JOURNAL FOR SOCIAL SCIENCE STUDIES
An International Peer-Reviewed Open Access Journal

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 4 • August 2026

PLYOMETRIC TRAINING REDUCES ANTERIOR CRUCIATE LIGAMENT INJURY RISK IN FEMALE VOLLEYBALL PLAYERS: A PRE-TEST POST-TEST TRIAL

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DOI: https://doi.org/10.5281/zenodo.22326675

Keywords
Plyometric training, ACL injury prevention, female athletes, volleyball, biomechanics, neuromuscular control.

Article History
Received: 28 June 2026
Accepted: 15 August 2026
Published: 31 August 2026

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Abstract

Anterior cruciate ligament (ACL) injuries are a growing concern among female volleyball players in Pakistan due to the sport's repetitive high-impact movements. Despite international evidence supporting plyometric training as an injury-prevention strategy, data specific to Pakistani female athletes remain limited. A pre-test post-test study was conducted involving 20 female volleyball club players aged 20–30 years. Participants completed a 12-week plyometric training program (three sessions per week, 30 minutes each) at the Sindh Sports Board Karachi. Lower-limb kinematics, eccentric torques, and hop performance were evaluated at baseline and after intervention using a Vicon motion capture system, a Biodex dynamometer, and standardized functional hop tests. Data were analyzed with paired t-tests (SPSS v26, $p < 0.05$). Ethical approval was granted by the Research Supervisory Committee, Health Services Academy, Islamabad (Protocol No. HSA/2026/001). These results show how effective the 12-week plyometric training program is and prove the research hypotheses without any doubt. On the basis of the results obtained, significant changes were found in biomechanical, torque and functional performance parameters. In particular, according to the statistical analysis based on the use of paired t-tests, there was a considerable reduction in the angles of knee abduction and hip adduction during motion. Moreover, the dynamic strength assessment revealed significant increases in eccentric hip abductor and adductor torques. The functional assessment through the hop tests indicated the improved lower limb power and agility. A structured 12-week plyometric program effectively mitigates ACL injury risk factors and enhances lower-limb function among female volleyball club players. Integrating this training into national programs could improve athletic safety and performance. Limitations include the absence of a control group and a relatively small sample.

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Introduction

ACL injuries are among the most debilitating sports-related conditions, especially in volleyball, where rapid deceleration, pivoting, and jumping are routine. Female athletes are reported to be two to eight times more susceptible than males, largely due to differences in biomechanics, hormonal profiles, and neuromuscular control (Arendt et al., 1995).

In Pakistan, volleyball is increasingly popular among women, yet non-contact ACL injuries often occurring during landings and changes in direction remain a major concern, accounting for nearly 70% of all ACL cases (Hewett et al., 2005). These injuries can derail athletic careers and impose long-term complications such as joint instability and early-onset osteoarthritis (Mandelbaum et al., 2005).

Plyometric training, characterized by explosive, stretch–shortening muscle actions, has demonstrated substantial preventive benefits across multiple sports, enhancing neuromuscular coordination and reducing injury risk by up to 60% (Hewett et al., 2005). While evidence exists for badminton and basketball players (Alikhani et al., 2019; Benjaminse et al., 2017), comparable data on Pakistani female volleyball players are virtually absent.

This study therefore addresses a key gap in regional sports science: evaluating the effect of a structured plyometric program on biomechanical risk factors for ACL injury in female volleyball club athletes. Grounded in neuromuscular control theory, the study hypothesizes that improved eccentric strength and hip stability will translate into safer knee and hip kinematics during dynamic movement.

Objectives

1. To determine the impact of 12 weeks of plyometric training on lower-limb kinematics (hip adduction, medial rotation, and knee abduction).
2. To examine changes in eccentric hip and knee torque production.
3. To assess functional performance improvements through hop-based tests.

Hypotheses:

- *H1*: Training will significantly reduce knee abduction and hip adduction angles.
- *H2*: Eccentric hip abductor and adductor torques will increase post-training.
- *H3*: Functional hop performance will improve significantly.

Power analysis (80% power, $\alpha = 0.05$) determined that 18 participants were sufficient to detect a 15% change in knee abduction. Twenty athletes were enrolled to account for attrition.

Methods

Study Design and Ethics

A single group pre-test/post-test design was conducted from January to April 2026 at Sindh Sports Board, Karachi. Ethical clearance was obtained from the Health Services Academy's Research Supervisory Committee (HSA/2026/001). All participants provided written informed consent in accordance with the Declaration of Helsinki.

Participants

Twenty female volleyball club players (mean age 23.8 ± 3.2 years; height 170 ± 8 cm; weight 65 ± 7 kg) participated. Inclusion criteria were: active participation in national tournaments, ≥5 years of competitive experience, and no recent musculoskeletal injury. Exclusion criteria included previous ACL reconstruction, pregnancy, or concurrent training programs.

Training Intervention

The intervention comprised 24 sessions over 12 weeks, conducted thrice weekly on alternate days. Each 30-minute session included progressively challenging plyometric drills such as 180° jumps, bounding, squat jumps, and tuck jumps, with repetitions increasing from 10–15 to 20–25. Sessions were supervised by certified coaches, and attendance was recorded to ensure compliance.

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Weeks	Exercise Type	Sets	Reps	Rest (s)
1–4	180° jumps	3	10–15	60
5–8	Bounding, broad jumps	4	15–20	60
9–12	Tuck jumps, wall jumps	4	20–25	45

Outcome Measures

Assessments were conducted at baseline and week 12 by blinded evaluators.

- **Kinematic Analysis:** Maximum excursions of hip adduction, hip medial rotation, and knee abduction during single-leg squats were captured via a 100 Hz Vicon system.
- **Eccentric Torques:** Peak torques of hip abductors/adductors and knee flexors/extensors were measured using a Biodex System 4 dynamometer at 60°/s.
- **Functional Performance:** Triple-hop distance (cm) and six-meter timed hop (s) were used to evaluate lower-limb power and control.

Statistical Analysis

Data normality was verified through the Shapiro–Wilk test. Pre- and post-intervention differences were analyzed using paired *t*-tests, with Cohen's *d* for effect size estimation. Significance was set at $p < 0.05$. All analyses were conducted in SPSS v26.

Results

All 20 participants completed the program with full adherence.

Lower-Limb Kinematics

Knee abduction decreased significantly from 13.5 ± 2.3° to 11.6 ± 2.0° (−14%, $p = 0.01$, $d = 0.87$), and hip adduction from 15.8 ± 2.6° to 12.9 ± 2.2° (−18%, $p < 0.001$, $d = 1.14$). No significant change was observed in hip medial rotation ($p = 0.13$).

Eccentric Torques

Hip abductor torque increased from 95.4 ± 11.2 Nm to 114.5 ± 12.0 Nm (+20%, $p < 0.001$, $d = 1.06$), while hip adductor torque improved from 88.7 ± 10.3 Nm to 101.1 ± 10.8 Nm (+14%, $p = 0.01$, $d = 0.74$).

Functional Performance

Triple-hop distance improved from 520 ± 40 cm to 650 ± 45 cm (+25%, $p < 0.001$), and six-meter hop time decreased from 2.5 ± 0.3 s to 2.1 ± 0.2 s (−16%, $p < 0.001$).

Variable	Baseline (Mean ± SD)	Post (Mean ± SD)	*p*-value	Effect Size (*d*)
Knee Abduction (°)	13.5 ± 2.3	11.6 ± 2.0	0.01	0.87
Hip Adduction (°)	15.8 ± 2.6	12.9 ± 2.2	<0.001	1.14
Hip Abductor Torque (Nm)	95.4 ± 11.2	114.5 ± 12.0	<0.001	1.06
Hip Adductor Torque (Nm)	88.7 ± 10.3	101.1 ± 10.8	0.01	0.74
Triple-Hop (cm)	520 ± 40	650 ± 45	<0.001	1.00
6-m Hop Time (s)	2.5 ± 0.3	2.1 ± 0.2	<0.001	0.94

Discussion

This study demonstrates that a 12-week plyometric training regimen significantly reduces biomechanical risk factors linked to ACL injury in female volleyball athletes. Reductions in knee abduction and hip adduction confirm the hypothesis that improved neuromuscular coordination stabilizes lower-limb alignment

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during landings (Hewett et al., 2005; Enginsu et al., 2014).

Increased hip abductor and adductor torque suggests stronger eccentric control of the pelvis and knee, echoing previous findings that emphasize the role of hip stability in mitigating knee valgus stress (Alikhani et al., 2019; Doeringer et al., 2018). Functional improvements in hop performance indicate better force production and control—attributes essential for volleyball performance and injury prevention (Luqman et al., 2024).

The absence of change in hip medial rotation may reflect exercise specificity, as the selected drills primarily targeted frontal-plane stabilization. Although the sample size was limited, the consistency of findings across multiple measures supports the robustness of the results.

Organizational and environmental factors, such as the quality of coaching and support for female athletes, can also influence intervention effectiveness (Luqman, 2016; Luqman, 2019, 2020). Expanding access to structured preventive programs across training centers could strengthen national injury prevention frameworks.

Conclusion

A supervised 12-week plyometric training program substantially improved neuromuscular control, lower-limb strength, and functional performance, collectively reducing biomechanical risk factors for ACL injury among female volleyball club players in Pakistan.

These results support incorporating plyometric protocols into regular training curricula. Future studies should adopt randomized controlled designs, larger cohorts, and follow-up assessments to evaluate long-term injury incidence.

Acknowledgments

The authors gratefully acknowledge the support of the Health Services Academy, Islamabad. The authors declare no conflicts of interest.

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