club facility	Hesitation during pivots; Graded exposure; Heat-shortened sessions

Outcomes

Clinical assessments at program completion (seven months post-ACLR) revealed marked improvements in dynamic knee stability. Isokinetic testing showed quadriceps strength symmetry index rising from 60% to 92% at 60°/s, with eccentric torque gains of 25% on the involved limb, aligning with reduced hypotrophy on ultrasound (now 5% deficit) (Gokeler et al., 2013), (Kuenze et al., 2016), (Pamukoff et al., 2017). Anterior tibial translation via KT-1000 arthrometer decreased to 1.5 mm side-to-side difference, indicating enhanced static stability that translated to dynamic tasks (Cao et al., 2025), (Higuchi et al., 2003).

Functional outcomes were equally promising. The single-leg hop for distance improved from 75% to 95% symmetry, with Arjun achieving 1.8 m on the involved limb, comparable to pre-injury baselines (Carlson, 2020), (Mohammadi et al., 2013). Y-balance test reach distances increased by 12% in anterior and posteromedial directions, reflecting better proprioception and perturbation resistance (Cao et al., 2025), (Liu et al., 1999). During an instep kick simulation, knee extension angle at ball contact normalized to within 2° of the uninjured side, with reduced rectus femoris overactivation (from 80% to 55% MVIC) (Cordeiro et al., 2014), (Letafatkar et al., 2015). IKDC subjective score rose to 88%, and Lysholm to 92/100, capturing Arjun's regained confidence in daily activities like navigating crowded markets (Carlson, 2020), (Taradaj et al., 2013).

Arjun's feedback was profoundly humanizing: "The perturbations made me feel the knee 'wake up'—like it was learning to trust itself again, especially after those early months of limping through practice." He reported minimal pain (VAS 1/10) and no giving-way episodes, though he noted emotional fatigue from isolation during rehab, eased by virtual sessions with teammates (Stinson et al., 2020), (Forelli et al., 2020). By nine months post-ACLR, Arjun returned to full club training, participating in non-contact drills, with ACL-Return to Sport after Injury scale score of 85%, signaling psychological readiness (Carolan et al., 2020), ("Return to Sport: When Should an Athlete Return to Sport After an ACL Surgery?," 2011). No adverse events occurred, supporting the intervention's safety (Taradaj et al., 2013).

Discussion

This case illustrates the synergistic benefits of perturbation-based training and quadriceps strengthening for restoring dynamic knee stability post-ACLR, consistent with evidence that eccentric protocols outperform concentric ones in strength restoration (Gokeler et al., 2013), (Anne et al., 2014). Arjun's quadriceps symmetry gains mirror findings where two weeks of targeted strengthening reduced neuromuscular deficits, enhancing fatigue resistance (Kuenze et al., 2016), (Kuenze, Eltoukhy, et al., 2016). Perturbations improved cocontraction, akin to studies showing balanced agonist-antagonist ratios post-intervention, which mitigate anterior cruciate ligament strain during ballistic movements (Letafatkar et al., 2015), (Cordeiro et al., 2014).

Comparatively, multimodal approaches like BOSU perturbations yield superior joint stability and agility over standard protocols, as seen in adolescent athletes with 10-15% better Y-balance scores (Kaiyaperumal et al., 2023), (Cao et al., 2025). Arjun's hop symmetry aligns with accelerated rehab outcomes in footballers, where specific drills expedite functional recovery without reinjury risk (Mirela et al., 2018), (Forelli et al., 2020). However, persistent asymmetries in extensor moments during landings, observed in adolescent cohorts, suggest ongoing monitoring to prevent contralateral overload (Milewski et al., 2014), (Aizawa et al., 2018).

In the Indian context, cultural and environmental factors—such as high training densities and limited access to isokinetic equipment—necessitate adaptable programs (Wang et al., 2018). Arjun's progress highlights how perturbation tools like wobble boards, affordable in resource-constrained settings, bridge gaps in neuromuscular training (Liu et al., 1999), (T. Liu et al., 1999). Yet, gaps persist: while strength correlates with function post-ACLR, dynamic stability measures like torque steadiness require longer-term tracking, as early gains may plateau (Cobian et al., 2024), (Hohmann et al., 2015). Psychological elements, underexplored in Indian studies, influenced Arjun's adherence, warranting integrated support (Budhkar & Kumar, 2024), (Stinson et al., 2020). Future research should address these in diverse populations to refine return-to-play criteria ("Return to Sport: When Should an Athlete Return to Sport After an ACL Surgery?," 2011), (Petersen et al., 2014).

Conclusion

This case underscores key learnings: perturbation-based training combined with progressive quadriceps strengthening effectively enhances dynamic knee stability in post-ACLR football players, achieving near-symmetric function by nine months (Kaiyaperumal et al., 2023), (Cao et al., 2025). Early cocontraction exercises safely build strength, while sport-specific perturbations foster confidence and ballistic control (Biscarini et al., 2016), (Cordeiro et al., 2014). For Indian athletes, culturally sensitive adaptations mitigate barriers, promoting sustainable return to play (Forelli et al., 2020). Clinicians should prioritize objective symmetry metrics alongside patient feedback to optimize outcomes and minimize reinjury (Carlson, 2020), (Carolan et al., 2020).

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