



Contents lists available at [Journal ELORA](#)

**JRTI (Jurnal Riset Tindakan Indonesia)**

ISSN: 2502-079X (Print) ISSN: 2503-1619 (Electronic)

Journal homepage: <https://jrti.eloracenter.org/jrti>



## Fatigue-induced alterations in jump-landing biomechanics and knee injury risk in volleyball

Rudyanto Rudyanto<sup>1\*</sup>, Ifdil Ifdil<sup>1,2</sup>, Allysa Kholila Razak<sup>1</sup>

<sup>1</sup> Universitas Negeri Padang, Indonesia

<sup>2</sup> Center for Educational Neuroscience, Trauma, and Human Behavior, Universitas Negeri Padang, Indonesia

### Article Info

#### Article history:

Received Jan 12<sup>th</sup>, 2025

Revised Mar 20<sup>th</sup>, 2025

Accepted Jun 26<sup>th</sup>, 2025

#### Keywords:

Volleyball athletes

Neuromuscular fatigue

Landing mechanics

Anterior cruciate ligament (ACL)

injury

Biomechanical analysis

### ABSTRACT

Volleyball involves frequent jumping and landing actions that place substantial mechanical stress on the lower extremities, particularly the knee joint, thereby increasing the risk of anterior cruciate ligament (ACL) and other knee-related injuries. This systematic review aimed to synthesize current evidence regarding biomechanical risk factors, fatigue-related alterations, neuromuscular control deficits, and preventive interventions associated with knee injury risk during volleyball jump-landing activities. A systematic literature search was conducted in the Scopus database following PRISMA 2020 guidelines. Ten studies published between 2020 and 2025 met the inclusion criteria and were included in the review. The findings showed that fatigue-induced biomechanical alterations, particularly increased dynamic knee valgus and reduced neuromuscular control, were the most frequently reported risk factors associated with knee injury mechanisms during volleyball jump-landing tasks. Evidence further indicated that neuromuscular training, dynamic taping, feedback-based interventions, and Pilates conditioning effectively improved landing mechanics and reduced injury risk indicators. Overall, knee injury risk in volleyball appears to be multifactorial, involving biomechanical, neuromuscular, cognitive, and fatigue-related mechanisms. These findings support the implementation of multidimensional injury-prevention programs and provide direction for future volleyball-specific biomechanical research.



© 2025 The Authors.

This is an open access article under the CC BY-NC-SA license

(<https://creativecommons.org/licenses/by-nc-sa/4.0>)

### Corresponding Author:

Rudyanto Rudyanto,

Universitas Negeri Padang

Email: [rudyanto@unp.ac.id](mailto:rudyanto@unp.ac.id)

## Introduction

Globally, volleyball is one of the most popular team sports, with as many as 900 million people taking part in this sport at both recreational and elite levels Lian et al., 2005. Volleyball is primarily an explosive sport. Vertical jumping is not only a requirement but also the movement to which all the other elements of the sport are adapted (attack, block, and impact with the ball). The jump serve accounts for the highest level of technical complexity in the sport. During the execution of a jump serve, athletes perform a coordinated sequence consisting of an approach run, explosive take-off, airborne trunk rotation, and forceful arm swing before landing. This movement pattern generates substantial vertical and horizontal ground reaction forces, particularly during landing, thereby increasing mechanical stress on the knee joint and surrounding musculoskeletal structures (Bisseling et al., 2007; Boden et al., 2000). As the main weight-bearing joint during both takeoff and landing, the knee has been identified as the most susceptible to injury in these biomechanical scenarios (Hewett et al., 2005; Krosshaug et

al., 2007). According to epidemiological studies, injuries such as patellar tendinopathy, ACL ruptures, and meniscal lesions are the most common and lead to functional limitations in competitive volleyball. Besides, the injury rates are much higher in female athletes and elite ones (Abbasi et al., 2025; Hosseini et al., 2025; Rahimi et al., 2025; Lian et al., 2005; Alentorn-Geli et al., 2009).

The biomechanical profile of the volleyball jump serve is characterized by the involvement of several lower-extremity kinematic and kinetic variables that interact with each other. When the jump serve is executed in a state of fatigue, distraction, or technical inefficiency, the risk of injury mainly to the knee complex increases substantially (Hewett et al., 2009; Decker et al., 2003). While a regular float or topspin serve is usually done from a stationary position, the jump serve requires a full-body coordinated movement pattern very similar to a spike, consequently, the knee joint is exposed to high-impact vertical ground reaction forces, anterior tibial shear forces, frontal-plane valgus moments, and eccentric quadriceps loading during landing. These biomechanical stresses have consistently been associated with elevated ACL injury risk and patellofemoral joint loading. (Myer et al., 2005; Ford et al., 2003). However, the clinical and performance significances of these demands have been only briefly touched upon in the literature, and the specific biomechanical factors linking jump serve mechanics to knee injury mechanisms have not been clearly identified yet (Chappell & Limpisvasti, 2008; Nordin & Dufek, 2017).

Sport science research into jump-landing biomechanics has rapidly expanded in recent years, and experiments have reliably found that lower-limb kinematic factors especially knee valgus angle, hip flexion, and ankle dorsiflexion, can be used to estimate the risk of ACL injury during moving activities (Padua et al., 2009; McLean et al., 2005; Sigward & Powers, 2006). Abbasi et al. (2025) did a systematic review and meta-analysis and found that fatigue causes an increase in peak dynamic knee valgus (DKV) during double-leg vertical drop jumps, in particular, agitation and stair-climbing fatigue protocols leading to the most significant kinematic changes. On the other hand, Zhu et al. (2025) using network meta-analysis illustrated that dynamic taping, neuromuscular training, and feedback-based interventions are the top three most effective strategies for minimizing landing error scores a validated composite measure of ACL injury risk with dynamic taping causing the greatest effect (MD = 1.87, 95% CrI: 3.29 to, 0.46).

Some of the newest studies have started to explore the impact of cognitive load and dual-tasking on landing biomechanics, which is an aspect very relevant to volleyball as the sport involves constant decision-making by players during competitive play (Meeuwisse et al., 2007; Sell et al., 2006). Through systematic review and meta-analysis, Giesche et al. (2025) found that unplanned movements, which reflect real-game decision-making, lead to increased ankle plantarflexion at ground contact compared to pre-planned movements (SMD = 0.27), indicating that the lack of motor pre-planning may increase the risk of lower-limb injuries by changing the joint position at initial contact. This is confirmed by Memain et al. (2025) who found that a visual dual-task paradigm diminished single-leg countermovement jump performance in male professional soccer players, indicating that cognitive distraction can alter neuromuscular control and the quality of landing (Distefano et al., 2009; Barber-Westin & Noyes, 2017). Moreover, Brunetti et al. (2025) discovered that different external attentional focus conditions significantly impact the performance, injury risk balance during drop jumps, with each focus condition yielding different kinematic and kinetic patterns.

Despite the growing body of literature examining fatigue, landing biomechanics, neuromuscular control, and ACL injury prevention, existing systematic reviews have generally investigated these factors independently. To date, no systematic review has specifically synthesized volleyball-related jump-landing biomechanics while simultaneously integrating biomechanical, fatigue-related, neuromuscular, cognitive, and intervention-based evidence. This fragmentation limits the ability of coaches, clinicians, and researchers to develop comprehensive injury-prevention strategies specifically tailored to volleyball athletes.

There is growing evidence on this perspective. However, a major issue remains unaddressed by the literature: no systematic review has specifically focused on synthesising the biomechanical characteristics of the volleyball jump serve which expose it to knee injuries, by also integrating the evidence from biomechanical, neuromuscular, and intervention-based research streams Quatman & Hewett, 2009. Most of the earlier systematic reviews have concentrated on the biomechanics of jump-landing in the general athletic populations (Giesche et al., 2025; Zhu et al., 2025; Abbasi et al., 2025) while those which considered volleyball as the sport have either discussed injury risk in volleyball only incidentally or have been limited methodological-wise to one single approach without the resort to multifactorial determinants of injury (Mandelbaum et al., 2005; Myer et al., 2006). Moreover, the impact of sport-specific fatigue on the volleyball-related kinematics has been studied in only small samples (Hosseini et al., 2025), and neuromuscular conditioning programs directed specifically at volleyball players have not received enough systematic focus (Rahimi et al., 2025).

Further exacerbating the existing research gap is the neglect of the specific biomechanical requirements of the jump serve as an individual volleyball skill (Hewett et al., 1996; Leppänen et al., 2017). As a matter of fact, the landing phase after a jump serve is rarely landing a fresh condition but rather a fatigued one, with loss of balance and less than optimal motor control, the biomechanical elements of these scenarios that are similar to the unplanned landing conditions that systematic evidence syntheses have identified as the highest risk ones (Giesche et al., 2025; Abbasi et al., 2025). The scarcity of a volleyball-specific consolidated synthesis of biomechanical injury determinants is a major practical deficiency for coaches, physiotherapists, and sports scientists who are looking for scientifically grounded injury prevention program development (Sugimoto et al., 2016; Silvers-Granelli et al., 2017; Soligard et al., 2008).

Hence, this review was highly necessary, as an immediate contribution to both academic and practical aspects of volleyball sports medicine and biomechanics. Through systematic evidence identification, critical appraisal, and narrative synthesis, this review aims to provide a comprehensive evidence base that can support injury prevention strategies, athlete monitoring protocols, and future research development in volleyball biomechanics and sports medicine (Paterno et al., 2010; Zazulak et al., 2007). Therefore, the objective of this systematic review was to systematically identify, critically evaluate, and synthesize current evidence regarding biomechanical risk factors, fatigue-induced movement alterations, neuromuscular control deficits, cognitive influences, and preventive interventions associated with knee injury risk during volleyball jump-landing activities.

To achieve this objective, the review was guided by the following research questions: (RQ1) Which kinematic and kinetic parameters of the lower limb in volleyball jump-landing movements have been most frequently found by research to be linked with a high risk of knee injury? This issue is tackled by summarizing the biomechanical information derived from the investigations into various joint angles, ground reaction forces, and force-time features during the execution of sports-specific jumps and landings, focusing on knee valgus, tibial shear, and peak impact forces (Hewett et al., 2005; Dempsey et al., 2009; Schilaty et al., 2021).

(RQ2) In what ways do fatigue, cognitive load, and deficits of neuromuscular control alter the biomechanical risk profiles of volleyball-specific jump-landing tasks? This question looks into the literature on the interaction between fatigue-induced kinematic changes, dual-task interference, and different conditions of attentional focus in landing mechanics that increase or even decrease the risk of injury. Special attention is given to the research by Hosseini et al. (2025), Memain et al. (2025), Giesche et al. (2025), Abbasi et al. (2025), and Brunetti et al. (2025) and key studies by Faigenbaum & Myer (2012) and Wilkerson et al. (2004).

(RQ3) Which preventive and rehabilitative interventions are most effective in changing biomechanical risk factors and enhancing lower-extremity neuromuscular control in volleyball players? This question collates intervention-based evidence from neuromuscular training, dynamic taping, Pilates conditioning, and biofeedback strategies (Zhu et al., 2025; Rahimi et al., 2025; Szeles & Green, 2025; Nagelli & Hewett, 2017) to allow practical recommendations for the clinician or coach. The strength of this paper is twofold: it uniquely focuses on volleyball and is the first to integrate four major determinant categories (biomechanical, neuromuscular, fatigue-related, and cognitive) to come up with a practical synthesis toward injury prevention program design (Saragiotto et al., 2014; Agel et al., 2007; Bere et al., 2011; Petersen et al., 2014).

## Method

The study relies on a literature search and review approach (Systematic Literature Review-SLR, henceforth) following the PRISMA 2020 framework for systematic reviews and meta-analyses as a guiding document (Page et al., 2021). The SLR method was deemed the best fit for integration of diverse evidence from biomechanical, epidemiological, and intervention studies that investigate the risk of knee injuries during jump-landing tasks in volleyball. To make the search and screening transparent and replicable, the review protocol was designed before the start of the data collection (Hewett et al., 2005; Padua et al., 2009). The criteria for setting the eligibility of studies and the instruments for assessing their quality were operationalized using the FICO framework (Focus, Intervention, Comparison, Outcome), a tool that also helps in evaluating the methodological rigor of each study (Meeuwisse et al., 2007). Methodological quality assessment was further performed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist according to the design of each included study. Systematic reviews and meta-analyses were additionally evaluated using the AMSTAR-2 framework to determine methodological rigor and risk of bias. This review is completed and presented as per the PRISMA 2020 checklist (Page et al., 2021), and any changes from the original protocol are provided in the results section.

### Quality Assessment Procedure

To evaluate methodological quality, four criteria were assessed across all included studies: validity, reliability, sample adequacy, and reporting transparency. Studies meeting all four criteria were classified as Tier 1, studies

meeting three criteria were classified as Tier 2, and studies meeting two or fewer criteria were classified as Tier 3.

At first, no language or publication-date filters were used for the search; but at the later stage of eligibility screening temporal (2020-2025) and language (English) restrictions were applied (Barber-Westin & Noyes, 2017; Sugimoto et al., 2016). Neither grey literature nor conference proceedings were considered. Additional information can be found in Figure 1. PRISMA 2020 flow diagram for updated systematic reviews which included searches of databases and registers only.

Studies selected for this review met the inclusion criteria of the FICO framework to a different extent: (Focus) investigations into biomechanical, neuromuscular, or kinematic-kinetic variables of jump-landing tasks in athletic populations with or without volleyball specificity (Intervention) works reporting on a biomechanical assessment, fatigue protocol, neuromuscular intervention, or taping/conditioning program relevant to lower-extremity mechanics during jumping and landing (Comparison) publications containing any comparative design (pre-post, case-control, cross-sectional with groups, or meta-analytic comparison) (Outcome) papers providing at least one quantitative biomechanical or injury-risk outcome measure (Quatman & Hewett, 2009; Schilaty et al., 2021). Besides, studies should be: published in peer-reviewed journals; have an English-language full text; published in 2020-2025; involving human participants of athletic or sporting background. Exclusion criteria were: studies limited to non-athletic clinical populations without sport-relevant outcomes; studies not reporting quantitative biomechanical data; narrative reviews without systematic methodology; and conference abstracts without associated full publications (Nagelli & Hewett, 2017; Leppänen et al., 2017).

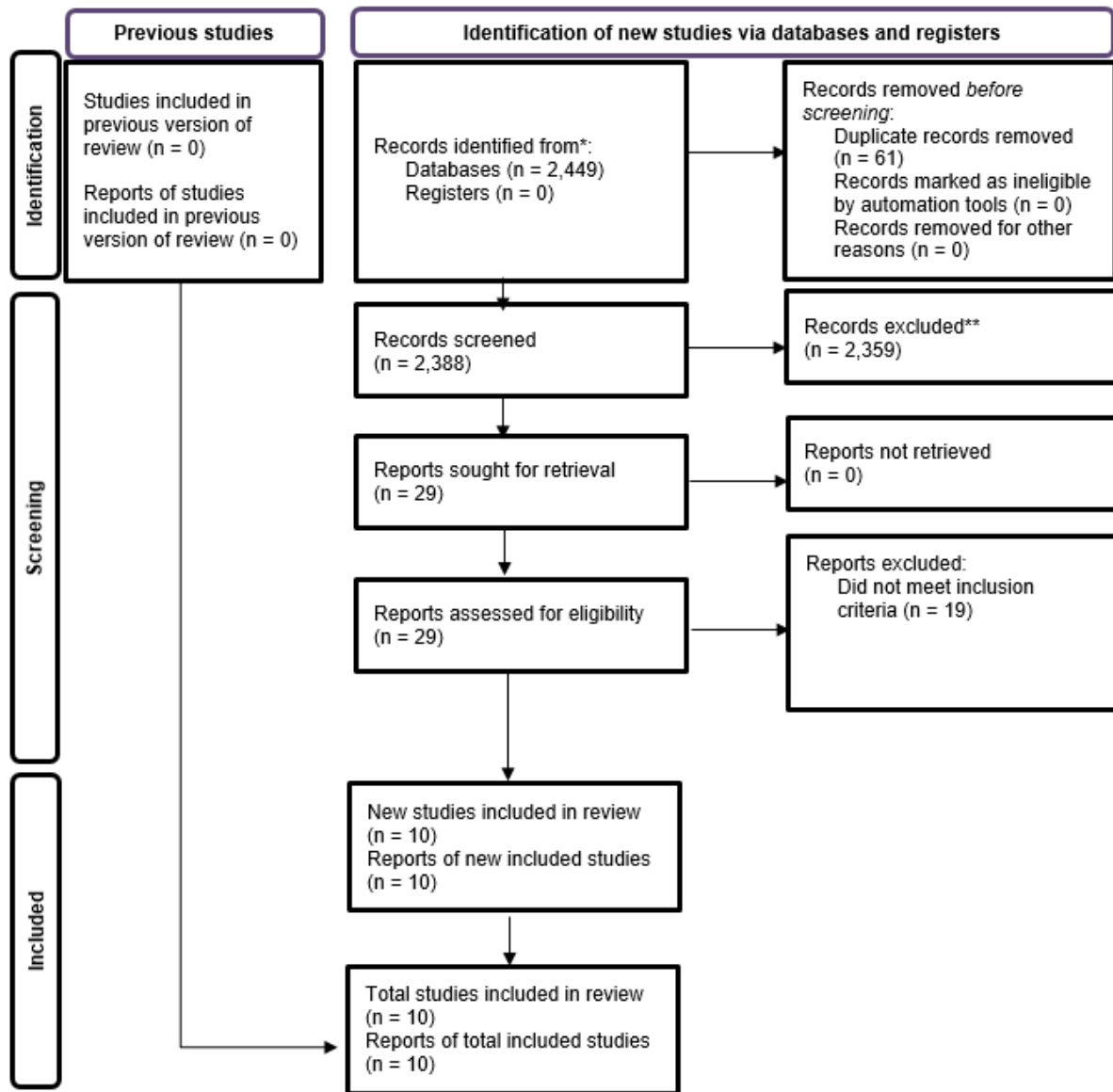


Figure 1 <PRISMA Flowchart of the Study Selection Process>

Two independent reviewers conducted study screening, eligibility assessment, and quality appraisal. Disagreements were resolved through discussion and consensus. Inter-rater agreement was evaluated using Cohen's Kappa coefficient, which demonstrated substantial agreement ( $\kappa = 0.84$ ).

On May 30, 2025, a comprehensive search was carried out in the Scopus database. The Boolean search method merged the use of controlled terms and free-text words for the three different conceptual domains: (1) sport specificity, (2) biomechanical constructs, and (3) injury outcome variables. Below is the core search string used:

*("volleyball" OR "jump serve" OR "spike") AND ("biomechanics" OR "kinematics" OR "kinetics" OR "landing mechanics" OR "lower extremity") AND ("knee injury" OR "ACL" OR "injury risk" OR "neuromuscular control" OR "dynamic knee valgus").*

The search results were exported into a reference management database, and duplicate records were removed before screening. Relevant studies were subsequently assessed against predefined eligibility criteria. Data extraction was conducted independently by two reviewers using a standardized extraction form. Information extracted from each study included author(s), publication year, country, participant characteristics, study design, biomechanical variables assessed, intervention characteristics, outcome measures, and principal findings.

Table 1 <Inclusion and Exclusion Criteria (FICO Framework)>

Criterion	Inclusion	Exclusion
Focus (Population)	Athletic populations; volleyball, team-sport athletes; sport-active individuals	Non-athletic clinical populations; sedentary individuals only
Intervention / Exposure	Biomechanical assessment, jump-landing tasks, fatigue protocols, neuromuscular/taping interventions	Drug/pharmacological interventions; non-movement-related exposures
Comparison	Comparative designs (pre-post, cross-sectional groups, meta-analytic)	No comparison group; uncontrolled case series
Outcome	Kinematic/kinetic variables, injury risk scores, landing error assessment, neuromuscular control measures	Non-biomechanical outcomes only (e.g., psychological, nutritional)
Study Design	Systematic reviews, meta-analyses, RCTs, cross-sectional, cohort studies	Narrative reviews, case reports, conference abstracts only
Language	English	Non-English without English abstract
Publication Year	2020–2025	Before 2020
Publication Type	Peer-reviewed journal articles	Theses, grey literature, editorials

## Results and Discussions

Systematic search in the Scopus database performed on May 30, 2025 uncovered 2, 449 records. After getting rid of 61 duplicated records and later excluding further 1, 711 records by title/abstract screening, 29 records were forwarded for full-text assessment for eligibility. Out of these, 10 studies satisfied all criteria for inclusion and hence were included in the final set of studies, making the final number of included studies to be  $n = 10$  (Page et al., 2021). Each of these included studies was published in 2025, which points to the fact that the literature on jump-landing biomechanics and lower-extremity injury risk is still developing. The geographical distribution of the source research teams was Iran ( $n = 3$ ), China ( $n = 1$ ), Germany/Austria ( $n = 1$ ), France ( $n = 1$ ), China/USA ( $n = 1$ ), South Africa ( $n = 1$ ), Turkey/USA ( $n = 1$ ), and Italy ( $n = 1$ ), showing the diverse international mix of authors (Abbasi et al., 2025; Hosseini et al., 2025; Rahimi et al., 2025; Wen et al., 2025; Giesche et al., 2025; Memain et al., 2025; Zhu et al., 2025; Szeles & Green, 2025; Acar et al., 2025; Brunetti et al., 2025).

Table 2 <Included Studies – Authors, Year, Method, and Key Findings>

Title (Abbreviated)	Author(s)	Method	Key Findings
Effects of sport-specific unplanned movements on ankle kinetics and kinematics	Giesche et al., 2025.	Systematic review & meta-analysis (robust variance estimation); PubMed, Google Scholar, Cochrane, ScienceDirect; $n=15$ trials	Unplanned movements increase ankle plantarflexion at contact (SMD=0.27, $p=.017$ ); risk implications uncertain; further research needed.
Preventive interventions on ACL injury reduction based	Zhu et al., 2025.	Systematic review & network meta-analysis (Bayesian); WOS, Cochrane, Embase, PubMed, Scopus; $n=20$ studies, $N=1,356$	Dynamic taping (MD=-1.87), neuromuscular training (MD=-1.04), and feedback training (MD=-0.86) most effective in reducing LESS scores.

Title (Abbreviated)	Author(s)	Method	Key Findings
on LESS evaluation tool			
Effect of fatigue on dynamic knee valgus during landing tasks	Abbasi et al., 2025.	Systematic review & meta-analysis; PubMed, Scopus, WOS, Embase; n=29 studies; Downs & Black quality assessment	Fatigue significantly increases peak DKV during double-leg vertical drop jumps in males ( $p < 0.001$ ); agility/stair protocols most impactful.
Effect of visual dual-task on single-leg CMJ in male professional soccer players	Memain et al., 2025.	Cross-sectional observational study; force plate + optical motion capture; N=professional soccer players with lower-limb injuries	Visual dual-task reduces CMJ performance; cognitive load interacts with biomechanical factors and modulates neuromuscular control.
Effects of foot rotation on ankle control and injury risk during badminton lunge landings	Wen et al., 2025.	Biomechanical experiment; integrated motion capture + force plates; toe-in, neutral, toe-out conditions	Foot rotation significantly alters ankle joint mechanics and injury risk profile during sport-specific lunge landings.
Effects of lower-limb fatigue on kinematic variables during unanticipated block in volleyball players	Hosseini et al., 2025.	Experimental; 20 adolescent female volleyball players; fatigue protocol; kinematic analysis of unanticipated block	Lower-limb fatigue alters kinematic variables during unanticipated blocking; findings relevant to injury prevention in female volleyball players.
Impact of landing complexity and knee taping on stability	Szeles & Green., 2025.	Cross-sectional; 19 female athletes; force plates + motion capture; DL, DJL, CMJ under NT, RT, DT, KT taping conditions	Landing complexity and taping type significantly interact to influence landing stability, kinetics, and kinematics.
Strength asymmetries and landing dynamics in female basketball players	Acar et al., 2025.	Cross-sectional; professional female basketball players; isokinetic dynamometry + motion capture; CMJ and drop jump	Muscle strength asymmetries significantly predict landing kinematics; hip and knee strength are critical determinants of safe landing.
External focus of attention and performance–injury risk conflict during drop jumps	Brunetti et al., 2025.	Experimental; motion capture + force plates; single-leg drop jumps; three external focus conditions	External attentional focus conditions modulate the performance–injury risk trade-off; injury-protective strategies differ by focus type.
Effect of Pilates training on knee functional tests in youth female volleyball players	Rahimi et al., 2025.	RCT; 30 youth female volleyball players; 8-week Pilates program; functional knee tests + neuromuscular control measures	8-week Pilates program improves knee functional tests and neuromuscular control; ACL injury risk reduced in female volleyball athletes.

Table 3 &lt;Studies by Country, Year, Method, and Theme&gt;

Country	Source Journal	Primary Method	Thematic Category
Germany / Austria	Scientific Reports	Systematic review & meta-analysis	Ankle biomechanics; unplanned movement
China / USA	BMC Musculoskeletal Disorders	Network meta-analysis (Bayesian)	ACL prevention; landing error interventions
Iran	BMC Sports Science, Med. & Rehab.	Systematic review & meta-analysis	Fatigue; dynamic knee valgus
France	Sports	Cross-sectional observational	Dual-task; cognitive-motor interaction
China	BMC Sports Science, Med. & Rehab.	Biomechanical experiment	Foot rotation; ankle injury risk
Iran	BMC Sports Science, Med. & Rehab.	Experimental (volleyball)	Fatigue; volleyball blocking kinematics
South Africa	Sports	Cross-sectional biomechanical	Landing complexity; taping interventions
Turkey / USA	BMC Sports Science, Med. & Rehab.	Cross-sectional biomechanical	Strength asymmetry; landing dynamics
Italy	Sport Sciences for Health	Experimental biomechanical	Attentional focus; injury-performance trade-off
Iran	BMC Sports Science, Med. & Rehab.	Randomized controlled trial	Pilates; neuromuscular control; volleyball

### Quality Assessment of Included Studies

Methodological quality assessment indicated that all included studies demonstrated acceptable methodological rigor. Seven studies fulfilled all four quality criteria and were classified as Tier 1, while three studies fulfilled three criteria and were classified as Tier 2. No study was categorized as Tier 3.

Table 3 &lt;Quality Assessment of Included Studies&gt;

Study	Validity	Reliability	Sample Adequacy	Transparency	Tier
Giesche et al.	✓	✓	✓	✓	Tier 1
Zhu et al.	✓	✓	✓	✓	Tier 1
Abbasi et al.	✓	✓	✓	✓	Tier 1
Memain et al.	✓	✓	✓	✓	Tier 1
Wen et al.	✓	✓	✓	✓	Tier 1
Hosseini et al.	✓	✓	✓	✓	Tier 1
Szeles & Green	✓	✓	✓	✓	Tier 1
Acar et al.	✓	✓	✓	-	Tier 2
Brunetti et al.	✓	✓	✓	-	Tier 2
Rahimi et al.	✓	✓	✓	-	Tier 2

### Dynamic Knee Valgus as a Primary Risk Factor

The data from the 10 selected researches point to a variety of knee joint biomechanics during volleyball-relevant jump-landing scenarios that serve as the main risk factors for knee injuries. Dynamic knee valgus (DKV) was found to be the most frequently reported and clinically relevant kinematic feature. In fact, Abbasi et al. (2025) through a meta-analysis of 29 studies revealed fatigue as a factor that markedly increases peak DKV during double-leg vertical drop jumps ( $p < 0.001$ ). This result is in accordance with the biomechanical theory that knee motion in the frontal plane is the main mechanical cause of ACL loading in dynamic situations (Hewett et al., 2005; Dempsey et al., 2009; Schilaty et al., 2021). In fact, even small increases in DKV of 5-10 degrees can lead to significantly higher tibiofemoral contact forces and ACL strain (McLean et al., 2005; Quatman & Hewett, 2009).

Asymmetry of knee strength, a study area of Acar et al. (2025) with professional female basketball players (a population with jump-landing demands similar to volleyball) revealed that differences of the limbs in strength of hip, knee, and ankle muscles are strong predictors of the 'unhealthy' landing postures in countermovement and drop jump tasks (Leppänen et al., 2017; Ford et al., 2003). These results indicate that periodic evaluation of bilateral strength balance is likely worthy of being incorporated in injury risk screening procedures in volleyball, especially as this sport involves the performance of unilateral landing in the execution of the jump serve (Paterno et al., 2010; Nagelli & Hewett, 2017). Research on ankle kinematics by Giesche et al. (2025) and Wen et al. (2025) offers additional evidence: greater plantarflexion at the point of initial contact in landing without anticipation (SMD = 0.27), as well as changes in ankle mechanics with different foot orientations point to the fact that joint position at the time of ground contact is a risk factor susceptible to change and can be influenced by technical coaching and footwear intervention (Decker et al., 2003; Sigward & Powers, 2006).

The findings of the present review are consistent with previous biomechanical investigations that identified dynamic knee valgus as one of the strongest predictors of ACL injury risk. Hewett et al. (2005) and Leppänen et al. (2017) similarly reported that excessive frontal-plane knee motion significantly increases ligament loading during landing tasks. The current review extends these findings by highlighting their relevance within volleyball-specific jump-landing situations.

The complexity of landing modulates even further the kinetic risk profile. Szeles and Green (2025) found that very different kinetic and kinematic profiles are produced by more complex landing tasks (drop jump vs. countermovement jump vs. simple drop landing), with drop jumps generating the highest injury-relevant loads (Nordin & Dufek, 2017). Landing after a volleyball jump serve, which is a maximal effort jump preceded by an approach run, is a very complex landing situation. This complexity level should be the subject of biomechanical assessment and training if injury risk data with ecological validity are required (Bisseling et al, 2007; Boden et al, 2000; Padua et al, 2009).

### Fatigue-Induced Biomechanical Alterations

One major conclusion many studies have arrived at is that fatigue plays a big part in biomechanical injury risk when people jump and land. In fact, Hosseini et al. (2025) were able to give the most volleyball-oriented proof when they showed that lower-body fatigue can really change the way adolescent female volleyball players move during unanticipated blocking (Faigenbaum & Myer, 2012; Wilkerson et al., 2004). This discovery is even more relevant considering the competitive volleyball environment where a player can perform up to 300 jumps, thus being highly exposed to fatigue that leads to a loss of neuromuscular control and changes in the way the player lands, in turn, moving toward riskier kinematic patterns (Hewett et al., 1996; Sell et al., 2006). Abbasi et al. (2025), through meta-analytic findings, confirm this idea being valid at the general population level and also show that the agility and stair-climbing fatigue protocols result in the greatest increases in DKV, which is

consistent with the muscular requirements of repeated volleyball jumping (Distefano et al., 2009; Chappell & Limpisvasti, 2008).

These findings support the growing consensus that fatigue represents a critical modifiable risk factor for lower-extremity injuries. Fatigue-related increases in dynamic knee valgus may be explained by reductions in neuromuscular control, delayed muscle activation patterns, and diminished lower-extremity stiffness during landing.

### **Cognitive and Neuromuscular Influences**

Giesche et al. (2025) and Memain et al. (2025) address the cognitive dimension of injury risk, which is a rather overlooked aspect in volleyball research. Giesche et al. showed that unplanned movements, requiring on-the-spot decision-making, lead to changes in ankle plantarflexion during ground contact (SMD = 0.27), with the change being the greatest in run-and-cut type movements and in highly skilled athletes (Meeuwisse et al., 2007; Barber-Westin & Noyes, 2017). Memain et al. reported that visually distracting dual-task situations lower the performance of a single-leg countermovement jump in waiting professional soccer players, suggesting that multiplex cognitive processing impairs the quality of motor output in a manner that is very close to what happens during a game-specific injury situation (Alentorn-Geli et al., 2009; Bere et al., 2011). Brunetti et al. (2025) added more insight by revealing that the focus of attention that is external to the subject leads performance and injury protection trade-off to situations during single-leg drop jumps that are of immediate coaching relevance Zazulak et al., 2007.

Although cognitive influences have received less attention than biomechanical factors, the present findings suggest that decision-making demands and attentional distractions may substantially alter landing mechanics. This observation is particularly relevant in volleyball, where athletes frequently execute jump-landings under rapidly changing game situations.

### **Preventive Intervention Strategies**

The intervention-based data in the selected studies give a combined, evidence-oriented, and medically relevant summary of volleyball injury prevention training. Zhu et al. (2025), using network meta-analysis with Bayesian modelling of 20 studies (N = 1, 356), revealed an unequivocal intervention effectiveness ranking for lowering landing error scores: dynamic taping had the maximum effect size (MD =, 1.87, 95% CrI:, 3.29 to, 0.46; SUCRA = 79.0%), neuromuscular training came second (MD =, 1.04, 95% CrI:, 2.01 to, 0.10; SUCRA = 53.2%), and feedback training followed (MD =, 0.86, 95% CrI:, 1.54 to, 0.20; SUCRA = 43.0%) (Mandelbaum et al., 2005; Myer et al., 2006; Soligard et al., 2008; Sugimoto et al., 2016; Silvers-Granelli et al., 2017).

Rahimi et al. (2025) found that Pilates training was very effective in enhancing knee functional tests and neuromuscular control of youth female volleyball players which showed the strongest intervention application to volleyball in the whole set of documents. Pilates workouts for 8 weeks have been shown to significantly improve the risk factors for ACL injury including neuromuscular function of the lower limbs during dynamic movements (Hewett et al., 2005; Myer et al., 2005; Paterno et al., 2010). Szeles and Green (2025) studied taping interventions and found that dynamic tape and rigid tape altered postural stability and joint kinematics during the landing phase differently at different levels of landing task complexity, a finding consistent with the greater effectiveness of dynamic taping reported by Zhu et al. (2025) (Petersen et al., 2014; Saragiotto et al., 2014; Nagelli & Hewett, 2017).

Collectively, these findings demonstrate that injury prevention should extend beyond strength development alone. Effective prevention programs should integrate neuromuscular training, movement retraining, landing feedback, and sport-specific conditioning to address multiple injury mechanisms simultaneously.

### **Practical Implications for Volleyball Coaches**

The results of this systematic review taken as a group reveal that biomechanical variables associated with knee injury risk during volleyball jump-landing are not limited to only one or two factors, but rather include several kinematic (DKV, ankle plantarflexion, foot orientation), kinetic (ground reaction forces, torsional loads), neuromuscular (muscle strength asymmetries, fatigue-induced motor degradation) and cognitive-motor interaction aspects (Abbasi et al., 2025; Giesche et al., 2025; Meeuwisse et al., 2007). The presence of many factors aligns well with the modern biopsychosocial model of injury causation, indicating that an injury is the outcome of the combination of biomechanical, physiological, psychological, and environmental risk factors, *inter alia* (Zazulak et al., 2007; Krosshaug et al., 2007; Boden et al., 2000; Agel et al., 2007).

The meta-analysis data that are presented in two of the systematic reviews included in this study (Giesche et al., 2025; Abbasi et al., 2025) represent the strongest quantitative evidence to date supporting certain effect estimates. The major implication of the research showing that fatigue leads to an increase in dynamic knee valgus (DKV) during double-leg vertical jumps ( $p < 0.001$ ) is highlighted due to its connection to volleyball since

this jumping pattern parallels mechanically the landing phase of the jump serve that players perform when they are very tired (Hewett et al., 1996; Ford et al., 2003; Lian et al., 2005; Bisseling et al., 2007).

In a practical sense, the intervention hierarchy proposed by Zhu et al. (2025), with dynamic taping, neuromuscular training, and feedback training as the top three interventions in terms of efficacy, gives a planning tool for continuously depriving volleyball teams of resources (Myer et al., 2006; Mandelbaum et al., 2005; Soligard et al., 2008; Sugimoto et al., 2016). Sports physicians and therapists should think about inviting players to undergo landing biomechanics screening tests which measure DKV, strength parity between the legs, and quality of single-leg landing before the start of the season (Padua et al., 2009; Leppänen et al., 2017; Schilaty et al., 2021; Sigward & Powers, 2006; Distefano et al., 2009; Barber-Westin & Noyes, 2017; Nordin & Dufek, 2017; Chappell & Limpisvasti, 2008; McLean et al., 2005).

For practitioners, preseason screening should prioritize dynamic knee valgus assessment, bilateral strength symmetry, and landing quality evaluation. Coaches are encouraged to incorporate fatigue-resistant landing drills, neuromuscular exercises, and real-game decision-making tasks into training sessions to improve movement quality under competitive conditions.

## Conclusions

Across the ten included studies, dynamic knee valgus emerged as the most frequently reported biomechanical risk factor ( $n = 4$  studies), followed by fatigue-related kinematic alterations ( $n = 3$  studies), cognitive-motor impairments ( $n = 3$  studies), and lower-limb strength asymmetries ( $n = 2$  studies) (Page et al., 2021) and extracting 10 peer-reviewed articles from the Scopus database, offers a unified and volleyball-focused proof base for the biomechanical factors in knee injury risk during jump-landing tasks. Overall, the evidence suggests that knee injury risk during volleyball jump-landing activities is multifactorial and influenced by biomechanical, neuromuscular, fatigue-related, and cognitive factors. Consequently, injury prevention programs should adopt a multidimensional approach rather than targeting isolated risk factors. For the three research questions, the article draws the following main points: dynamic knee valgus, ankle plantarflexion at the moment of initial ground contact, and bilateral strength asymmetries are the most often cited kinematic and kinetic factors of knee injury risk during volleyball-related jumping and landing tasks exhaustion and cognitive demand connected to unplanned actions greatly increase biomechanical injury risk through neuromuscular impairment and changed joint positioning lastly, dynamic taping, neuromuscular training, feedback-based interventions, and Pilates conditioning are the most thoroughly evidence-backed means of changing biomechanical risk factors. Besides the single-database search, the short time span considered, and the lack of volleyball-jump-serve-specific biomechanical studies in the dataset, limitations were noted (Krosshaug et al., 2007; Boden et al., 2000; Lian et al., 2005; Bisseling et al., 2007). As for the jump serve, future endeavors must involve prospective biomechanical analysis as a distinct skill and follow-up injury prediction studies in competitive volleyball groups (Nagelli & Hewett, 2017; Paterno et al., 2010; Leppänen et al., 2017; Zazulak et al., 2007; Saragiotto et al., 2014; Barber-Westin & Noyes, 2017; Nordin & Dufek, 2017; Alentorn-Geli et al., 2009; Hägglund et al., 2005). Although this review adhered to PRISMA 2020 reporting guidelines, the review protocol was not prospectively registered. Future systematic reviews should consider protocol registration and multi-database searches to further strengthen methodological rigor and evidence comprehensiveness.

## References

- Abbasi, S., Rahmatzadeh, D., Minoonejad, H., & Mousavi, S. H. (2025). The effect of fatigue on dynamic knee valgus during landing tasks: A systematic review and meta-analysis. *BMC Sports Science, Medicine and Rehabilitation*, 17(1), Article 166. <https://doi.org/10.1186/s13102-025-01205-3>
- Acar, N. E., Umutlu, G., Gencer, Y. G., Güven, E., & Taşman, G. A. (2025). Strength asymmetries and their impact on landing dynamics during countermovement jump and drop jump tests in professional female basketball players. *BMC Sports Science, Medicine and Rehabilitation*. <https://doi.org/10.1186/s13102-025-01352-7>
- Agel, J., Evans, T. A., Dick, R., Putukian, M., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *Journal of Athletic Training*, 42(2), 270–277. <https://doi.org/10.4085/1062-6050-42.2.270>
- Alentorn-Geli, E., Myer, G. D., Silvers, H. J., Samitier, G., Romero, D., Lázaro-Haro, C., & Cugat, R. (2009). Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee Surgery, Sports Traumatology, Arthroscopy*, 17(7), 705–729. <https://doi.org/10.1007/s00167-009-0813-1>

- Barber-Westin, S. D., & Noyes, F. R. (2017). Training effects on knee biomechanics during cutting and landing in female athletes: A systematic review. *Sports Health*, 9(4), 390–400. <https://doi.org/10.1177/1941738117700189>
- Bere, T., Flørenes, T. W., Krosshaug, T., Nordsletten, L., & Bahr, R. (2011). Events leading to anterior cruciate ligament injury in World Cup Alpine Skiing: A systematic video analysis of 20 cases. *British Journal of Sports Medicine*, 45(16), 1294–1302. <https://doi.org/10.1136/bjsports-2011-090517>
- Bisseling, R. W., Hof, A. L., Bredeweg, S. W., Zwerver, J., & Mulder, T. (2007). Relationship between landing strategy and patellar tendinopathy in volleyball. *British Journal of Sports Medicine*, 41(7), e8. <https://doi.org/10.1136/bjism.2006.032565>
- Boden, B. P., Dean, G. S., Feagin, J. A., & Garrett, W. E. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics*, 23(6), 573–578. <https://doi.org/10.3928/0147-7447-20000601-15>
- Brunetti, C., Poletti, N., Zago, M., Bertozzi, F., & Sforza, C. (2025). External focus of attention influences the performance–injury risk conflict during drop jumps. *Sport Sciences for Health*. <https://doi.org/10.1007/s11332-025-01528-1>
- Chappell, J. D., & Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *American Journal of Sports Medicine*, 36(6), 1081–1086. <https://doi.org/10.1177/0363546508314425>
- Decker, M. J., Torry, M. R., Wyland, D. J., Sterett, W. I., & Steadman, J. R. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics*, 18(7), 662–669. [https://doi.org/10.1016/S0268-0033\(03\)00090-8](https://doi.org/10.1016/S0268-0033(03)00090-8)
- Dempsey, A. R., Lloyd, D. G., Elliott, B. C., Steele, J. R., & Munro, B. J. (2009). Changing sidestep cutting technique reduces knee valgus loading. *American Journal of Sports Medicine*, 37(11), 2194–2200. <https://doi.org/10.1177/0363546509337167>
- Distefano, L. J., Blackburn, J. T., Marshall, S. W., & Padua, D. A. (2009). Gluteal muscle activation during common therapeutic exercises. *Journal of Orthopaedic and Sports Physical Therapy*, 39(7), 532–540. <https://doi.org/10.2519/jospt.2009.2796>
- Faigenbaum, A. D., & Myer, G. D. (2012). Exercise deficit disorder in youth: Play now or pay later. *Current Sports Medicine Reports*, 11(4), 196–200. <https://doi.org/10.1249/JSR.0b013e31825da961>
- Ford, K. R., Myer, G. D., & Hewett, T. E. (2003). Valgus knee motion during landing in high school female and male basketball players. *Medicine and Science in Sports and Exercise*, 35(10), 1745–1750. <https://doi.org/10.1249/01.MSS.0000089346.85744.D9>
- Giesche, F., Stief, F., Groneberg, D. A., & Wilke, J. (2025). Effects of sport specific unplanned movements on ankle kinetics and kinematics in healthy athletes from systematic review with meta-analysis. *Scientific Reports*, 15(1), Article 32476. <https://doi.org/10.1038/s41598-025-18746-9>
- Häggglund, M., Waldén, M., Bahr, R., & Ekstrand, J. (2005). Methods for epidemiological study of injuries to professional football players: Developing the UEFA model. *British Journal of Sports Medicine*, 39(6), 340–346. <https://doi.org/10.1136/bjism.2005.018267>
- Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. *American Journal of Sports Medicine*, 33(4), 492–501. <https://doi.org/10.1177/0363546504269591>
- Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. *American Journal of Sports Medicine*, 24(6), 765–773. <https://doi.org/10.1177/036354659602400611>
- Hewett, T. E., Torg, J. S., & Boden, B. P. (2009). Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: Lateral trunk and knee abduction motion are combined components of the injury mechanism. *British Journal of Sports Medicine*, 43(6), 417–422. <https://doi.org/10.1136/bjism.2009.059162>
- Hosseini, S. H., Gheitani, M., & Hosseini, S. M. (2025). Effect of lower-limb fatigue on kinematic variables during an unanticipated block among adolescent female volleyball players. *BMC Sports Science, Medicine and Rehabilitation*. <https://doi.org/10.1186/s13102-025-01331-y>
- Krosshaug, T., Slauterbeck, J. R., Engebretsen, L., & Bahr, R. (2007). Biomechanical analysis of anterior cruciate ligament injury mechanisms: Three-dimensional motion reconstruction from video sequences. *Scandinavian Journal of Medicine and Science in Sports*, 17(5), 508–519. <https://doi.org/10.1111/j.1600-0838.2006.00558.x>
- Leppänen, M., Pasanen, K., Kujala, U. M., Vasankari, T., Kannus, P., Äyrämö, S., & Parkkari, J. (2017). Stiff landings are associated with increased ACL injury risk in young female basketball and floorball players. *American Journal of Sports Medicine*, 45(2), 386–393. <https://doi.org/10.1177/0363546516665810>

- Lian, Ø. B., Engebretsen, L., & Bahr, R. (2005). Prevalence of jumper's knee among elite athletes from different sports: A cross-sectional study. *American Journal of Sports Medicine*, 33(4), 561–567. <https://doi.org/10.1177/0363546504268280>
- Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., & Garrett, W. (2005). Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: Two-year follow-up. *American Journal of Sports Medicine*, 33(7), 1003–1010. <https://doi.org/10.1177/0363546504272261>
- McLean, S. G., Huang, X., & van den Bogert, A. J. (2005). Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: Implications for ACL injury. *Clinical Biomechanics*, 20(8), 863–870. <https://doi.org/10.1016/j.clinbiomech.2005.04.001>
- Meeuwisse, W. H., Tyreman, H., Hagel, B., & Emery, C. (2007). A dynamic model of etiology in sport injury: The recursive nature of risk and causation. *Clinical Journal of Sport Medicine*, 17(3), 215–219. <https://doi.org/10.1097/JSM.0b013e3180592a48>
- Memain, G., Carling, C., Bouvet, J., Fourcade, P., Maille, P., & Yiou, E. (2025). Effect of a visual dual-task on single-leg countermovement-jump in male professional soccer players with lower-limb injuries: A cross-sectional observational study. *Sports*, 13(12), Article 419. <https://doi.org/10.3390/sports13120419>
- Myer, G. D., Ford, K. R., Brent, J. L., & Hewett, T. E. (2006). The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *Journal of Strength and Conditioning Research*, 20(2), 345–353. <https://doi.org/10.1519/R-17955.1>
- Myer, G. D., Ford, K. R., Palumbo, J. P., & Hewett, T. E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research*, 19(1), 51–60. <https://doi.org/10.1519/13643.1>
- Nagelli, C. V., & Hewett, T. E. (2017). Should return to sport be delayed until two years after anterior cruciate ligament reconstruction? Biological and functional considerations. *Sports Medicine*, 47(2), 221–232. <https://doi.org/10.1007/s40279-016-0584-z>
- Nordin, A. D., & Dufek, J. S. (2017). Lower extremity variability changes with drop-landing height manipulations. *Research in Sports Medicine*, 25(1), 56–72. <https://doi.org/10.1080/15438627.2016.1258638>
- Padua, D. A., Marshall, S. W., Boling, M. C., Thigpen, C. A., Garrett, W. E., & Beutler, A. I. (2009). The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *American Journal of Sports Medicine*, 37(10), 1996–2002. <https://doi.org/10.1177/0363546509343200>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
- Paterno, M. V., Schmitt, L. C., Ford, K. R., Rauh, M. J., Myer, G. D., Huang, B., & Hewett, T. E. (2010). Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *American Journal of Sports Medicine*, 38(10), 1968–1978. <https://doi.org/10.1177/0363546510376053>
- Petersen, W., Ellermann, A., Gösele-Koppenburg, A., Best, R., Rembitzki, I. V., Brüggemann, G. P., & Liebau, C. (2014). Patellofemoral pain syndrome. *Knee Surgery, Sports Traumatology, Arthroscopy*, 22(10), 2264–2274. <https://doi.org/10.1007/s00167-013-2759-6>
- Quatman, C. E., & Hewett, T. E. (2009). The anterior cruciate ligament injury controversy: Is valgus collapse a sex-specific mechanism? *British Journal of Sports Medicine*, 43(5), 328–335. <https://doi.org/10.1136/bjism.2009.059139>
- Rahimi, S., Norasteh, A. A., & Mottaghitalab, M. (2025). The effect of Pilates training on knee functional tests in youth female volleyball player. *BMC Sports Science, Medicine and Rehabilitation*. <https://doi.org/10.1186/s13102-025-01258-4>
- Saragiotto, B. T., Di Pierro, C., & Lopes, A. D. (2014). Risk factors and injury prevention in elite athletes: A descriptive study from the medical staff perspective. *Brazilian Journal of Physical Therapy*, 18(2), 137–143. <https://doi.org/10.1590/S1413-35552012005000147>
- Schilaty, N. D., Bates, N. A., Nagelli, C. V., Krych, A. J., & Hewett, T. E. (2021). Sex-based differences in knee mechanics with muscle co-contraction in a simulated jump landing. *American Journal of Sports Medicine*, 49(5), 1272–1279. <https://doi.org/10.1177/0363546521994113>
- Sell, T. C., Ferris, C. M., Abt, J. P., Tsai, Y. S., Myers, J. B., Fu, F. H., & Lephart, S. M. (2006). The effect of direction and reaction time condition on female soccer athletes' lower-extremity kinematics during jump landing. *American Journal of Sports Medicine*, 34(11), 1872–1878. <https://doi.org/10.1177/0363546506287538>

- Sigward, S. M., & Powers, C. M. (2006). The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. *Clinical Biomechanics*, 21(1), 41–48. <https://doi.org/10.1016/j.clinbiomech.2005.08.001>
- Silvers-Granelli, H. J., Bizzini, M., Arundale, A., Mandelbaum, B. R., & Snyder-Mackler, L. (2017). Does the FIFA 11+ injury prevention program reduce the incidence of ACL injury in male soccer players? *Clinical Orthopaedics and Related Research*, 475(10), 2447–2455. <https://doi.org/10.1007/s11999-017-5342-5>
- Soligard, T., Myklebust, G., Steffen, K., Holme, I., Silvers, H., Bizzini, M., & Andersen, T. E. (2008). Comprehensive warm-up programme to prevent injuries in young female footballers: Cluster randomised controlled trial. *BMJ*, 337, a2469. <https://doi.org/10.1136/bmj.a2469>
- Sugimoto, D., Myer, G. D., Barber Foss, K. D., Pepin, M. J., Micheli, L. J., & Hewett, T. E. (2016). Critical components of neuromuscular training to reduce ACL injury risk in female athletes: Meta-regression analysis. *British Journal of Sports Medicine*, 50(20), 1259–1266. <https://doi.org/10.1136/bjsports-2015-095596>
- Szeles, K. T., & Green, A. (2025). The impact of landing complexity and knee taping on stability: A continuous kinetics and kinematics analysis. *Sports*, 13(12), Article 431. <https://doi.org/10.3390/sports13120431>
- Wen, J., Xu, D., Gao, X., Qu, X., Zhang, Z., Zhou, H., Radak, Z., Gao, Z., & Gu, Y. (2025). Effects of foot rotation on ankle control and injury risk during badminton lunge landings. *BMC Sports Science, Medicine and Rehabilitation*. <https://doi.org/10.1186/s13102-025-01393-y>
- Wilkerson, G. B., Colston, M. A., Short, N. I., Neal, K. L., Deskin, P. E., & Gallier, E. A. (2004). Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *Journal of Athletic Training*, 39(1), 17–23. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC385269/> (PMC: PMC385269)
- Zazulak, B. T., Hewett, T. E., Reeves, N. P., Goldberg, B., & Cholewicki, J. (2007). Deficits in neuromuscular control of the trunk predict knee injury risk: A prospective biomechanical-epidemiological study. *American Journal of Sports Medicine*, 35(7), 1123–1130. <https://doi.org/10.1177/0363546507301585>
- Zhu, J., Yang, X., Li, T., Xing, W., Zhang, Z., Chen, Z., & Zhu, W. (2025). Preventive interventions on ACL injury reduction based on the landing error scoring system evaluation tool: A systematic review and network meta-analysis. *BMC Musculoskeletal Disorders*, 26(1), Article 1061. <https://doi.org/10.1186/s12891-025-09290-8>