Research Article

Investigating the Effects of a Warm-Up Injury Prevention Protocol on Risk Factors for Anterior Cruciate Ligament Injury in Elite Basketball Players

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ABSTRACT

Introduction: Athletes involved in sports requiring frequent cutting and pivoting movements are at increased risk of anterior cruciate ligament (ACL) injuries. This study investigates the effectiveness of neuromuscular warm-up exercises, including strength, balance, plyometric, and core stability training, in reducing ACL injury risk.

Materials and Methods: A total of 30 adolescent male basketball players (age = 13-18 years) were randomly assigned to either the control group (n=15; age = 15.66±1.7 years, height = 172.7±9.6 cm, weight = 66.74±11.2 kg) or the neuromuscular training (NMT) group (n=15; age = 14.73±0.70 years, height = 174.0±6.7 cm, weight = 64.79±10.8 kg). The NMT group performed a structured injury prevention warm-up program three times a week for eight weeks before regular basketball training (20 min), while the control group followed their usual basketball practice. Measurements of knee proprioception (including specific motion directions), knee valgus and flexion torque, trunk endurance via the Biering-Sorenson test, and isometric strength of various muscle groups were taken pre- and post-intervention.

Results: Significant improvements in isometric strength were observed in all assessed muscle groups in the NMT group ($P<0.05$); however, no significant changes were found in knee valgus, flexion torque, trunk endurance, or knee proprioception ($P>0.05$).

Conclusion: While the NMT protocol significantly improves isometric muscle strength in adolescent male basketball players, it does not show a direct effect on other ACL injury risk factors. Therefore, incorporating NMT into training routines may support strength development but should be combined with other targeted interventions to reduce ACL injury risk more effectively.

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Introduction

Anterior cruciate ligament (ACL) injuries are increasingly becoming common among athletes of all levels, with significant performance and financial implications, particularly for elite basketball players [1, 2]. In high-demand sports, such as basketball, the risk of ACL injuries is elevated due to intense actions, such as jumps, changes in direction, accelerations, and deceleration [3]. Despite decreasing physical demands from the first to the last quarter of a game, fatigue reduces joint stability, affecting single-leg postural control, position sense, and reaction time, which increases the risk of injury during changes in direction and landing from jumps [4].

ACL injury rates are higher during competition than practice, with senior athletes showing an injury rate ratio (IRR) of 2.02 (95% confidence interval [CI], 1.90–2.14) and young athletes showing an IRR of 2.38 (95% CI, 2.22–2.56). The most common injuries are in the lower limbs, especially ankle sprains and ACL tears [5]. These injuries result from a combination of extrinsic factors, such as training techniques, and intrinsic factors, such as ligament laxity, bone morphology, muscle weakness, and poor neuromuscular control [6]. Muscle weakness and compensatory movement patterns contribute to abnormal knee loading, increasing the risk of ACL injury [7]. Stiff landings (i.e. landing with a low knee flexion angle) can lead to increased knee loading, further raising the risk of ACL injuries [8].

Biomechanical factors, including trunk, hip, and knee kinematics, are critical in developing noncontact ACL injuries. The trunk accounts for about 50% of the body's mass, and even small deviations in its position can significantly affect hip and knee muscle demand and the forces placed on the knee joint [6]. Core stability plays an important role in preventing injuries, especially ACL injuries [9-13]. Strengthening core muscles has been linked to a reduced risk of lower extremity injuries, and some studies suggest that core stability may specifically reduce ACL injury risk [14, 15]. The hip is particularly important, as abnormal hip motion is often a contributing factor to improper knee mechanics and increased ACL injury risk [6].

Given the negative consequences of ACL injuries, primary prevention is essential to reduce first-time injury rates and minimize both short- and long-term consequences [6]. Understanding injury biomechanics in game situations is crucial for developing effective injury prevention programs [16]. Neuromuscular training (NMT) programs, which include both general and sport-specific exercises for strength, stability, balance, core strength, plyometrics, and agility, have been shown to reduce lower extremity injuries [17]. However, the effectiveness of preventive programs can be limited by athletes' poor long-term adherence [18]. For this reason, integrating NMT into warm-up routines may help overcome this challenge and become a key strategy for injury prevention. Accordingly, this study evaluates the effectiveness of a multicomponent NMT warm-up program in reducing ACL injury risk factors among elite youth basketball players. The risk factors evaluated in this study are selected based on their effects in previous studies, researchers' recommendations in this field, and their importance in ACL injuries.

Materials and Methods

Study participants

The participants were recruited from a basketball team in the Iran Basketball Professional League (age between 13-18 years). Before enrollment, the participants were fully informed about the study objectives and procedures and provided written informed consent before initial measurements. This study was registered in the Iranian Registry of Clinical Trials (IRCT) with approval number (No.: IRCT20240907062968N1), adhering to national and international regulations, including the Declaration of Helsinki II.

The inclusion criteria were as follows: 1) Having at least three years of basketball playing experience, and 2) Practicing three times a week for 1.5 h. Meanwhile, the exclusion criterion was a having history of lower extremity injury or surgery within six months before testing. The participants were excluded from the analysis if they failed to attend at least 90% of training sessions. Eligibility was determined by a sports physician and a certified strength and conditioning specialist. None of the participants had prior exposure to prevention or specific dynamic balance training, ensuring the validity of the testing protocol.

Out of 34 screened players, 30 male athletes were eligible and randomly assigned to either the experimental group (n=15, age=14.73±0.70 years, height=174±6.7 cm, body mass=64.79±10.8 kg/m²) or the control group (n=15, age=15.66±1.7 years, height=172.7±9.6 cm, body mass=66.74±11.2 kg). Randomization was conducted using a computer-generated randomization list with concealed allocation. Assessors were blinded to group assignments by ensuring they had no access to the randomization list and were not involved in the intervention sessions or group allocation procedures. The experimental group performed neuromuscular warm-up training, while the control group engaged in standard tactical-technical basketball practice. Both groups attended all training and testing sessions but were blinded to the study's warm-up purpose.

The baseline data collected included medical history, age, height, body mass, training characteristics, injury history, team basketball experience, and performance level. Height was measured using the Vogel & Halke Seca device (Germany, accuracy = 1 mm), and body mass was assessed with a Kistler dynamometer board (Switzerland, sampling frequency = 1000 Hz). No significant differences in demographic characteristics were observed between the groups (Table 1).

Table 1. Warm-up protocol

Exercise	Distance Traveled (m)	Time (s)	Repetition	Rest (S)*
Run slowly	28-56	15-25	1	10
Running with a high knee	28-56	15-25	1	10
Running backward with a zig-zag movement	28-56	15-25	1	10
Dribbling with the ball and moving sideways	28-56	25-35	1	10
Jump-single leg hold with the ball	28-56	15-25	1	10
Crossover-hop-hop-hold	28-56	15-25	1	10
Ley up with the ball	28-56	20-25	4-6	10
Vertical jump, catch the ball, and land in a stable position	28	20-25	4-6	10
Change of direction and jump with the ball	28	20-25	4-6	10
Jump from the box and land on the compressed sponge	-	50-70	1	10
Landing with one leg on a sponge and catching the ball	-	50-70	1	10
Vertical jump, catch the ball, jump 360 degrees (both sides)	-	50-70	1	10
BOSU (round) double knee-hold	-	40-60	1	10
BOSU (round) single knee-hold	-	40-60	1	10
BOSU (round) double knee-hold and catch the ball	-	50-70	1	10
Single leg 4-way BOSU (round) hop-hold with Ball catch	-	50-70	1	10
Prone bridge (elbows and knees) hip extension opposed shoulder flexion	-	50-70	10	30
Prone bridge (elbows and toes) hip extension	-	50-70	10	30
Prone bridge (elbows and toes) hip extension opposite shoulder flexion	-	50-70	10	30
Russian hamstring curl	-	50-70	8-10	10
Squat pops	-	15-25	-	30
Knee tucks	-	15-25	-	30
Lung pops	-	15-25	-	30

Notes: S* indicates second.

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Study design and intervention

This quasi-experimental study employed a pre-post-test design and was conducted as a field trial. The experimental group participated in a 20-min warm-up, three times a week for eight weeks, in addition to their regular 90-min basketball practice sessions [19]. The control group followed their usual basketball exercises, which were the same as those performed by the experimental group. A certified strength and conditioning specialist led the training sessions, providing both verbal and visual feedback. Exercise volume increased as exercises were correctly performed, with progression achieved by transitioning from stable to unstable positions to challenge lower extremity strength and core stability. No acute injuries occurred during the training sessions.

Testing procedures

The isometric strength of selective muscles

Isometric strength was assessed using a standardized testing protocol, confirmed to be reliable, with muscles selected based on their role in preventing ACL injuries [19]. Peak isometric force was measured for trunk flexors, trunk extensors, hip extensors, knee flexors, knee extensors, plantar flexors, dorsiflexors, and hip abductors using a hand-held dynamometer (MMT, North Coast, made in America; Figure 1). A strap controlled the force applied by the tester, and all test positions were gravity-resisted, based on established protocols in the literature [20]. The test was performed in three 5-s attempts, with 30-s rests in between, and the average of the three repetitions was recorded.

For the hip extensor test, the participant was prone with the test leg at 90° knee flexion. The dynamometer was placed over the posterior aspect of the shank, just proximal to the ankle joint. The subject was instructed to flex the dominant knee maximally [20]. In the trunk flexor test, the participant was supine with knees flexed at 90°. The legs were secured to the table, and the dynamometer was positioned on the sternum, aligned with the chest. The subject exerted force by lifting the trunk and the force generated was recorded. For trunk extensor strength, the participant was prone with legs firmly secured, and the dynamometer head was placed at the inferior angle of the scapula, aligned between the shoulder blades [21].

For hip abductor strength, the participant lay side-lying with a pillow between the legs. The tested leg (upper leg) was positioned at 0° hip abduction, and the dynamometer was placed 5 cm proximal to the lateral femoral condyle, with additional straps to minimize pelvic movement. To measure ankle plantarflexion and dorsiflexion strength, the participant was seated with legs fully extended and hands on the chest. The dynamometer strap was positioned over the metatarsal heads to ensure consistent force application [22] (Figure 2).

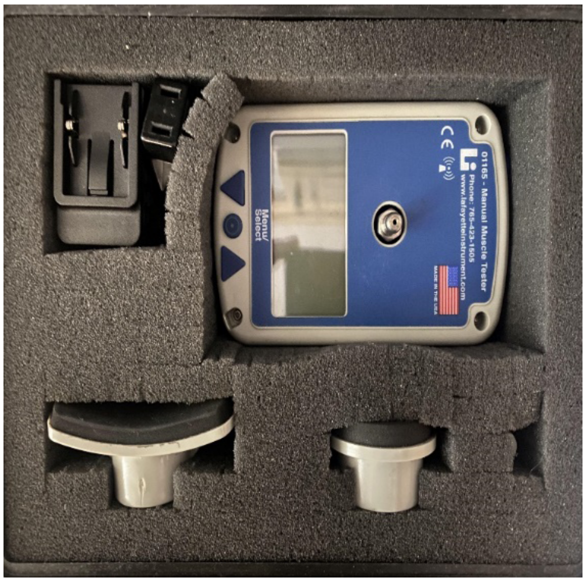

Figure 1. MMT, North Coast, made in America

Figure 2. Isometric strength of participants as measured during the study

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Proprioception

To assess joint position sense, the dominant leg was chosen as the reference for testing. Since the active test is more functional and efficient than the passive test, it was used in this study. The participants were familiarized with the procedure beforehand, and all markers remained fixed during the assessment. Three 1.5 cm circular markers were placed sequentially on the upper third of the greater trochanter, the superior part of the lateral malleolus, and the iliotibial band (with the knee at a 90-degree angle). In a closed kinetic chain position, the participant stood on the dominant leg with hands resting on a surface (e.g. a chair) for balance. A 5-cm wedge-shaped pad was placed under the heel to eliminate the passive effect of the gastrocnemius muscle. The non-dominant leg was relaxed with the knee flexed and supported beside the participant. With eyes closed, the participant shifted weight onto the testing leg. Starting with the knee at 0 degrees, they flexed it to 40–60 degrees and held this position for 5 s before returning to the starting position. Next, they replicated the movement, maintaining the angle for 3 s before returning to 0 degrees. This sequence was repeated three times.

Each time the leg stabilized at the target position. A photo was taken using a tripod-mounted camera with proper lighting. Images were transferred to a computer, and AutoCAD software was used to measure joint angles. Straight lines were drawn connecting the centers of the markers, and the numerical value of the angle was calculated using the software [23, 24].

Knee-valgus and flexion torque

Reflective markers were placed on the greater trochanter and lateral malleolus of both legs, with Velcro circles on each patella's center. A research assistant demonstrated the jump-land sequence, and athletes completed one trial to ensure understanding. No verbal instructions on landing or jumping techniques were provided, except to land straight in front of the box for proper camera alignment. The sequence involved jumping off a box, landing, and immediately performing a maximum vertical jump, repeated three times. A research assistant reviewed all three trials and selected the one best representing the athlete's jumping ability for analysis. Frame-by-frame video analysis captured two key images.

Pre-Land: The moment the athlete's toes just touched the ground, representing the most extended knee position while controlling stance width.

Land: The deepest point of knee flexion, representing the most out-of-control position during landing. Kinovea software was used for the final analysis, focusing on the superior leg. The pre-land and land images were analyzed to assess knee-valgus and flexion torque [25-27].

Trunk endurance

For the trunk extension test, also known as the Biering Sorensen test, the participant was instructed to lie prone off the edge of a plinth with all body parts above their anterior superior iliac spines hanging off the table. Three straps were then performed to hold the lower extremities onto the table as follows: One at the gluteal fold, one just above the knee joints, and one just above the ankles. Afterward, the participants were allowed to rest their upper extremities on a chair before starting. They were then instructed to cross their arms in front of their chest and to lift their upper body until their trunk was horizontal with the ground. Time started when the participant achieved the starting position. Accordingly, this position was held until fatigue or their body deviated from horizontal, and the test was then ended. The Biering Sorensen test has been found to have good reliability with intraclass correlation coefficient scores greater than or equal to 0.77 [28, 29].

Results

The results of the independent t-test showed no significant difference in demographic characteristics between the two groups (P=0.067; Table 2). Due to the normality of the data distribution, parametric tests were used for data analysis. The results of the independent t-test showed that the isometric strength of trunk flexors, trunk extensors, plantar flexors, Dorsi flexors, hip abductors, hip extensors, knee flexors, knee extensors was significantly increased (P<0.05). However, no statistically significant differences were observed in the knee-valgus (P=0.551) and flexion moment (P=0.812), trunk endurance (P=0.812), and knee proprioception (P=0.925) tests (Table 3).

Discussion

This study evaluated the effect of a warm-up injury prevention training program on risk factors associated with ACL injuries in adolescent professional basketball players. The results showed that NMT warm-ups significantly improved isometric strength in various muscle groups, including trunk flexors, trunk extensors, plantar flexors, dorsiflexors, hip abductors, hip extensors, knee flexors, and knee extensors. Core stability training as part of the warm-up enhanced core strength, as confirmed by the tests. Additionally, core stability exercises improved trunk muscle strength and recruitment, addressing muscle imbalances commonly associated with trunk dysfunction [30]. Enhancing core muscle efficiency to stabilize the trunk in different planes may reduce the risk of non-contact ACL injuries in athletes [31]. Furthermore, landing biomechanics and postural control are closely linked to core muscle strength. Previous studies demonstrated improvements in neuromuscular control following core exercises, leading to better landing biomechanics [30].

Neuromuscular control dysfunction in the core during sports activities can cause uncontrolled trunk displacement, a known risk factor for ACL injuries [30, 32]. Research indicates that reduced core muscle strength increases body fluctuations, disrupts balance, and applies excessive force to the ACL [33]. Recent emphasis has been placed on improving trunk strength and endurance, as the core is the origin of body movements and a vital component of the kinetic chain. In sports and functional tasks, the core plays a pivotal role in transmitting forces from the ground to the upper limbs. Inefficiency in the core can impair performance and increase the likelihood of ACL injuries [34, 35]. Core stability offers numerous benefits, from enhancing musculoskeletal health to preventing injuries.

The present results indicate that incorporating core stability training into the prevention training protocol (PTP) for basketball players enhances core strength, as demonstrated by significant improvements in trunk flexion strength, trunk extension strength, and hip abduction strength. However, no significant improvement was observed in trunk extensor muscle endurance, likely due to the absence of endurance training for trunk muscles in our protocol. Reduced muscle endurance can lead to abnormal movement or displacement in various body

Table 2. Demographic characteristics of participants

Variables	Minimum	Maximum	Mean±Standard Deviation
Age (year)	13	18	15.2±1.3
Height (cm)	154	188	173.3±8.2
Weight (kg)	46.2	86.8	65.7±10.9

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Table 3. Description of research variables

Variable	Measurement Time	Groups	Mean±Standard Deviation
Trunk extension isometric strength (kg)	Pre-test	Control	10.48±1.75
		Experiment	9.44±1.70
	Post-test	Control	9.70±1.20
		Experiment	10.68±1.90
Trunk flexion isometric strength (kg)	Pre-test	Control	9.92±1.50
		Experiment	10.84±2.50
	Post-test	Control	10.2±2.06
		Experiment	13.3±1.70
Hip abduction isometric strength (kg)	Pre-test	Control	12.27±1.91
		Experiment	9.88±2.16
	Post-test	Control	11.06±2.50
		Experiment	12.25±3.22
Hip extension isometric strength (kg)	Pre-test	Control	11.61±2.86
		Experiment	10.30±2.92
	Post-test	Control	11.20±2.21
		Experiment	12.66±2.13
Knee extension isometric strength(kg)	Pre-test	Control	27.55±2.10
		Experiment	16.69±2.41
	Post-test	Control	16.28±2.90
		Experiment	18.71±1.76
Knee flexion isometric strength (kg)	Pre-test	Control	12.60±2.74
		Experiment	11.06±2.44
	Post-test	Control	11.44±2.20
		Experiment	13.17±2.27
Plantar flexion isometric strength (kg)	Pre-test	Control	11.86±2.29
		Experiment	11.32±2.32
	Post-test	Control	10±1.37
		Experiment	12.3±2.10
Dorsi flexion isometric strength (kg)	Pre-test	Control	8.43±1.62
		Experiment	7.36±1.15
	Post-test	Control	8.46±1.77
		Experiment	9.24±1.67
Knee proprioception	Pre-test	Control	4.55±3.3
		Experiment	5.33±4.4
	Post-test	Control	3.44±1.4
		Experiment	5.48±3.3
Sorensen Biering test (s)	Pre-test	Control	94.88±31.04
		Experiment	98.3±28.7
	Post-test	Control	90.02 ±22.2
		Experiment	94.96±28.7
Initial knee flexion angle (degree)	Pre-test	Control	145.8±6.3
		Experiment	145.2±5.06
	Post-test	Control	148.2±5.9
		Experiment	144.6±7.05
Maximum knee flexion angle (degree)	Pre-test	Control	98.98±9.1
		Experiment	94.17±8.02
	Post-test	Control	98.88±10.4
		Experiment	93.58±7.69
Maximum valgus angle (degree)	Pre-test	Control	11.66±182.1
		Experiment	35.4±178.7
	Post-test	Control	-57.5±171.05
		Experiment	10.9±182.5

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parts. Previous studies have highlighted the critical role of trunk muscle endurance in protecting the spinal column. Endurance is more important than maximum strength for core muscles, as 55% to 58% of abdominal muscle fibers are type I fibers [31]. Since spinal muscles are postural and maintain stability during standing and forward/backward bending, they must be fatigue-resistant. The endurance capacity of these muscles directly reflects their fatigue resistance [31].

The relationships among these factors have seldom been evaluated. Muscular strength, defined as the ability of muscles to exert force, is fundamental to performing many tasks in sports [36]. Since the knee extensor muscles eccentrically contract to control knee flexion during landing, studies suggest that a reduced initial contact knee-flexion angle and knee-flexion excursion may be associated with weak knee-extensor strength, both of which are predictors of ACL injuries [32]. Additionally, weak knee-flexor strength has also been identified as a potential risk factor for non-contact ACL injuries [37, 38].

Increasing hip abductor strength may enhance neuromuscular control of the knee during jump landings [39]. Therefore, hip abductor strength should be prioritized in exercise protocols due to its strong association with valgus displacement and ACL injuries [40]. Knee valgus results from combined movements of the hip and tibia and is influenced by proximal and distal joints, including the trunk, hip, and ankle [41]. Poor hip control can cause excessive internal rotation and adduction, increasing stress on the ACL. However, the relationship between hip muscles and knee movement in the frontal plane remains unclear [42]. For example, some researchers have found no correlation between knee movement in the frontal plane and hip muscle strength when examining two-dimensional knee valgus [39].

The findings revealed no significant effect of NMT on reducing knee valgus and flexion torque. This aligns with a previous study reporting increased angular displacement of knee flexion during bilateral vertical jumps with double-leg landings in young male volleyball athletes after a 6-week program of plyometric, balance, and core stability exercises [41]. Similarly, evidence indicates that combining core stability with balance training does not impact knee-flexion torque during landing [41]. Smaller hip and knee-flexion angles are a potential concern for knee injuries, as reduced knee flexion has been linked to higher anterior tibial shear forces and ground reaction forces, increasing the risk of ACL injuries. However, opposing evidence exists. Some studies have found that knee-flexion angle during jump landings does not significantly predict ACL injuries, with frontal plane knee abduction angles and moments identified as stronger predictors instead [41].

A recent study on ACL injury mechanisms in NBA players identified three categories of injuries based on movement sequences and lower limb kinematics at ground contact: 1) Single-leg casting, 2) Bilateral prohop, and 3) Single-leg landing after contact [32]. In all three mechanisms, the injured limb contacted the ground during a deceleration event outside the base of support. ACL rupture in these scenarios is likely explained by the combination of a large ground reaction force applied to an extended knee and trunk lateral flexion [32]. Key factors contributing to ACL injuries include hip abduction and trunk tilt toward the injured leg at initial contact, as well as increased knee valgus and flexion after initial contact. These patterns are often seen in situations such as attacking the basket and landing after a jump [16].

Finally, training programs that integrate various components, known as NMT, including strength, core stabilization, balance, and agility, have proven effective in preventing both general and ACL injuries [5, 17, 43]. Future research is recommended to replicate this study with larger sample sizes and to validate these findings across male and female basketball players of different ages and skill levels.

Conclusion

The implemented interventions effectively target key factors contributing to ACL injuries in basketball athletes, particularly through the strengthening of the hip and core muscles, which are effective in preventing such injuries. By incorporating proximal interventions into regular warm-ups and strength training routines, athletes could reduce their risk of injury and enhance their performance on the court. Future studies could build on these findings by exploring the long-term effects of these interventions, as well as their applicability across different levels of competition and age groups. Further research may also examine the optimal frequency, intensity, and duration of training programs to maximize ACL injury prevention.

Study limitations

This study faced some limitations. First, participants in both groups continued their usual 90-min basketball practice, which raises questions about whether the results would differ for athletes in other sports or for female athletes. Additionally, the 8-week training duration may not have been sufficient, as it did not produce significant effects on knee valgus, proprioception, or trunk endurance.

Ethical Considerations

Compliance with ethical guidelines

This study was registered in the Iranian Registry of Clinical Trials (IRCT) with approval number (No.: IRCT20240907062968N1), adhering to national and international regulations, including the Declaration of Helsinki II. All the participants provided written informed consent.

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Authors' contributions

Conceptualization: Vahid Mazloum; Data curation: Ali Honarvar, Mohammad Ali Soleymanfallah; Formal analysis: Vahid Mazloum, Ali Honarvar; Methodology: Vahid Mazloum, Ali Honarvar; Project administration: Vahid Mazloum; Supervision: Mohammad Ali Soleymanfallah; Writing – Original draft: Ali Honarvar.

Conflict of interest

The authors declared no conflict of interest.

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