Case Report

Neuromuscular Adaptations to Plyometric Exercises in Late-Phase ACL Reconstruction Rehabilitation: A Case Report

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ABSTRACT

Background: Postanterior cruciate ligament (ACL) reconstruction rehabilitation poses significant challenges in restoring optimal neuromuscular function and athletic performance. Although plyometric training has shown promise in late-stage rehabilitation, its comprehensive effects on muscle strength, dynamic balance, and functional performance require further investigation. **Objective:** This study aimed to evaluate the therapeutic efficacy of a structured plyometric exercise protocol on muscle strength, dynamic balance, and functional outcomes in young athletes who underwent ACL reconstruction. **Methods**: A single-case study of a 16-year-old male soccer athlete who underwent right anterior cruciate ligament (ACL) reconstruction was conducted. The intervention comprised three sessions of progressive plyometric exercises over a seven-day period. Outcomes were assessed via a modified sphygmomanometer test for muscle strength, the Y balance test for dynamic balance, and the Tegner Lysholm knee scoring scale for functional ability. **Results**: Knee flexor strength improved from 50 to 100 mmHg (100% increase), and extensor strength increased from 110 to 130 mmHg (18.2% increase). The dynamic balance composite score increased from 88% to 108%. The functional performance on the Tegner–Lysholm scale improved from 90 to 95 points, primarily because of reduced pain scores. **Conclusion**: This case demonstrates that a structured plyometric exercise protocol may effectively improve muscle strength, dynamic balance, and functional performance during late-stage ACL rehabilitation. These findings suggest the potential utility of return-to-sport protocols, although large-scale investigations are warranted.

KEYWORDS

Anterior cruciate ligament reconstruction, plyometric exercise, postoperative care, sports medicine, general medicine

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INTRODUCTION

The knee joint is one of the most biomechanically sophisticated structures in human anatomy and serves two crucial functions: maintaining stability during weight-bearing movements and facilitating mobility during locomotion [1]. Among its critical components, the anterior cruciate ligament (ACL) plays a paramount role in preventing anterior tibial translation and maintaining optimal knee biomechanics to protect meniscal integrity [2]. ACL injuries represent a significant challenge in sports medicine, occurring predominantly during high-impact activities such as soccer, basketball, volleyball, and gymnastics [3]. The mechanism of ACL rupture encompasses both direct trauma, resulting from lateral or anterior knee impact, and indirect trauma, typically occurring during hyperextension with rotational components and valgus stress [4,5].

The epidemiological landscape of ACL injuries presents statistics, with an incidence rate of 29–32 cases per 100,000 people in European countries. In Singapore, racial distribution analysis revealed a predominance of Chinese individuals (60.5%), followed by Malay (23%), Indian (8.4%), and other ethnicities (8.11%). Notably, Indonesian statistics indicate a significant burden, with ACL injuries accounting for 9% of knee-related conditions; ACL injuries are the second most prevalent musculoskeletal issue after back pain, affecting 48 per 1,000 patients [6].

Management strategies for ACL injuries include reconstructive surgery and conservative approaches, with reconstruction being the preferred intervention when the degree of ligament fiber damage exceeds 50% and is accompanied by joint instability [7]. Postreconstruction rehabilitation presents multiple challenges, including diminished muscle strength, compromised endurance, reduced flexibility, and impaired joint stability, which collectively affect functional capacity [8]. The comprehensive rehabilitation protocol outlined by Cooper and Hughes encompasses multiple phases: preoperative injury recovery, immediate postsurgical care, strength and neuromuscular control development, progressive activity reintroduction, and injury prevention strategies [9].

The success of post-ACL reconstruction depends heavily on targeted rehabilitation protocols, particularly in phase 4, where the focus shifts to progressive strength training, balance enhancement, landing mechanics, and agility development [10]. Plyometric exercise has emerged as a promising intervention strategy [11], resulting in significant improvements in strength, muscular explosive endurance, proprioception, joint stabilization, coordination of motion, and a reduced risk of repetitive injuries [12,13]. With this method, postreconstruction ACL patients can compete optimally again in the field. This study aimed to evaluate the therapeutic efficacy of plyometric exercise protocols in post-ACL reconstruction rehabilitation.

CASE PRESENTATION

A 16-year-old soccer player attended soccer practice in November 2022. During training, the patient tripped over his or her foot and twisted it outward. The patient subsequently underwent physiotherapy at the RSWN facility. The patient subsequently returned to play soccer but sustained another injury to the same leg. In May 2024, the patient experienced discomfort in his right knee and underwent MRI at Kariadi General Hospital. The result was a partial rupture of the right ACL. In July, ACL reconstruction was performed at Kariadi General Hospital, and physiotherapy treatment was performed at the RSWN three times a week until now. Currently, the patient's condition is no longer painful, the knee is fully bent, and the patient can perform daily activities, but it is not perfect. In accordance with the Melbourne ACL Rehabilitation Guide, this phase is phase 4

MATERIALS AND METHODS

Study design and setting

This single case study was obtained from K.R.M.T. Hospital. Wongsonegoro Semarang Hospital in December 2024, following institutional ethical guidelines. The study participants were 16-year-old male soccer athletes (An. Z), who underwent right anterior cruciate ligament (ACL) reconstruction. The patient reported subjective limitations in strength, agility, and endurance and expressed reluctance to return to competitive play because of these functional deficits.

Intervention protocol

The rehabilitation program comprised three supervised physiotherapy sessions conducted between December 5 and 12, 2024. The intervention focused on a progressive plyometric exercise protocol that was systematically designed to address lower extremity function and neuromuscular control. The protocol incorporated six distinct plyometric movements (Figure 1): four repetition chops with forward steps over mini-hurdles; four repetition chops with lateral steps over mini-hurdles; bilateral forward jumps across mini-hurdles; bilateral lateral jumps across mini-hurdles; combined bilateral forward jumps with unilateral lateral steps over mini-hurdles; and bilateral lateral jumps integrated with forward cone steps. Each exercise modality was performed five times across two sets, with standardized rest intervals between sets to ensure optimal neuromuscular adaptation and to prevent fatigue-induced compensation patterns. The progression and intensity of the exercises were monitored and adjusted on the basis of the patient's performance and symptomatic response to ensure safe advancement through the protocol while maintaining biomechanical quality.

Figure 1. Plyometric movement: four repetition chops with forward steps over mini-hurdles, four repetition chops with lateral steps over mini-hurdles, bilateral forward jumps across mini-hurdles, bilateral lateral jumps across mini-hurdles, combined bilateral forward jumps with unilateral lateral steps over mini-hurdles, and bilateral lateral jumps integrated with forward cone steps.

Ethical considerations

The study adhered to ethical guidelines for research involving human subjects, including obtaining informed consent from participants and maintaining the confidentiality of personal information. Approval for the study was obtained from the relevant institutional review board.

Outcome measurements

1. *Muscle strength assessment,* muscle strength was evaluated via a modified sphygmomanometer test selected for its clinical validity, portability, and cost-effectiveness

[14]. This modified sphygmomanometer is an easily available tool, and its use is flexible and accurate. This measurement tool demonstrates excellent reliability, with intraclass correlation coefficient (ICC) values ranging from 0.72-0.94 [15].

2. *Dynamic balance evaluation*, dynamic balance was assessed via the Y balance test (YBT), a validated measure of lower-extremity neuromuscular control that integrates strength, flexibility, balance, stability, and range of motion components [16]. The composite score was calculated by summing the reach distances in three directions, normalized to the lower limb length, with bilateral asymmetry quantified as the interlimb reach difference [8]. The YBT has high reliability, with within-rater ICC values ranging from 0.85-0.91 and interrater ICCs ranging from 0.85-0.93 [17].
3. Assessment of functional performance, functional ability was evaluated via the Tegner Lysholm Knee Scoring Scale, an 8-item questionnaire designed to assess knee joint stability [18]. This instrument has excellent reliability, with an ICC of 0.94 [19].

RESULTS

Muscle strength assessment

Serial assessments of knee muscle strength were conducted across three therapeutic sessions (T0-T3) via a modified sphygmomanometer test. The intervention yielded substantial improvements in both the knee flexor and extensor muscle groups of the elderly participants. Knee flexor strength markedly increased from baseline (50 mmHg) to the final assessment (100 mmHg), representing a 100% improvement. Concurrently, knee extensor strength showed progressive enhancement from the initial measurement (110 mmHg) to the final evaluation (130 mmHg), indicating an 18.2% increase (Table 1).

Table 1. Sequential evaluation of knee muscle strength via a modified sphygmomanometer

Region	Movement	T0	T1	T2	T3
Knee	Flexion	50 mmHg	50 mmHg	90 mmHg	100 mmHg
	Extension	110 mmHg	110 mmHg	120 mmHg	130 mmHg

Remarks: Values are expressed in millimeters of mercury (mmHg); T0 = baseline assessment; T1-T3 = subsequent therapeutic sessions.

Dynamic balance assessment

The Y balance test (YBT) demonstrated progressive improvement in dynamic postural control during therapeutic sessions. The composite score increased substantially from the baseline (88%) to the final assessment (108%), representing a 22.7% enhancement in overall dynamic balance performance (Table 2).

Table 2. Sequential Y balance test composite scores

Composite Value	T0	T1	T2	T3
	88%	92%	96%	108%

Remarks: T0, baseline assessment; T1-T3 = subsequent therapeutic sessions

Functional performance outcomes

The Tegner Lysholm knee scoring scale assessment revealed an improvement in functional capacity from the initial assessment (90 points) to the final assessment (95 points). Notably, the primary contribution to this improvement was observed in the pain domain, which improved from 20 to 25 points, whereas the other functional parameters remained stable (Table 3).

Table 3. Tegner Lysholm knee scoring scale results (initial and final assessments)

Section	T0	T3
Limp	5	5
Using canes/crutches	5	5
Locking sensation in the knee	15	15

Section	T0	T3
Knee fatigue	20	20
Pain	20	25
Swollen	10	10
Climbing stairs	10	10
Squat	5	5
Total	**90**	**95**

Remarks: represent the points achieved in each functional domain, with higher scores indicating better functions.

DISCUSSIONS

Our findings indicated significant improvements in knee flexor and extensor strength following the structured plyometric exercise protocol. The most notable enhancement occurred between T1 and T2, with the flexor strength increasing by 80% (from 50 to 90 mmHg) and the extensor strength increasing by 9.1% (from 110 to 120 mmHg). This asymmetric improvement pattern suggests differential adaptation rates between muscle groups, potentially influenced by postreconstruction neural inhibition patterns [19]. The observed strength gains align with the established mechanistic understanding of plyometric training, where rapid stretch–shortening cycles enhance muscle–tendon unit force production through improved neuromuscular efficiency and mechanical power output [20].

The sequential improvement in the Y-balance test composite scores from baseline (88%) to the final assessment (108%) represented a clinically significant enhancement in dynamic stability. This 22.7% improvement exceeded the typical measurement error and suggested meaningful functional recovery. The enhancement in dynamic balance likely reflects the improved integration of multiple sensory systems, including visual, vestibular, and proprioceptive inputs [21]. Specifically, the emphasis on rapid force development and positional awareness in the plyometric protocol appears to enhance mechanoreceptor function across multiple tissue types, including muscles, tendons, joints, fascia, and cutaneous structures [22].

The Tegner Lysholm knee scoring scale demonstrated a moderate but clinically relevant improvement from 90 to 95 points, which was driven primarily by increased pain scores. This improvement, while numerically small, represents meaningful progress in functional capacity [23]. The observed functional gains align with previous research, indicating that plyometric training in combination with rapid eccentric-concentric coupling enhances both strength parameters and motor control efficiency [11]. This adaptation is particularly relevant for athletes who require explosive power development and refined neuromuscular control for sport-specific activities to enhance performance.

Clinical implications

The collective improvements in strength, balance, and functional measures suggest that structured plyometric training may serve as an effective therapeutic modality for late-stage ACL reconstruction rehabilitation. The progressive nature of the adaptations observed from T0 to T3 indicates that the intensity and progression of the protocol were appropriately calibrated for this recovery phase. However, the differential improvement rates across outcome measures highlight the importance of comprehensive assessment in guiding rehabilitation progression.

Limitations

This case report has several notable limitations that warrant consideration. First, as a single-case study, the findings cannot be generalized to a broader population of post-ACL reconstruction patients. Second, the relatively short intervention period (three sessions over seven days) may not have fully captured long-term adaptations to plyometric training. Third, although multiple outcome measures were used, the absence of objective biomechanical analysis and muscle activation patterns limited our understanding of the underlying mechanisms contributing to the observed improvements. Additionally, the lack of follow-up assessments beyond the intervention period prevented the evaluation of the durability of therapeutic gains.

CONCLUSIONS

This case report provides preliminary evidence supporting the efficacy of structured plyometric training in enhancing neuromuscular function following ACL reconstruction. The observed improvements across multiple outcome domains, such as muscle strength, dynamic balance, and functional performance, suggest that appropriately prescribed plyometric exercises may effectively address common postreconstruction deficits. Although the limitations of a single-case design preclude broad generalization, these findings contribute to the growing body of evidence supporting the integration of plyometric training into late-stage ACL reconstruction rehabilitation protocols. Future research employing larger cohorts, extended intervention periods, and comprehensive biomechanical analyses could further elucidate the optimal implementation of plyometric training in sport-specific rehabilitation programs. These insights may ultimately inform more effective return-to-sport protocols for athletes after ACL.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization: SF, AP, HM; Methodology: SF; Software, Validation: SF, HM; Formal Analysis, Investigation: SF; Resources: SF, HM; Data Curation, Writing - Original Draft: SF; Writing - Review & Editing: SF, AP; Visualization: SF; Supervision: AP, HM

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