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REVIEW

THE ROLE OF EXERCISE INTERVENTIONS IN PREVENTING KNEE INJURIES AMONG FEMALE BASKETBALL PLAYERS: A SYSTEMATIC REVIEW

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LEVEL OF EVIDENCE: 1a

ABSTRACT

Background: Knee injuries, such as ligament injuries including the anterior cruciate ligament (ACL), are among the most common non-contact injuries in team sports. This systematic review aimed to evaluate the effectiveness of exercise interventions in preventing knee injuries among female basketball players.

Methods: This study was conducted as a systematic review following the PRISMA guidelines and registered in PROSPERO (ID: CRD42024517592). A comprehensive search was performed in Google Scholar, PubMed, Science Direct, PEDro, EMBASE, Web of Science, and Scopus using the following keywords: "Injury prevention program" OR "exercise training" OR "prevention training" OR "warm up program" OR "dynamic knee valgus" OR "knee injuries" OR "anterior cruciate ligament" OR "basketball player" OR "females" covering publications from 2000 to January 2025. All included studies were published in English.

Results: Out of 1,749 records, 16 studies met the inclusion criteria. The exercise programs included plyometric, neuromuscular, balance, and multimodal interventions. Some studies reported statistically significant improvements in some outcomes associated with knee injury prevention, such as reduced dynamic knee valgus, increased knee flexion during landing, enhanced muscle activation, improved balance, and better jump performance.

Conclusion: Overall, the evidence suggests that neuromuscular and multifaceted training programs, which include a combination of strength, balance, flexibility, plyometric, and agility exercises, may be effective in improving certain biomechanical factors associated with knee injury prevention in female basketball players. Incorporating technical feedback and supervised practice appears to enhance the effectiveness of these programs.

Study registration: registered in PROSPERO with ID CRD42024517592.

KEYWORDS

Exercise interventions, Anterior cruciate ligament, Knee joint, Prevention injury, basketball

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INTRODUCTION

Basketball is one of the most popular sports worldwide, and the number of sports injuries in this sport has increased with the growing number of participants, especially among young athletes. High levels of exercise are associated with an increased risk of injury, with an overall injury rate of 14.4 per 1000 hours of training in young athletes[1-3]. Currently, basketball is one of the most vulnerable ball games[4]. Although trunk, head, and upper extremity injuries are common in basketball, evidence suggests that most injuries (58-66%) occur in the lower extremities. Overuse injuries (e.g., tendinopathy, stress fractures) and traumatic injuries (e.g., ligament sprains) are also observable in the basketball population[5, 6].

Approximately 10–25% of all sports injuries involve the knee, with ligaments accounting for nearly 45% of these injuries, and the anterior cruciate ligament (ACL) being the most commonly affected ligament[7]. Most studies have called the lower limb the most vulnerable area in basketball, where the ankle and knee have the highest incidence of injuries, regardless of sex and age group[8-10]. ACL injury ranks first in basketball regarding injury severity[11]. ACL injury is the most common knee ligament injury and often results from a noncontact mechanism, over 70% of which occur during landing[12]. Research has shown that the risk of knee joint injuries in female athletes of sports such as basketball, volleyball, handball, and soccer, which involve jumping, pivoting, and changing directions quickly and frequently, is 4 to 6 times greater than that in male athletes of the same sport[13-15]. The number of noncontact ACL tears is significantly greater in women's basketball than in men's basketball[16-18].

Therefore, injury prevention should be a primary goal because of the unfortunate consequences of sports injuries. Extensive efforts are being made to prevent sports injuries, including protective measures such as rules of the game, protective equipment (such as crash helmets, pads, and braces), training programs, and warm-ups[19]. The epidemiology of basketball injuries is an essential first step in developing targeted and evidence-based interventions to provide recommendations for injury prevention, as studies have shown that noncontact tears of the ACL ligament, which occur following a spin or landing from a jump shot in basketball, are the most common injury mechanisms[16,17]. Therefore, an athlete's ability to achieve the correct dynamic alignment of the lower limb segments in the movement planes can be a critical factor in the occurrence of knee injuries in sports[20]. The results of various studies have shown that applying exercise programs to correct abnormal alignment in joints can reduce damage to the ACL[21,22]. The design of injury prevention programs for athletes should emphasize variables such as improving balance, the biomechanics of the lower limbs, muscle activity, performance, strength, and power; reducing the force on the ground (reaction force)[23]; shear and plyometric movements; and the principle of specificity of the sports discipline[22]. A plyometric training program, if well designed and implemented, will have a positive effect on a basketball player's speed, agility, jumping ability, and ultimately can help prevent noncontact knee injuries[24].

Thus, the importance of preventing sports injuries, especially knee ligament injuries, in athletes, particularly female basketball players, is high. Therefore, various special programs are used to prevent particular injuries in each sport. Given the high prevalence of knee injuries in this population, this systematic review aimed to investigate the role of exercise interventions in preventing knee injuries in female basketball players.

MATERIALS AND METHODS

Search strategy

This study was conducted as a systematic review through the PRISMA method[25] and registered in PROSPERO (ID: CRD42024517592). A comprehensive search was performed in Google Scholar, PubMed, Science Direct, PEDro, EMBASE, Web of Science, and Scopus to investigate the role of exercise interventions in preventing knee injuries among female basketball players.

Search terms were organized into three groups:

Group 1: "Injury prevention program" OR "prevent noncontact injury" OR "exercise training" OR "prevention training" OR "neuromuscular" OR "plyometrics" OR "proprioceptive" OR "training" OR "prevention" OR "prevention and control" OR "warm up program" OR "prevention strategies"; Group 2: "knee valgus" OR "dynamic knee valgus" OR "ACL injury mechanism" OR "landing" OR "kinematics" OR "knee injury risk" OR "knee injuries" OR "knee joint" OR "anterior cruciate ligament" OR "sport injuries" OR "lower extremity" OR "lower limb injuries"; Group 3: "basketball player" OR "basketball athletes" OR "basketball" OR "females" OR "women" OR "girls".

Terms within each group were combined using OR, and the three groups were combined using AND. Searches were limited to studies published in English between 2000 and January 2025, and no additional restrictions were applied. A manual search and reference checking were also conducted to identify additional relevant studies not retrieved through the electronic databases.

Following the search process, the studies were exported to the EndNote Reference Library (Version 20; Clarivate Analytics, Thomson Reuters Corporation, Philadelphia, Pennsylvania) software, and any duplicate entries were removed. Subsequently, two authors (H.Z. and M.R.) independently screened all titles and abstracts. They also independently assessed the quality of included studies. Any disagreements were resolved through discussion and consensus. A senior researcher reviewed the final list of included studies to ensure alignment with the study's aim.

First, the title and then the abstract of the articles were studied after the search results were collected. If the articles were consistent with the inclusion and exclusion

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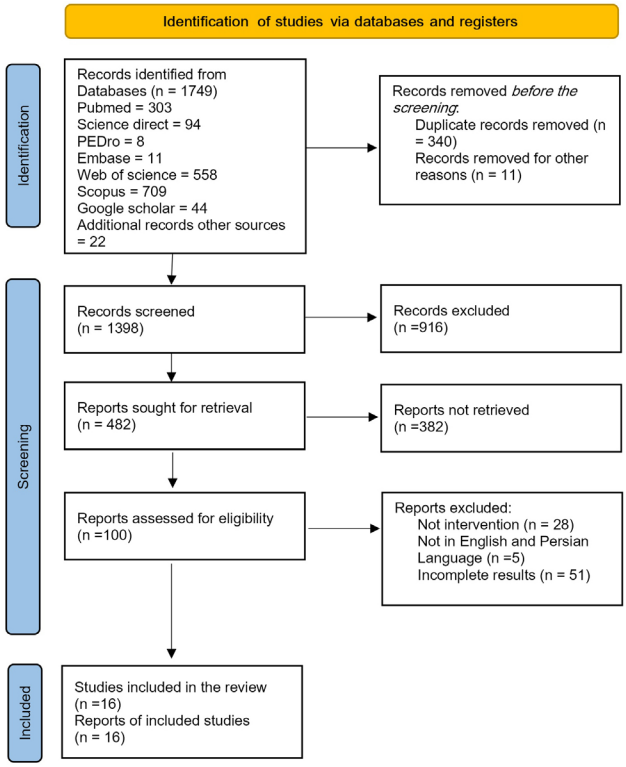


Figure 1. *PRISMA flow diagram for eligible studies.*

criteria, their results were used in the present review study; otherwise, they were discarded. The criteria for including studies were checked through the PICOS flowchart. The PICOS framework was used to guide the study selection process *(Table 1)*.

Selection of studies

In the first stage, the titles and abstracts of studies focused on the effect of exercise interventions on preventing knee injuries in female basketball players were screened. In the second stage, the complete text was screened according to the specificity of the target population.

The inclusion criteria were as follows: studies that investigated the effect of exercise interventions on the prevention of knee injuries; studies on female basketball players, with participants' ages ranging from 12 to 25 years (this age range was not pre-specified but reflects the ages reported in the included studies), regardless of sports level; English studies; original research articles that were experimental, semiexperimental, and randomized clinical trials indexed from 2000 to January 2025; and articles that were published in full text.

The exclusion criteria were as follows: studies that investigated the effect of exercise interventions on preventing injuries to joints other than the knee joint (such as the ankle, hip, and lower limbs), studies that focused on mixed sports players (volleyball, soccer, etc.), studies on males, studies whose participants were mixed (male and female), articles that were not published in English, articles that were published as summaries in congresses and seminars, articles that were published as descriptions, reviews, meta-analyses, case studies, pilots, etc., articles with small or ambiguous populations, characteristics and sample sizes, and articles whose methods and practices were not well defined.

The following data were extracted from each included study: author and year, sample characteristics (number and age of participants), details of the intervention program (type, duration, and frequency), analyzed factors or outcome measures (e.g., biomechanical, neuromuscular, and performance-related measures, and actual injury incidence), and the main results.

Quality of the reviewed research

The research evaluated the method quality of the relevant studies through the Pedro scale[26]. The current scale encompasses 11 modules. They met the following criteria: 1. Determination of participant eligibility criteria, 2. Participants' random allotment, 3. Allotment of concealment, 4. Similarity among groups in relevant variables in the pretest stage, 5. Deprive of understanding of the participant, 6. To maintain understanding of the researcher who implemented the exercise program, 7. The evaluators were instructed to measure the dependent variable 8. The ratio of participants who had no less than one key outcome in the measured dependent variable was 9. Complaisance of participants with the intervention, 10. There were significant differences among the groups, and

Structure components	Description
Population	Female basketball players (ages in included studies ranged from 12 to 25 years; this range was not pre-specified)
Intervention	Various exercise interventions aimed at preventing knee injuries in female basketball players, including plyometric, core, hip-focused, balance, agility, and multimodal neuromuscular programs.
Comparison	Comparisons between intervention and control/usual training groups as reported in the included studies; this review summarizes and reports the findings without performing direct comparisons.
Outcome	Biomechanical, neuromuscular, and performance-related measures associated with knee injury risk (e.g., knee valgus, H/Q ratio, jump-landing mechanics, dynamic balance), and actual injury incidence reported in some studies (e.g., ACL injury, total injuries).
Study Type	Original research studies (including randomized and semi-experimental clinical trial studies) were included in the present study. Descriptive, review, meta-analysis, pilot, and case studies were excluded from the present study.

Table 1. *PICOS framework.*

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Study	Design	Population	Program	Outcomes	Results
Wilkerson, et al. (2004)[28]	Quasi-experimental (non-randomized controlled trial)	19 healthy female collegiate basketball players EG: 11 (19±1.4 years), CG: 8 (19±1.1 years)	6-week preseason conditioning program. (Plyometric jump training, stretching, and isotonic strengthening). 3/7	HPT & QPT (60°.s^{-1} & 300.s^{-1}). FSD impact index. Lunging maneuvers (force plate). T-pattern agility drill. H/Q.	A significant group x trial interaction was found for HPT at 60°.s^{-1}. NS → None of the other variables. Significant group x trial interaction was apparent for the H/Q ratio at 60°.s^{-1} but not at 300.s^{-1}.
Kato, et al. (2008)[29]	Randomized Controlled Trial (RCT)	20 healthy female college basketball players EG:10 (20.4±1.0 years) CG: 10 (20.5±0.9 years)	4-week short-term intervention exercise program. (Squats, Lunges, Jump landing, Lung walking, Twist) and balance training. 3/7 20 min Before or after the usual practice sessions of the club.	angle of coronal plane alignment (CPA) knee flexion angle (KFA) torsion angle (TA) (during the stop action at pre, 2 W, 4 W)	EG VS CG: Following 2 W: ↓ CPA, ↓TA, NS→KFA Following 4 W: ↓ CPA, ↓TA, NS→KFA NS → between other data of the 2w and 4w in EG.
Lim, et al. (2009)[30]	Randomized Controlled Trial (RCT)	22 high school female basketball players EG: 11 (16.2±1.2 years) CG: 11 (16.1±1.0 years)	8-week (SIPTP). 6 parts (warm-up, stretching, strengthening, plyometrics, agility and alternative exercise–warm down). 20 min warm-up before team practice.	Biomechanical properties associated with ACL injury during rebound-jump task: (jump height, knee flexion, interknee distances, knee internal rotation angle, maximum knee extension torques, Maximum knee valgus moment). Muscle strength and flexibility. H/Q.	↑ knee flexion angle ↑ knee distance ↑ maximum knee abduction torque ↓ H/Q ↓ maximum knee extension torque NS → jump height, and maximum knee internal rotation angle.
Wilderman, et al. (2009)[31]	Randomized Controlled Trial (RCT)	30 female intramural basketball players EG: 15 (21.07±3.62 years) CG: 15 (21.07±1.83 years)	6-week agility training program (designed as a 4-phase program) 4/7 15 min	quadriceps and hamstrings muscle activation (EMG) knee flexion angles peak vertical ground reaction force (during a side-step pivot maneuver)	↑ MH activation ↓ VMO activation NS → KFA & peak vertical ground reaction force
Herrington (2010)[32]	Pretest–posttest intervention (single group)	15 female basketball players aged 18–22 years (19.1±1). EG: 15	4 weeks of the jump-training program. 3/7 15 min	KVA during DJT landing task and jump shot. Crossover hop test.	The mean reduction of drop jump knee valgus: (Left:9.8° Right:12.3°) The mean reduction of jump shot knee valgus: (left:4.5° right:4.3°) Crossover hop distance showed an average percentage improvement on distance jumped of 73.6%. (left leg:111 cm, right leg 110 cm).
Nagano, et al. (2011)[33]	Pretest–posttest intervention (single group)	8 female basketball athletes aged 19.4±0.7 years. EG: 8	5-week jump and balance training program. 3/7 20 min	knee flexion angle, Tibial rotation, and the knee varus/valgus angle during single limb drop landing. EMG of the rectus femoris and Hamstrings (H/Q) at Pretraining 1, Pretraining 2, and Posttraining.	↑ Knee flexion angle (position of the knee at foot contact). ↑ Knee flexion angle (during landing). NS → Tibial rotation and knee varus/valgus angles after training. ↑ Activity of the hamstrings 50 ms before foot contact ($p < 0.05$).
Noyes, et al. (2012)[34]	Pretest–posttest intervention (single group)	57 female high school basketball players aged 14–17 years. EG: 57	6-week sports-specific training program. (dynamic warm-up, jump training, flexibility exercises, strength, agility, acceleration, speed, and endurance drills) 3/7 90–120 min	drop-jump test multistage fitness test vertical jump test 18-m sprint test	↑ Vo2max score ↑ knee separation distance (DJT). Sig → improvement in the vertical jump test. NS → sprint test.

Study	Design	Population	Program	Outcomes	Results
Fontenay, et al. (2013)[35]	Prospective, non-randomized interventional study	24 young female basketball players (mean age: 15.5 years ± 0.66). EG1: Specific Physical Training Group (SPTG n=9) EG2: specific Physical and Mental Training Group (PMTG n=7) CG: Control Group (n=8)	(SPTG: 8-weeks physical training program. (balance, plyometric, strengthening, and core training) 2/7 20 min. PMTG: (basketball+ physical training +mental training) CG: only practice basketball	Dynamic valgus during DJT. Peak Vertical Impact Force (PVIF). Rate of Force Development (RFD). Jumping performance (flight time)	↓ dynamic valgus NS → PVIF and RFD. Jumping performance improved by 12% in SPTG (↑ flight time in SPTG) and remained constant in PMTG and CG.
Otsuki, et al. (2014)[36]	Prospective non-randomized controlled trial	60 female junior high school basketball players (13.1±0.8 years). EG: 32 CG: 28	6-month injury prevention program. As a warm-up routine. 3/7 20 min.	Knee valgus motion & knee flexion range of motion during a drop vertical jump. Probability of a high knee abduction moment (pKAM).	↑ Knee valgus in CG but no change in EG. ↓ Knee flexion in CG but no change in EG. ↑ pKAM in CG but no change in EG.
Pfile, et al. (2016)[37]	Prospective case series (pre-post single group)	11 Division I women's basketball players: EG: 11 (19.40 ± 1.35 years)	6-Week Neuromuscular-Control-Training Program. 3/7 30 min.	The normalized SEBT composite score normalized peak isometric H:Q ratio LESS total score (At pretest, posttest 1, and posttest 2)	4-year observation: 16 Overall ACL injury (0.25/1000AEs). 13 Noncontact MOIs: (0.21/1000AEs) 8-year intervention: 9 Overall ACL injury (0.10/1000AEs) 8 Noncontact MOIs: (0.08/1000AEs) Intervention VS observation: Sig → RR reduction overall P = 0.017 Noncontact P = 0.026
Omi, et al. (2018)[38]	Prospective cohort study	757 female collegiate basketball players: Observation group for 4 years: 309 players (19.6±1.2) Intervention group for 8 years: 448 players (21.9±1.5)	8 years hip-focused ACL injury prevention program: (Jump-landing, Strengthening, Balance exercises). 3/7 20 min.	Athlete-exposures (AEs) ACL numbers and mechanisms of injury (MOIs) relative risk (RR) absolute risk reduction (ARR) numbers needed to treat (NNT) compliance	4-year observation: 16 Overall ACL injury (0.25/1000AEs). 13 Noncontact MOIs: (0.21/1000AEs) 8-year intervention: 9 Overall ACL injury (0.10/1000AEs) 8 Noncontact MOIs: (0.08/1000AEs) Intervention VS observation: Sig → RR reduction overall P = 0.017 Noncontact P = 0.026
Sasaki, et al. (2019)[39]	Randomized Controlled Trial (RCT)	17 female collegiate basketball players. EG: 9 (19.7 ± 0.9 years) CG: 8 (20.3±2.5 years)	8-week core-muscle–training program (bench, side bench, and Nordic hamstrings). 4 times or more each week for 8 weeks (an average of 4.7 times per week).	hip, knee, and trunk kinematics; knee kinetics during drop-jump & single-legged squat (SLS) (3D) isokinetic muscle strength.	DJT: ↑ maximal trunk flexion angle ↓ peak knee-valgus moment NS → KVA, KFA SLS: ↑ peak trunk-flexion angle, KFA ↓ peak knee-valgus moment and trunk lateral-inclination angle ↓ KVA NS → CG
Sabet, et al. (2019)[40]	Randomized Controlled Trial (RCT)	40 female basketball players who demonstrated neuromuscular deficits on the tuck jump test (22.4 ± 1.7 years). EG: 20 (23.42 ± 1.72 years) CG:20 (22.45±1.68 years)	6-week NMT program. 3/7 30 min with 10 min warm-up and cool-down.	PT of hip abductors, external rotators, knee flexors, and extensors muscles by isokinetic dynamometer. Single-leg hop test single leg triple crossover hop test	Sig → improvement for the peak torque and time to peak torque in hip and knee muscles (both concentric and eccentric states at 60 and 180°sec) in EG. Sig → improvement in single-leg hop and single-leg triple crossover hop tests. NS → CG.

Study	Design	Population	Program	Outcomes	Results
Otsuki, et al. (2021)[41]	Quasi-experimental (non-randomized controlled trial)	154 adolescent female basketball players. 6 group: ET:18 (12.9±0.7) EC:17 (12.6±0.6) LT:28 (13.8±1.0) LC:22 (14.0±0.9) PT:33 (15.9±0.7) PC:36 (16.0±0.6)	6-month injury prevention training program (such as pivoting and cutting). 3/7 20 min as warm up.	Medial knee displacement and knee flexion during DJT. probability of high knee abduction moment (pKAM)	↑ Medial knee displacement in EC but no change in ET. ↓ Knee flexion in EC but no change in ET. ↑ pKAM in EC but no change in ET. ↓ pKAM in PT but no change in PC.
Sánchez-Morales, et al. (2024)[42]	Randomized Controlled Trial (RCT)	98 female basketball players (mean age: 14.70 ± 2.97 years) EG: 49 (14.71±3.13 years) CG: 49 (14.69 ± 2.84 years)	EG: conventional injury prevention training + a gluteus maximus strength program CG: conventional injury prevention training 5 months 2/7	Total injury incidence Dynamic stability (SEBT) Vertical Jump height DKV Pain assessment (VAS scale)	↓ injury rate for both groups compared to the previous season. Sig → improvements in PL direction of SEBT in the CG (right leg). EG: improvements in overall, P, PM, PL dynamic stability of the right leg, and A, M, PM direction of the left leg. Sig → improvement in jump height in both groups. NS → knee valgus & pain
Rostami, et al (2024)[43]	Randomized Controlled Trial (RCT)	30 female basketball players (mean age: 15.50 ± 1.52 years) EG: 15 (16.00 ± 1.60 years) CG: 15 (15.00 ± 1.30 years)	8-week STOP-X Training Program 3/7 25-40 min	DKV (SLL) Static balance (BASS STICK) Y-balance test (YBT)	Sig → DKV (F = 119.46; P = 0.001; ES = 0.81, PC=↓34.36%) Sig → improvement in static balance (F = 56.45; P = 0.001; ES = 0.66, PC=↑59.64%) Sig → improvement in total dynamic balance score (F = 107.57; P = 0.001; ES=0.79, PC=↑19.84%)

Table 2. *Summary of studies conducted on the effect of exercise interventions on the prevention of knee injuries in female basketball players. Notes: EG = experimental group; CG = control group; ↑ = increase; ↓ = decrease; PT = peak torque; HPT = hamstring peak torque; QPT = quadriceps peak torque; FSD = forward-step down; H/Q = hamstring to quadriceps ratio; 3/7 = three sessions per week; NS = no significant differences; Sig = significant differences; P = P value; SIPTP = sports injury prevention training program; KVA = knee valgus angle; DJT = drop- jump test; EMG = electromyography; PVIF = Peak Vertical Impact Force; RFD = Rate of Force Development; CPA = angle of coronal plane alignment; KFA = knee flexion angle; NMT= Neuromuscular Training TA = torsion angle; VMO = vastus medialis oblique; MH = medial hamstrings; LESS= Landing Error Scoring System; DKV= dynamic knee valgus; SEBT= Star Excursion Balance Test; VAS= Visual Analog Scale; P= Posterior PL= Postero-Lateral; PM= Postero-Medial; A= Anterior; M= Medial; SLL= single-leg landing; YBT= Y-balance test; ES= Eta-Squared; PC= Percentage change.*

11. Measures of point and variability for no less than one dependent variable. Satisfaction of a criterion had a score of 1, and a summary of the outcomes obtained from items 2 to 11 provided an overall score[27]. Studies whose total score was less than 5 or greater than 6 were considered "low" or "high" quality, respectively[26,27]. Although the PEDro scale was originally developed for randomized controlled trials (RCTs), it was used here as a general indicator of methodological quality due to the limited number of available studies, and results for non-RCTs were interpreted with caution.

RESULTS

Figure 1 shows the selected studies. A total of 1398 abstracts (from among 1749 articles) were identified for review after removing duplicate titles. After reviewing the abstracts of the articles, 1298 articles were removed, and 100 articles were selected for full-text study. After reviewing all the articles, eighty-four articles were removed, and 16 articles were included in the present study. A total of 16 studies examining the effects of exercise interventions on knee injury prevention in female basketball players were included. Participants ranged in age from 12 to 25 years, encompassing adolescent, high school, and collegiate athletes, with sample sizes varying from 8 to 757 players. Intervention programs varied in duration from 4 weeks to 8 years and included plyometric and jump-landing training, strength and conditioning exercises, balance and core training, agility drills, flexibility exercises, and neuromuscular training. Most interventions were conducted 3-4 times per week, with session durations ranging from 15 to 120 minutes. Outcome measures included biomechanical parameters (e.g., knee valgus and flexion angles, tibial rotation), muscle strength (e.g., hamstring and quadriceps peak torque, H/Q ratio), dynamic and static balance (e.g., SEBT, Y-balance test), performance tests (e.g., drop-jump test, vertical jump, sprint tests), and injury incidence. Overall, interventions were effective

PEDro scale criteria*													
Studies	1	2	3	4	5	6	7	8	9	10	11	Total score	Quality
1. Wilkerson, et al.(2004)[28]	■	□	□	□	□	□	□	■	■	■	■	x	Low
2. Kato, et al. (2008)[29]	■	□	□	□	□	□	□	■	■	■	■	x	Low
3. Lim, et al. (2009)[30]	■	■	□	□	□	□	□	■	■	■	■	x	Low
4. Wilderman, et al. (2009)[31]	■	■	□	□	□	□	□	■	■	■	■	x	Low
5. Herrington (2010)[32]	■	□	□	□	□	□	□	■	■	■	■	x	Low
6. Nagano, et al (2011)[33]	■	□	□	□	□	□	□	■	■	■	■	x	Low
7. Noyes, et al (2012)[34]	■	□	□	□	□	□	□	■	■	■	■	x	Low
8. Fontenay, et al (2013)[35]	■	□	□	□	□	□	□	■	■	■	■	x	Low
9. Otsuki, et al (2014)[36]	■	□	□	■	□	□	□	■	■	■	■	x	Low
10. Pfile, et al (2014)[37]	■	□	□	■	□	□	□	■	■	■	■	x	Low
11. Omi, et al (2018)[38]	■	□	□	□	□	□	□	■	■	■	■	x	Low
12. Sasaki, et al (2019)[39]	■	■	□	□	□	□	□	■	■	■	■	x	Low
13. Sabet, et al (2019)[40]	■	■	■	□	□	■	■	■	■	■	■	x	High
14. Otsuki, et al (2021)[41]	■	□	□	□	□	□	□	■	■	■	■	x	Low
15. Morales, et al (2024)[42]	■	■	□	□	□	□	□	■	■	■	■	x	Low
16. Rostami, et al (2024)[43]	■	■	■	□	■	□	□	■	■	■	■	x	High
*PEDro scale for measuring the quality of studies: Items 1 to 11 are mentioned in the research methodology section. The sum of items 2-11. ■ 1 point and □ 0 point.													

Table 3. *The results of the quality assessment of the reviewed studies.*

in improving neuromuscular control, muscle strength, dynamic stability, and reducing knee valgus and ACL injury risk factors, while some studies reported no significant changes in specific outcomes.

Table 2 presents a summary of the findings of the articles. *Table 3* reports the results of the quality assessment of the reviewed studies.

Training period

The duration of exercise interventions varied between 4 and 8 weeks in most studies. Three studies conducted the interventions for 5-6 months[36,41,42], and only one study did so for 8 years[38]. A total of 1362 people (experimental group: 806 people and control group: 556 people) were included in these studies. The largest number of participants (757 people) and training duration (8 years) were included in the study of Omi et al.[38].

Evaluation groups and interventions

Four studies had no control group and had only one experimental group[32-34,37]. One study had three groups[35], and the other study had 6 groups[41]. Two control and experimental groups participated in other studies[28-31,36,38-40,42,43]. All exercise groups received exercise interventions to prevent injury, and the control groups only performed their usual exercises.

The included articles used various exercise interventions, such as injury prevention protocols, neuromuscular training, plyometrics, core stability, jumping exercises, jumping and balance combinations, physical and mental exercise combinations, and agility exercises. The control group followed a regular basketball training program.

Dependent variables under the influence of injury prevention exercise interventions

This review investigated the effects of exercise interventions on the following variables: number of ACLs and mechanisms of injury (MOIs); isokinetic muscle strength (peak torque of the hip abductors, external rotators, hamstrings, and quadriceps); electromyography (EMG) of the quadriceps and hamstrings; the hamstring to quadriceps ratio (H/Q); muscle flexibility; lunging maneuvers; the T-pattern agility drill; one-leg and crossover hop tests; the 18-m sprint test; static and dynamic balance; the Vo2max score; jumping performance (flight moment and jump height); the forward-step down (FSD) impact

index; knee kinematics (inter-knee distances, knee internal rotation angle, maximum knee extension torques, maximum knee valgus moment, angle of coronal plane alignment (CPA)); the knee flexion angle; the tibial rotation angle; the torsion angle; the knee varus/valgus angle; and trunk and lower limb kinematics in jump landing tasks. However, most studies have evaluated isokinetic muscle strength, the H/Q ratio, and the valgus and knee flexion angles.

DISCUSSION

This review investigated the role of exercise interventions in preventing knee injuries among female basketball players. Sixteen articles were included in the present review according to the inclusion and exclusion criteria. Therefore, the following section discusses the results of 16 studies in different groups.

It should be noted that the included participants ranged in age from 12 to 25 years, representing a heterogeneous group in terms of biological maturity, training load, and sports experience. This variability may influence the response to exercise interventions and should be considered when interpreting the results.

Kinematics and kinetics of the lower limbs in jump-landing tasks

Most ACL injuries are of the noncontact type, and the knee valgus angle is a predictor of noncontact damage to this ligament, which is also associated with the abductor torque on the knee joint[44]. Four studies reduced the dynamic knee valgus (DKV) angle during jump-landing tasks through a 4-week[29,32] and 8-week[35,43] multifaceted protocol, including jumping exercises, a combination of physical and mental exercises, and neuromuscular training. Additionally, in the study of Pfile et al., LESS scores significantly improved after six weeks of neuromuscular-control training[37]. These studies have emphasized various factors, including jumping, balance, plyometric, and strength exercises through training methods. In addition to exercises, they used verbal and technical feedback. The results of the aforementioned articles support the importance of feedback and technical corrections to improve landing biomechanics. As the study of Otsuki et al.[36] showed, the knee valgus angle and PKAM during drop jump did not significantly decrease after 6 months of the injury prevention program in the experimental group, but increased in the control group. The reason is likely that performing 6 months of injury prevention exercises may not improve the knee valgus angle, but it can prevent a downward trend in individuals who are at risk of injury. Some studies have shown increased inter-knee distances during drop jumps[34] and rebound jumps[30] after injury prevention training programs. However, in a study conducted by Nagano et al.[33], the DKV did not significantly differ after 5 weeks of jumping and balance exercises, possibly because of a lack of strengthening exercises for the lower limb muscles. Another reason for the lack of effect of this study on the DKV angle is its very small sample size and the lack of a control group. In the study of Sasaki et al.[39], the knee valgus angle did not significantly decrease in the drop jump after eight weeks of core stability exercises, but a significant decrease in the knee valgus angle was observed in the single-legged squat (SLS) test. No significant difference was observed in knee flexion during the drop jump, while knee flexion increased in the SLS. The kinetics and kinematics of the lower limb during landing from vertical jumps or rebound jumps, and drop jumps can change compared to those of other tests, such as SLS. The results showed that the lateral movement of the trunk during the SLS test and the peak knee valgus movement during the drop jump test were reduced after core muscle training. Weakness or lack of muscular endurance of the core muscles is presumed to be a determining factor in knee valgus in repeated landing jumps[45]. Decreased activity of the trunk and hip stabilizers can cause the trunk to move to the side and increase knee abduction loads[46]. Activating the stabilizing muscles of the trunk and pelvis to balance the movements of the trunk and adjust the posture of the lower limb during the execution of dynamic skills can partially control the acceleration of the trunk and prevent injury by maintaining the stability of the lower limb. Thus, in this research, core muscle training might improve neuromuscular control of the trunk and lower limbs. However, it is uncertain whether performing only these 3 exercises (Bench, Sideways bench, and Nordic hamstrings) will reduce the incidence of ACL injuries sufficiently. Apparently, we need to determine a mechanism to develop an effective ACL injury prevention program that includes exercises other than core stability exercises to reduce the incidence of ACL injuries.

Increasing the knee flexion angle may lead to changes in the function of the quadriceps and hamstring muscles. Quadriceps muscle contraction at less than 30 degrees of flexion causes ACL strain[47-49]. The contraction of the hamstring because of its connection to the tibia at a low angle cannot reduce the strain on the ACL in mild knee flexion[48-50]. Quadriceps contraction at a flexion angle greater than 60 degrees does not increase the strain on the ACL[49], and tibial anterior translation and tibial internal rotation decrease because of quadriceps contraction[51]. On the other hand, hamstring contraction reduces tibial anterior translation and tibial internal rotation at these angles[52]. Therefore, increasing the knee flexion angle during landing may have a positive effect on reducing the strain on the ACL. Knee flexion, according to the literature, increased after eight weeks of the injury prevention program[30] and after 5 weeks of jump-balance exercises[33]. Similarly, the knee flexion angle in two studies[36,41] was not significantly different between the experimental groups, but it decreased in the control group.[29]Kato et al. reported that the knee flexion angle did not significantly differ between the groups after 4 weeks of neuromuscular training, possibly because of the shorter program and the lower number of training sessions during the week.

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Muscle strength

The normal functional ratio of the hamstrings to the quadriceps is reportedly 1:1[53,54]. This means that the hamstrings and quadriceps must be in functional balance to minimize injuries to the lower limbs, especially the knee. Li et al. reported that assigning a numerical value of 1 to the functional ratio of hamstring strength to quadriceps strength minimizes tibial anterior translation and is useful for individuals with ACL ligament dysfunction[53]. Eccentric functions are much stronger than concentric functions because of the intervention of the elasticity of connective tissues in eccentric contraction[54]. Therefore, the numerical strength functional ratio that compares the eccentric activity of the hamstrings with the concentric activity of the quadriceps should be greater. The nature of the sport of basketball, which often involves vertical jumping and running, appears to increase the strength of the quadriceps on hamstrings. Hence, hamstring resistance exercises are recommended for this group of athletes. The effect of exercise interventions on lower limb strength has been reported in some studies, 4 of which measured isokinetic peak torques[28,30,39,40]. Three studies showed increased peak knee flexor torque at different angles[28,39,40]. A study conducted by Wilderman et al. revealed an increase in hamstring activation during side-step pivoting following 6 weeks of agility training. Since a low level of hamstring activity may be a predisposing factor for ACL sprains in women[55], these types of exercises prevent excessive stress on the ACL by limiting excessive anterior tibial translation during functional movements. Women use the quadriceps muscle more than the hamstring muscles during sports activities[13]. Overusing the quadriceps muscles can lead to an imbalance between the strength and activation patterns of the hamstrings and quadriceps, which causes anterior tibial translation and subsequent stress on the ACL ligament[56]. Therefore, co-contraction of the hamstring and quadriceps muscles is necessary to stabilize the knee joint and prevent anterior tibial translation[57]. Four studies investigated the hamstring-to-quadriceps ratio[28,30,33,37]. Six weeks of the preseason conditioning program improved the hamstring-to-quadriceps ratio at an angle of 60 degrees in one study. Therefore, depth receivers and plyometric exercises, in addition to this training program, can be suitable[28]. However, the hamstrings to quadriceps ratio decreased after 8 weeks of injury prevention training[30] and showed no significant difference after 5 weeks of jumping and balance training[33] or after 6 weeks of neuromuscular-control training[37]. One reason this variable is not significant in these two studies is their very small sample size, and it is impossible to ensure that the results are generalizable to all female basketball players. Additionally, these two studies had no control group[33,37]. Women have weaker hamstrings than men[58], and eccentric hamstring strengthening exercises, such as Nordic curl alone or integrated with other sports methods, are recommended for team sports that include the predominance of knee extension actions, such as football or basketball. This balances the predominance of the knee extension component caused by specific sports activities (such as jump landing, stop jumping, or side cutting maneuvers) and increases the functional H/Q ratio.

Beyond the studies included in this review, additional evidence points to factors that could indirectly influence the risk of knee injuries. For example, an eight-week proprioceptive neuromuscular facilitation (PNF) program was shown to enhance postural stability and performance in elite male basketball players, suggesting that neuromuscular training may play a supportive role in controlling knee joint mechanics[59]. In addition, data on anthropometric characteristics and physical performance in female basketball players highlight how chronological age and biological maturity affect lower limb dimensions, sprinting, and jumping abilities, which might indirectly modify knee loading and injury susceptibility[60]. Collectively, these observations indicate that integrating both neuromuscular interventions and consideration of maturational status could be valuable when designing injury prevention programs for female basketball athletes.

Limitations

This review has several limitations. First, the participants included in the studies ranged in age from 12 to 25 years, representing a heterogeneous group in terms of biological maturity, training load, and sports experience. This variability may influence the response to exercise interventions and should be considered when interpreting the results. Second, most of the included studies had small sample sizes, which may limit the generalizability of the findings. Third, variations in the type, duration, and intensity of exercise programs across studies make it difficult to compare results. Fourth, only studies published in English were included, which may have led to the exclusion of relevant research published in other languages. Fifth, only a very few of the included studies reported actual injury risk, while most focused on surrogate outcomes, such as biomechanical or functional measures (e.g., dynamic knee valgus, H/Q ratio, joint angles, muscle strength, and balance). Therefore, despite improvements in these measures, it remains unclear whether these changes actually translate into a reduced risk of knee injury. Future research should include longer follow-ups and report injury incidence to provide stronger evidence regarding the effectiveness of prevention programs. Finally, although the PEDro scale was used to assess methodological quality, it was originally developed for randomized controlled trials. Therefore, its use for non-RCTs may not fully reflect study quality, and these results should be interpreted with caution.

CONCLUSION

By analyzing the collected articles, we concluded that several programs have a positive effect on the prevention

of ACL injuries among female basketball players by reducing the relevant risk factors. As the results show, the most commonly used exercise program is the neuromuscular program, the structure of which comprises several types of exercise. Therefore, a training program that combines several factors can be more effective in reducing the amount of DKV and subsequently in reducing the incidence of ACL damage than a training program that focuses on only one or two factors. Because strength training alone may not improve lower extremity biomechanics, the effectiveness of ACL injury prevention training appears to be more significant when multimodal interventions per week, such as strength, balance, flexibility, plyometric, or agility training over 6 weeks or more, and three training sessions, are included. Since multimodal interventions with feedback and technical corrections are more effective for modifying biomechanical risk factors than protocols without technical feedback, adding technical feedback should be an essential part of injury prevention protocols for team sports athletes. We also believe that, before performing advanced plyometrics, athletes should first learn proper jumping and landing techniques through a neuromuscular training program under the close supervision of coaches with feedback. However, since only a few studies reported actual injury incidence, and improvements in surrogate outcomes do not necessarily guarantee a real reduction in injury risk, further research is needed to confirm whether these programs truly reduce real ACL injuries.

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