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Kinematic assessment of the dominant and non-dominant legs at initial contact: Implications for lower limb injury risk during spike and block landings in professional volleyball players

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ABSTRACT

Purpose of the study: Jump landings after spike and block jumps in volleyball are among the primary contributors to lower limb injuries, particularly involving the anterior cruciate ligament (ACL). Understanding kinematic differences between these two common landing scenarios can enhance injury prevention strategies. The purpose of this study is to investigate the differences in lower limb landing kinematics between spike and block jumps, as well as between the dominant and non-dominant legs, in professional volleyball players.

Methods: Twenty-seven elite male volleyball players performed spike and block jumps over a standard net (2.43 m). Three-dimensional lower limb joint angles at initial contact (IC) were recorded using a motion capture system (200 Hz) synchronized with force plates (1000 Hz). Jump height was also measured. Paired t-tests compared joint angles between spike and block landings and between dominant and non-dominant legs ($p \leq 0.05$).

Results: Spike jumps resulted in significantly higher jump heights compared to block jumps ($p = 0.002$). At initial contact, spike landings demonstrated significantly less knee and hip flexion, greater ankle plantarflexion, and a higher degree of non-dominant knee valgus compared to block landings. No significant inter-limb differences were found during block landings; however, spike landings showed significant asymmetries, with the non-dominant leg exhibiting riskier knee alignment and reduced flexion compared to the dominant leg.

Conclusion: Spike landings involve biomechanically riskier patterns than block landings, particularly in the non-dominant leg, potentially elevating ACL injury risk. Coaches should emphasize balanced lower-limb strength, enhanced knee and hip flexion during landing, and targeted neuromuscular training to mitigate these landing asymmetries.

Keywords: Volleyball, Landing biomechanics, Dominant vs non-dominant leg, ACL injury risk, Jump landing kinematics

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Sports Medicine: research and practice

Кинематическая оценка доминирующей и недоминирующей ноги в момент первого контакта: последствия для риска травм нижних конечностей при приземлениях после атакующих и блокирующих прыжков у профессиональных волейболистов

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АННОТАЦИЯ

Цель исследования: Приземления после атакующих (спайковых) и блокирующих прыжков в волейболе являются одной из основных причин травм нижних конечностей, особенно передней крестообразной связки (ПКС). Понимание различий в кинематике приземлений между этими двумя типами прыжков может способствовать улучшению стратегий профилактики травм. Цель данного исследования — изучить различия в кинематике приземлений нижних конечностей между прыжками при атаке и блоке, а также между доминирующей и недоминирующей ногой у профессиональных волейболистов.

Методы: Двадцать семь элитных волейболистов-мужчин выполняли атакующие и блокирующие прыжки через стандартную сетку (2,43 м). Трёхмерные углы суставов нижних конечностей в момент первого контакта с поверхностью фиксировались с помощью системы захвата движения (200 Гц), синхронизированной с силовыми платформами (1000 Гц). Также измерялась высота прыжка. Парные *t*-критерии Стьюдента использовались для сравнения углов суставов между типами прыжков и между доминирующей и недоминирующей ногой ($p \leq 0{,}05$).

Результаты: Атакующие прыжки сопровождались значительно большей высотой прыжка по сравнению с блокирующими ($p = 0{,}002$). В момент первого контакта приземления после спайка характеризовались значительно меньшим сгибанием в колене и тазобедренном суставе, большей подошвенной флексией голеностопного сустава и выраженным вальгусом колена недоминирующей ноги по сравнению с блоком. Значимых различий между ногами при блокирующих приземлениях не наблюдалось, однако при приземлениях после спайка выявлялись выраженные асимметрии: недоминирующая нога демонстрировала более опасное выравнивание коленного сустава и меньшее сгибание по сравнению с доминирующей ногой.

Заключение: Приземления после атакующих прыжков сопровождаются более рискованной биомеханической схемой, особенно для недоминирующей ноги, что потенциально увеличивает риск повреждения ПКС. Тренерам рекомендуется уделять внимание развитию симметричной силы нижних конечностей, улучшению сгибания в коленном и тазобедренном суставах при приземлении, а также проведению целенаправленных нейромышечных тренировок для уменьшения асимметрии при приземлениях.

Ключевые слова: волейбол, биомеханика приземления, доминирующая и недоминирующая нога, риск травмы ПКС, кинематика приземлений при прыжках

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1. Introduction

Vertical jumps and landings are fundamental to volleyball performance, with players averaging around 83 jumps per training session and 71 per match [1, 2]. These frequent jumps, especially the explosive spike (attack) and block at the net, impose substantial loads on the lower extremities. Epidemiological reports indicate that a large proportion of volleyball injuries occur during the landing phase of spikes and blocks [3]. Notably, Garcia et al. (2022), citing Takahashi et al. (2019), reported that up to 75 % of anterior cruciate ligament (ACL) injuries in volleyball are associated with jump-landing tasks, mostly in non-contact situations [2, 4]. ACL injuries are among the most severe knee injuries for volleyball athletes, often requiring surgery and long rehabilitation [5]. Understanding the biomechanics of landings is therefore critical for injury prevention and performance optimization.

Successful landings require effective dissipation of ground reaction forces, maintenance of balance, and joint stability. Insufficient lower-limb flexion (“stiff” landings) and poor neuromuscular control can increase impact forces and injury risk [6-8]. Prior research has identified key kinematic risk factors in jump landings. In particular, dynamic knee valgus, a multi-planar collapse involving excessive hip internal rotation and adduction, knee abduction (valgus), and ankle eversion, is strongly linked to ACL injury risk [9]. Biomechanical analyses show that greater knee valgus angles and moments during landing correspond with higher ACL loading [10]. Conversely, reduced hip and knee flexion angles and limited ankle dorsiflexion range (i.e. landing more flat-footed) are also associated with elevated ACL injury risk, due to a "braking" effect that increases strain on passive structures [10]. For example, landing with less hip flexion range of motion was prospectively associated with higher ACL injury rates in young athletes [7, 11]. At the ankle, a more plantarflexed (toe-first) foot position at initial contact has been suggested to protect the knee by reducing valgus loading [12]. Thus, the optimal landing technique likely involves a coordinated strategy: adequate hip-knee flexion to absorb shock, while also utilizing ankle plantarflexion to modulate impact distribution.

In volleyball, players must often perform landings under varying conditions – a spike jump usually involves forward momentum and an asymmetrical one-foot-dominant take-off, whereas a block jump is typically straight upward with a more symmetrical two-foot take-off. These differences in approach and task may lead to distinct landing mechanics and potentially different injury risks. Additionally, athletes have a preferred dominant leg (often defined as the leg they would choose for a single-leg jump or that they feel more stable on) and a non-dominant leg. Imbalances between the legs can be problematic: side-to-side asymmetries in strength or technique might predispose the weaker or less coordinated limb to injury. Some studies have found limb dominance effects on landing biomechanics. For instance, during single-leg drop landings, the dominant limb can exhibit different kinematics or coordination patterns compared to the non-dominant limb [13, 14]. In multi-directional volleyball landings, limbs may use different joint moment strategies to handle similar loads [15]. However, the literature is not entirely consistent—certain analyses reported no significant kinematic differences between dominant and non-dominant limbs in jump landings, whereas others noted that the dominant leg could be at higher risk due to less optimal control in some scenarios [14]. These discrepancies highlight a knowledge gap regarding how limb dominance interacts with specific volleyball tasks (spike vs. block landings).

To date, there has been limited research focusing on in-game volleyball jumps (as opposed to standardized drop jumps) comparing the landing mechanics of the dominant and non-dominant legs. A more ecologically valid understanding of spike and block landings could reveal important asymmetries or technique differences that contribute to common injuries like ACL tears or ankle sprains. Therefore, the purpose of this study was to examine the three-dimensional kinematics at initial contact of the dominant and non-dominant lower limbs during spike and block landings in professional volleyball players. We aimed to determine how each leg's joint angles (hip, knee, ankle in sagittal, frontal, transverse planes) differ between the two jump types, and to interpret whether those differences indicate altered injury risk profiles. We hypothesized that spike landings, due to their forward momentum and typically one-foot lead, would involve greater hip and knee flexion (to absorb impact) but potentially more asymmetry between legs, whereas block landings might show more symmetric but stiffer (less flexed) lower-limb positions. We also expected the non-dominant leg to possibly exhibit riskier kinematics (such as more valgus or rotation) given it may have less neuromuscular control compared to the dominant leg. The findings of this study can help identify biomechanical factors associated with each landing technique and foot, informing targeted training and injury prevention strategies for volleyball players.

2. Methods

2.1. Participants

Twenty-seven elite male volleyball players from Iran's top professional league volunteered for this study. All were actively training and competing ≥ 5 days per week. Mean (± SD) age, height, weight, and BMI were 25.1 ± 2.1 years, 1.83 ±0.07 m, 75.9 ± 9.1 kg, and 22.6 ± 2.7 kg/m², respectively. Sample size was determined using G*Power ($\alpha = 0.05$, power = 0.80) to ensure sufficient sensitivity for within-subject comparisons. Inclusion criteria required no lower/upper limb injuries in the past year. Athletes with a history of ACL injury or lower-limb surgery were excluded. All reported right-leg dominance. Informed consent was obtained from all participants. The study was approved by the institutional ethics committee and followed the Declaration of Helsinki.

2.2. Instrumentation and procedure

All testing was performed in a biomechanics laboratory with a regulation volleyball net set at men's official competition height (2.43 m). A three-dimensional motion capture system (Vicon Motion Systems, Oxford, UK) with six T20 cameras (200 Hz) was used to record kinematics of the lower extremities. Prior to data collection, a technician placed 14 reflective markers (14 mm diameter) on anatomical landmarks of each subject's lower body according to the Plug-In Gait Marker Set model (Vicon Peak, Oxford, UK) [16]. This model allowed calculation of segment and joint angles for the hip, knee, and ankle in three planes. Kinetic data were simultaneously captured using two Kistler force plates (9281CA, Kistler Instrumente AG, Switzerland) embedded in the floor (1000 Hz sampling). The force plates were positioned so that each foot would contact a separate plate upon landing, enabling detection of initial ground contact (defined as the moment vertical force first exceeded 10 *N*) [17]. Kinematic and force data were time-synchronized through the Nexus 1.8.5 software (Vicon Motion Systems, Oxford, UK).

Before the jump trials, each athlete completed a standardized 15-minute warm-up of dynamic exercises for the upper and lower body, consistent with typical volleyball pre-match warm-ups (light jogging, dynamic stretches, jumping drills). To familiarize participants with the lab setup, they performed a few practice jumps (both spike and block movements). Jump height capabilities were then assessed to standardize effort: each player performed two maximal spike jumps (with a three-step approach) and two maximal block jumps, and the highest reach was recorded for each. For the spike jump, an approach run (typically 2–3 steps) was used and

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the player jumped as if spiking a ball overhead. For the block jump, players started near the net with both feet and jumped straight up with arms simulating a block. We set a target such that during actual test trials, players aimed to jump ~90 % of their maximal jump height for consistency and safety. Each participant performed six randomized trials of spike and block landings (Figs. 1 and 2). For spike trials, players mimicked an attack after an approach and landed bilaterally on force plates following a simulated set. For block trials, they reacted to a simulated set with a vertical jump and landed with arms raised. All landings were performed naturally with instructions to prepare for immediate movement. A 1-minute rest was provided between jumps. The three best-quality trials per condition (clean foot contact and marker visibility) were selected.

Marker trajectories were filtered using a 4th-order Butterworth low-pass filter (6 Hz) [18]. Joint angles of the hip, knee, and ankle were calculated using the Plug-In Gait model at the instant of initial contact (IC), defined as the first frame with vertical GRF >10 *N*. Angles were assessed in sagittal (flexion/extension), frontal (adduction/abduction), and transverse (internal/external rotation) planes. Positive values represented flexion, adduction, and external rotation. Jump height was calculated as the vertical displacement of the ASIS marker between standing and jump peak. Each subject's three trials were averaged for analysis.

Fig. 1. Execution technique of the spike landing in professional volleyball players
Рис. 1. Техника выполнения приземления после нападающего удара у профессиональных волейболистов

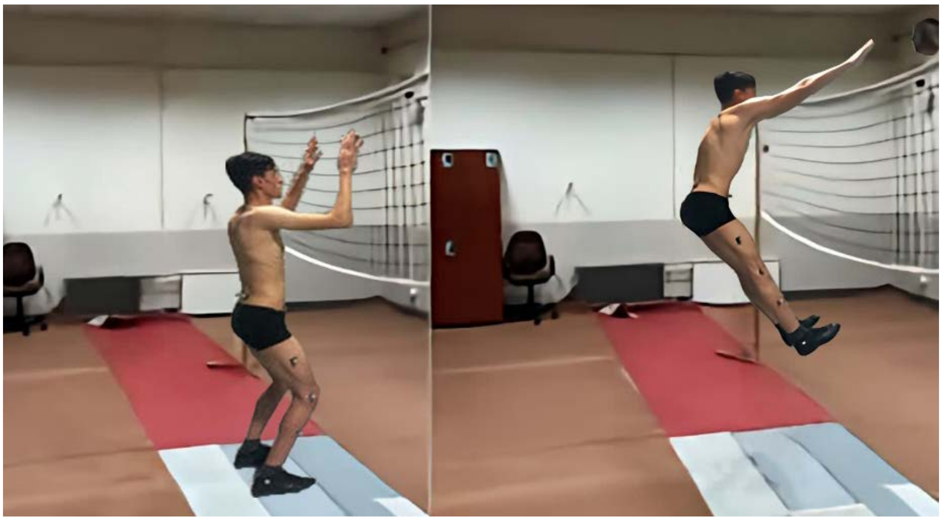

Fig. 2. Execution technique of the block landing in professional volleyball players
Рис. 2. Техника выполнения приземления после блокирования у профессиональных волейболистов

2.3. Statistical analysis

All statistical analyses were conducted in SPSS v26.0 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test confirmed that kinematic variables were normally distributed. Descriptive statistics (mean ± standard deviation) were computed for all measures. A paired (dependent) samples *t*-test was used to compare spike vs. block landing outcomes. Specifically, for each leg (dominant and non-dominant), spike and block joint angle values were compared to identify task-related differences. This approach tested within-subject differences in landing kinematics for the same leg under two conditions. In addition, effect sizes (Cohen's *d*) were calculated for each comparison to assess the magnitude of differences, interpreted as small ($d = 0.20$), moderate ($d = 0.50$), and large ($d \geq 0.80$). Statistical significance was set at $p \leq 0.05$ for all comparisons.

3. Results

The average jump height during spike and block tasks in professional volleyball players was 57.17 ± 9.05 cm and 51.62 ± 6.69 cm, respectively, showing a statistically significant difference ($p = 0.002$), with athletes demonstrating approximately 10 % higher jump heights during spike jumps compared to block jumps.

The results of comparisons between tasks are presented in Table 1. Block landings were characterized by significantly greater hip flexion angles compared to spike landings for both non-dominant ($p = 0.001$) and dominant ($p = 0.001$) legs, demonstrating approximately 50 % greater hip flexion. Additionally, block landings showed significantly greater knee flexion angles for both non-dominant ($p = 0.001$) and dominant ($p = 0.001$) legs, nearly doubling the knee flexion angles compared to spike landings. Conversely, spike landings exhibited significantly increased ankle plantarflexion for both non-dominant ($p = 0.001$) and dominant ($p = 0.001$) legs, with angles approximately 91 % higher compared to block landings, reflecting a more pointed toe position during initial contact.

In the frontal plane, hip abduction angles were significantly greater in block landings compared to spike landings for both non-dominant ($p = 0.001$) and dominant ($p = 0.001$) legs, indicating a wider stance during block landings. Knee

Table 1

Comparison of lower limb joint angles in three planes for the dominant and non-dominant legs at the moment of landing after a spike and block in professional volleyball players (angles in degrees [°], mean ± SD)

Таблица 1

Сравнение углов суставов нижних конечностей в трёх плоскостях для доминирующей и недоминирующей ноги в момент приземления после атакующего и блокирующего прыжков у профессиональных волейболистов (углы в градусах [°], среднее ± стандартное отклонение)

Variables	Foot	Assignment		Sig. (*t*)	Cohen's *d*
		Block	Spike		
Hip sagittal angle at IC	Non-dominant leg	36.70 ± 9.23	24.02 ± 3.76	**0.001(6.954)**	**1.34**
	Dominant leg	35.80 ± 9.56	23.74 ± 4.17	**0.001(6.681)**	**1.28**
Hip frontal angle at IC	Non-dominant leg	-11.58 ± 3.92	-3.20 ± 1.49	**0.001(-5.398)**	**1.04**
	Dominant leg	-9.94 ± 4.56	-3.95 ± 2.76	**0.001(-5.949)**	**1.14**
Hip horizontal angle at IC	Non-dominant leg	3.46 ± 1.42	11.01 ± 3.70	0.075(-1.856)	0.36
	Dominant leg	3.60 ± 1.81	17.04 ± 3.90	0.110(-1.652)	**0.32**
Knee sagittal angle at IC	Non-dominant leg	31.64 ± 4.40	14.41 ± 3.33	**0.001(6.867)**	**1.32**
	Dominant leg	30.18 ± 4.07	16.69 ± 3.82	**0.001(7.338)**	**1.41**
Knee frontal angle at IC	Non-dominant leg	3.36 ± 1.89	7.55 ± 2.72	**0.049(-2.061)**	0.40
	Dominant leg	3.06 ± 1.34	4.86 ± 2.23	0.416(-0.826)	0.16
Knee horizontal angle at IC	Non-dominant leg	3.13 ± 1.15	-2.41 ± 0.67	**0.008(2.879)**	**0.55**
	Dominant leg	3.08 ± 1.92	1.02 ± 0.16	0.437(0.789)	0.15
Ankle sagittal angle at IC	Non-dominant leg	-12.29 ± 4.36	-23.38 ± 7.33	**0.001(5.613)**	**1.08**
	Dominant leg	-12.30 ± 5.29	-23.15 ± 5.63	**0.001(7.424)**	**1.43**
Ankle frontal angle at IC	Non-dominant leg	0.10 ± 0.03	0.35 ± 0.03	0.300(-1.057)	0.20
	Dominant leg	0.42 ± 0.06	0.56 ± 0.05	0.589(-0.546)	0.10
Ankle horizontal angle at IC	Non-dominant leg	-4.19 ± 1.47	-7.27 ± 2.88	0.365(0.922)	0.18
	Dominant leg	-3.72 ± 1.74	-7.33 ± 2.10	0.405(0.846)	0.16

Note: (+) indicates flexion and (-) indicates extension in the sagittal plane, (+) indicates adduction and (-) indicates abduction in the frontal plane, and (+) indicates external rotation and (-) indicates internal rotation in the horizontal plane.

Примечание: (+) обозначает сгибание и (-) обозначает разгибание в сагиттальной плоскости, (+) обозначает аддукцию и (-) обозначает абдукцию во фронтальной плоскости, (+) обозначает наружную ротацию и (-) обозначает внутреннюю ротацию в горизонтальной плоскости.

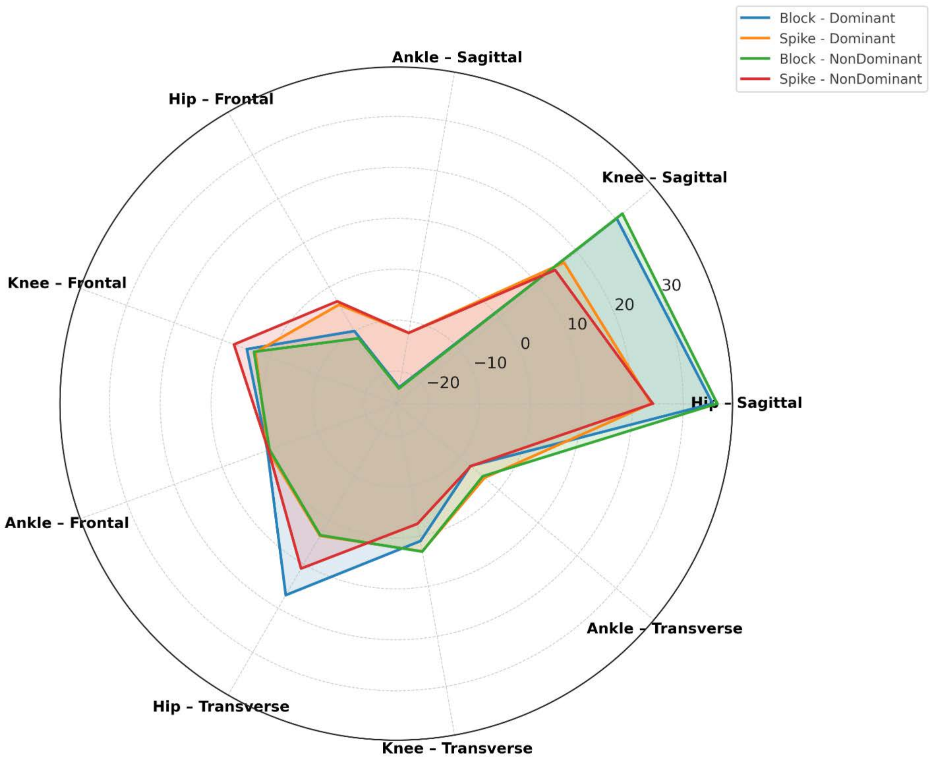

Fig. 3. Radar chart of lower limb joint angles (°) at initial contact across spike and block landings for dominant and non-dominant legs
Рис. 3. Диаграмма в виде радиального графика, отображающая углы суставов нижних конечностей в момент первого контакта при приземлении после атакующего и блокирующего прыжков для доминирующей и недоминирующей ноги

frontal angle showed a significant difference only in the non-dominant leg (p = 0.049), being greater during spike landings. In the horizontal plane, a significant difference was found only for the non-dominant knee joint (p = 0.008), indicating greater external rotation during block landings compared to spike landings. No other significant transverse plane differences were observed for hip or ankle joints between tasks. Radar chart visualization (Fig. 3) effectively illustrates

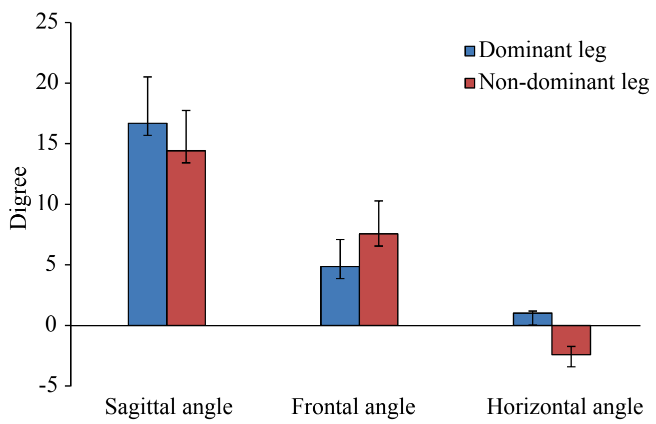

Fig. 4. Comparison of knee joint kinematics (sagittal, frontal, and transverse planes) between dominant and non-dominant legs during spike landings in professional volleyball players
Рис. 4. Сравнение кинематики коленного сустава (сагиттальная, фронтальная и горизонтальная плоскости) между доминирующей и недоминирующей ногой при приземлении после атакующего прыжка у профессиональных волейболистов

these overall kinematic differences between spike and block landings, highlighting complementary sagittal adjustments (greater hip and knee flexion in blocks, greater ankle plantarflexion in spikes) and the subtle frontal and transverse plane differences in joint alignment. Effect size analysis (Cohen's d) indicated large effects for hip sagittal angles (d = 1.34 and 1.28), knee sagittal angles (d = 1.32 and 1.41), and ankle sagittal angles (d = 1.08 and 1.43) between spike and block landings for both non-dominant and dominant legs. Moderate effects were observed for hip frontal angles, while other comparisons showed small or negligible effects.

The comparison between dominant and non-dominant legs within each task revealed additional meaningful insights. While no significant differences were detected between legs during block landings across any joint or plane, spike landings exhibited significant bilateral asymmetries specifically at the knee joint. The dominant leg showed significantly greater knee flexion in the sagittal plane (p = 0.028), more knee adduction in the frontal plane (p = 0.006), and greater external rotation in the transverse plane (p = 0.021) compared to the non-dominant leg in spike. These significant inter-leg differences during spike landings are visually summarized in the bar chart presented in Fig. 4.

4. Discussion

The present study compared the landing biomechanics of spike jumps and block jumps, revealing distinct kinematic strategies and leg asymmetries between these two volleyball-related tasks. As expected, the dynamic spike jump produced a ~10 % greater jump height than the block jump, consistent with the extra approach momentum and countermovement involved. However, this higher jump height was accompanied by markedly different landing mechanics.

Block jump landings were characterized by significantly deeper hip and knee flexion (approximately 50 % and 100 % greater, respectively) in both limbs, whereas spike jump landings were notably stiffer, with much less flexion at the hip and knee. Spike landings also featured about 91 % more ankle plantarflexion at contact, indicating a more toe-first landing [19]. From a biomechanical perspective, greater knee and hip flexion during landing, allows effective energy absorption through increased eccentric muscle activity, reducing peak impact forces transmitted through the lower limbs [6, 20]. Previous literature suggests that greater knee and hip flexion during landing is associated with reduced ACL loading and may potentially contribute to lower injury risk, although these studies did not directly compare injured and non-injured athletes [13, 21]. Conversely, the relatively stiff landing posture characteristic of spike jumps, involving less knee and hip flexion, may increase lower limb joint stress and potential injury risk, particularly for ACL and knee joint structures [22, 23]. These findings align with previous research highlighting limited knee flexion as a significant injury risk factor in dynamic landing tasks [24]. Block landings, done very close to the net with mostly vertical flight, use a softer, more controlled strategy with greater hip/knee flexion. In contrast, spike landings follow an approach with forward momentum and longer take-off, yielding a relatively stiffer, less-flexed posture; match data also show attack jumps are typically higher than blocks, increasing deceleration demands [2, 25, 26]. Deeper hip/knee flexion increases eccentric energy absorption and attenuates impact, whereas limited knee flexion is linked to greater frontal-plane knee loads and higher ACL loading/strain [27]. Therefore, coaching cues that preserve or increase hip/knee flexion in spike landings—and that manage approach speed—are biomechanically justified [28].

In the frontal plane, block and spike landings revealed distinct strategies for maintaining stability. Block landings showed greater hip abduction, indicating a wider stance that may enhance lateral stability and promote more neutral knee alignment [29]. In contrast, spike landings involved reduced hip abduction and increased knee valgus, particularly in the non-dominant leg. This medial knee displacement, combined with decreased external rotation, creates a risky biomechanical profile. Dynamic valgus coupled with internal tibial rotation is known to elevate ACL strain [13, 30]. These findings suggest that spike landings, especially on the non-dominant side, may pose greater risk, while block landings offer a more protective alignment for the knee.

The presence or absence of inter-limb asymmetry in these tasks further underscores how task demands shape biomechanics. In block jump landings, we found no significant differences between the dominant and non-dominant legs in any plane, indicating a symmetric contribution of both limbs. This symmetry may be expected in block jumps, a mostly vertical, two-foot landing task, and aligns with studies reporting that healthy and uninjured athletes generally show nearly symmetric kinetics and kinematics during controlled double-leg landings, with only small asymmetries at the hip and ankle in the frontal and transverse planes [22, 31].

In contrast, spike jump landings elicited pronounced asymmetrical behavior between the legs. The dominant limb landed with greater knee flexion and a more externally rotated, varus (adducted) knee alignment, while the non-dominant limb exhibited a more extended knee, greater valgus collapse, and more internal rotation. Biomechanically, this suggests the athlete relied more on the dominant leg to eccentrically absorb the landing (hence bending it more), whereas the non-dominant leg, which often serves as the lead foot in a spike jump landing, may not have flexed as much and instead collapsed medially. This asymmetry is consistent with the concept of leg dominance influencing landing strategy. Volleyball spike approaches are typically executed such that a right-handed hitter's final step is with the left (non-dominant) foot forward, leading to a landing that loads the left leg more heavily [13]. As a result, the non-dominant limb often bears greater landing forces due to a unilateral loading bias. Our findings are consistent with previous reports on single-leg landings and cutting maneuvers, where the non-dominant limb showed poorer postural stability, less optimal alignment, and a stiffer landing posture with greater medio-lateral center-of-pressure excursion, largely attributed to lower muscular strength, particularly weaker hamstrings [19].

Our spike landing data concur: the non-dominant leg's reduced flexion and increased valgus could stem from deficits in strength or neuromuscular control, making it the weak link during the high-impact landing. This notion is further supported by studies showing the non-dominant limb can experience significantly larger impact forces [23] and that it generally has to compensate for the dominant limb's preferential use in lead-up movements [13]. Conversely, the dominant leg's more favorable mechanics (greater flexion, less valgus) during spike landings might be due to it being the stronger limb, capable of better shock absorption. Taken together, these results highlight a clear interplay between jump type and leg dominance: a symmetric task like a block jump encourages both limbs to share the load evenly, whereas the asymmetric nature of a spike jump (due to approach steps and hitting strategy) leads to the non-dominant limb being placed in a mechanically disadvantageous position.

Our findings show that spike landings, especially on the non-dominant limb, involve stiffer sagittal mechanics and less favorable frontal/transverse alignment than block landings, consistent with ACL-loading mechanisms [13, 19, 31]. These markers highlight practical applications for screening and coaching (e.g., monitoring flexion, controlling valgus/transverse motions, strengthening the non-dominant side). Although interventions were not tested here, RCT-level evidence supports neuromuscular training to improve landing mechanics and reduce ACL risk surrogates [32–35].

5. Conclusion

This study identified task- and limb-specific kinematic differences during volleyball landings. Compared to block jumps, spike jumps were characterized by reduced hip and knee flexion, greater ankle plantarflexion, and a less favorable frontal/transverse knee profile, particularly on the non-dominant side. These patterns are consistent with mechanisms linked to higher ACL-relevant loading and may indicate a potentially elevated biomechanical risk, especially for the non-dominant limb. Because this study involved a healthy athletic cohort and an observational, non-interventional design without an injured comparator, the findings should be interpreted as markers of potential risk rather than direct evidence of injury incidence, and they cannot be generalized to all lower-limb injuries. From an applied perspective, these markers may help guide screening and coaching strategies, such as monitoring hip and knee flexion at initial contact, emphasizing frontal/transverse control, and targeting non-dominant limb strength, although their effectiveness should be verified in future controlled or prospective studies.

Authors contribution:

Mahdi Majlesi — writing original draft, review & editing, validation, supervision, methodology, conceptualization.

Elaheh Azadian — methodology, project administration, writing original draft, review & editing.

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Вклад авторов:

Махди Маджлеси — написание первоначальной версии рукописи, обзор и редактирование, валидация, контроль, методология, концептуализация.

Элахех Азадиан — методология, администрирование проекта, написание первоначального проекта, рецензирование и редактирование.

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