Review Paper

Kinematic Changes of the Lower Limb in Individuals With Chronic Ankle Instability During Unilateral Landing Tasks: A Systematic Review

Mahsa Hakimi Poor[1], Reza Rajabi [1*], Mohammad Hosein Alizadeh[1], Shahrzad Zandi[1]

1. Department of Health and Sports Medicine, Faculty of Sport Sciences and Health, University of Tehran, Tehran, Iran.

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ABSTRACT

Purpose: Ankle sprain is one of the most common sports injuries and many people suffer from chronic ankle instability after ankle sprains. Changes in the function of the lower limbs following chronic ankle instability make a person susceptible to re-injury of ankle sprains. This is a systematic review of studies that investigated the kinematic changes of the lower limbs in people with chronic ankle instability during unilateral jump landing tasks.

Methods: Articles in English were searched in Google Scholar, Science Direct, PubMed, Scopus, ProQuest, and Cochrane Library databases without a time limit until 2021 with keywords related to "chronic ankle instability," "kinematics," and "single-leg jump-landing." The inclusion criteria included the subjects being male and female with ankle instability and the type of single-leg jump-landing task. The modified checklist of Downs and Black (1998) was used to evaluate the quality of the studies.

Results: Based on the inclusion and exclusion criteria and the study quality review, 15 articles out of 762 studies, which investigated the kinematics of the lower limbs in the performance of unilateral jump landing, were comprehensively examined.

Conclusion: According to the findings of this study, individuals with chronic ankle instability showed kinematic changes in the lower limbs during various unilateral jump landing tasks. These changes are possible factors for the recurrence of ankle sprain injury. The findings show the necessity of developing and creating a rehabilitation program that comprehensively considers the kinematic changes.

Keywords:

Kinematics, Chronic ankle instability, Single leg jump-landing, Systematic review

*** Corresponding Author:**
Reza Rajabi, PhD.
Address: *Department of Health and Sports Medicine, Faculty of Sport Sciences and Health, University of Tehran, Tehran, Iran.*
Phone: *+98 (0912) 1772997*
E-mail: *rrajabi@ut.ac.ir*

Highlights

- The limitations created by chronic ankle instability on the sensorimotor system change the dominant landing strategies.

- Regarding ankle kinematics, the results seem to be conflicting, and an increase and decrease of dorsiflexion and inversion, respectively have been reported.

- Regarding knee kinematics, most studies have reported the reduction of knee flexion in different phases before and after the impact.

- Regarding hip kinematics, most studies have reported an increase in hip flexion, adduction, and internal rotation.

Plain Language Summary

Ankle sprain injury is one of the most important and common injuries among athletes and people who are physically active. One of the most annoying complications of this injury is the occurrence of chronic instability of the ankle, which is accompanied by a feeling of giving way, laxity, pain, and swelling, which leads to a defect in sports performance and disruption in the daily activities of the affected person. Also, it has been reported that chronic instability of the ankle can be the cause of the early development of osteoarthritis. The summary of the studies reviewed in this research showed that the change in the kinematics of the lower limbs (ankle, knee, and hip), especially in the jump-landing movement, can be related to the occurrence of chronic ankle instability, and these changes are possible risk factors for the reoccurrence ankle sprain injury. This finding highlights developing and creating a rehabilitation program that comprehensively considers the kinematic changes created.

1. Introduction

Ankle joint injuries are the most common body injuries reported, about 10% to 30% of all injuries [1]. Ankle injuries have different types, among which lateral ankle sprain accounts for 75% to 85% of injuries [2, 3]. The prevalence of this injury is high, especially in sports (such as volleyball, basketball, and handball) fields with a lot of jump-landing and turning (twisting), changing speed, and direction [4]. This injury causes the athlete to stay away from the activity for several weeks, or in many cases, a long period is needed to recover fully [5].

Chronic ankle instability (CAI) is one of the most frequent and annoying complications of acute ankle sprains. Chronic instability of the ankle is a condition that is characterized by the feeling of giving way, pain, swelling, and the reoccurrence of sprains, which leads to limitations in daily and sports activities [6, 7]. This injury is attributed to two potential causes: mechanical instability and functional instability or a combination of them. Mechanical instability is caused by pathological laxity after an ankle ligament injury, and functional instability is caused by sensory defects of proprioceptor and neuromuscular control after ligament injury [8, 9].

Although it is unclear how ankle sprains progress to CAI, it is estimated that CAI develops in 47% to 73% of people who suffer from ankle sprains [6, 10-13], which increases a person's risk of future ankle sprains by 70% to 80% [14]. It has also been reported that CAI can be the cause of the early development of osteoarthritis [15, 16]. Previous studies have indicated that CAI is related to defects in static and dynamic posture control, changes in movement strategies and patterns, neuromuscular dysfunction, and proprioceptive disorder [17].

In recent studies, it has been determined that the kinematic pattern of the knee and ankle joints changes after ankle instability [18, 19]. Research on the changes in movement patterns following ankle sprains shows that people with CAI have different kinematics in jumping-landing, stairs ascent and descent, walking, and so on [9, 18-22]. In this regard, research has shown that people with CAI land with less knee flexion and more ankle dorsiflexion and inversion than healthy people in performing a jump-landing task [9, 22-24]. However, other studies reported that people with CAI land with more knee flexion, while they have less dorsiflexion and more eversion in the ankle joint [25-27].

As noted, the development of CAI can, on the one hand, disturbs neuromuscular control, and on the other hand, creates compensatory strategies and movement patterns in the lower limbs, which is a protective mechanism to adapt to the various conditions. However, in some cases, the same adaptations and changes in movement patterns are considered as one of the potential risk factors for re-injury [28, 29]. Therefore, this finding shows the importance of accurately identifying changes in the movement pattern of people with CAI. Then again, landing (single-leg landing) is a common task in sports activities that requires dynamic stability and is also a common mechanism of ankle sprain injury [30]. Therefore, much attention has been paid to landing mechanics in relation to ankle instability in previous literature.

Many studies have been conducted on the changes in movement patterns following ankle sprain injury and the occurrence of CAI, but as mentioned, these studies have conflicting results, which can be caused by the differences in methodology, selection criteria of CAI groups, data processing techniques, and reporting method. This status makes it difficult to provide a comprehensive conclusion regarding disorders and changes in movement patterns in people with ankle instability. Therefore, a review of the conducted studies helps to make the right decision in this regard.

Considering that, researchers may lack sufficient time to collect, evaluate, and synthesize all related texts. Hence, we performed the systematic review to answer such questions in an accessible method for decision-makers [31]. This systematic review aims to provide an in-depth analysis of the studies that investigated the kinematic changes of the lower limbs in people with CAI during unilateral jump landing tasks.

2. Materials and Methods

The present review study investigates the kinematic changes of the lower limbs in people with CAI during unilateral jump landing tasks.

Search strategy

Articles in English published until December 31, 2021, were searched in the Google Scholar, Science Direct, PubMed, Scopus, ProQuest, and Cochrane Library databases with the following keywords and Boolean functions:

("Chronic ankle instability" OR "ankle instability" OR "functional ankle instability" OR "ankle sprain") AND ("Kinematic" OR "Biomechanics" OR "movement pattern" OR "motion pattern" OR "movement strategies" OR "motion analysis") AND ("single leg landing" OR "unilateral landing" OR "Landing" OR "one leg landing") AND ("ankle" OR "knee" OR "hip" OR "lower extremity" OR "lower limb").

In this study, the main keywords (between each category with other categories) in the search databases were combined using the Boolean function "AND" and their synonym keywords (within each category) were combined using the Boolean function "OR".

Selection of studies

After searching the databases, all identified articles were entered into the Endnote software, version 20.4.1 and the duplicate articles were removed. Then, all titles and abstracts were reviewed to find articles related to the research topic.

The inclusion criteria included the following items:

1- Their samples should include male and female athletes with CAI,

2- The type of single-leg jump-landing task on the test leg (from the platform or ground surface),

3- The kinematic pattern of the lower limb joints measured before landing or after contact with the ground.

The following inclusion criteria were implemented to screen studies for eligibility:

1- Articles with participants (male and female) that had a history of at least one ankle sprain injury and were classified as having CAI,

2- Articles reporting kinematic variables of the lower limb during a unilateral jump-landing task) from the height or ground level), and

3- The articles were available in English and peer-reviewed full-text manuscripts.

The following exclusion criteria were also implemented to screen studies:

Review articles, animal or cadaver studies, articles that only the introduction was available, conference proceedings, and articles that investigated the kinematics of the lower limb in running, walking, and in general tasks except single-leg jump landing.

All articles were discussed and reviewed by two investigators, and the disagreements were judged and decided by the group supervisor as the final reviewer. After reviewing the abstracts, the full text of the articles was studied independently by two investigators in terms of eligibility. Then, the articles were categorized based on the tasks to be tested, the type and time of measurement, and the joints to be tested.

Quality evaluation

To assess the quality and risk of bias in selected studies, a modified checklist was used, which is derived from the checklist of Downs and Black (1998) [32]. Downs and Black's checklist is a valid tool to assess the methodological quality of randomized and non-randomized studies of health care interventions [32, 33]. The reliability of this checklist, which was reviewed by three experienced judges, was reported as high (KR-20=0.89). Also, its validity has been reported as high by using the test-re-test of 10 randomized trials and 10 non-random trials (r=0.88) [32].

In the modified checklist, 14 out of 27 items of Downs and Black's checklist (1, 2, 3, 5, 6, 7, 10, 11, 12, 16, 18, 20, 21, 22) were used. These items were included to assess overall reporting bias, external validity, internal validity bias, and internal validity [18, 33]. The maximum possible score for each study was 15. The same two investigators who assessed the studies for eligibility scored the studies according to the modified checklist. If disagreements on scores were greater than 10%, the two investigators would discuss the differences to reach a final decision. If no agreement was reached, a third investigator would act as the final decision maker. Studies that scored greater than 50% (score 7) in the modified quality checklist were included in this review [18, 33].

Data extraction

In the current study, in several stages, accurate determination of the problem, collection, analysis, and interpretation of the findings was done according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guideline [34] (Figure 1). The results related to the kinematics of the subjects' lower limb joints were extracted from the included articles. The following data were extracted and summarized in the tables: type of study design, participant groups, sample size, type of jump-landing task, and main dependent variables.

3. Results

By searching the keywords in various databases, 762 articles were found. Then duplicate articles (360 articles) were eliminated and the title and abstracts of 402 articles were examined. After the screening of titles and abstracts, 355 articles were excluded and 47 remaining articles were reviewed. According to inclusion and exclusion criteria, 18 full-text articles were reviewed and 29 articles were excluded from the review process because they did not provide the type of task or kinematic information that we were looking for (for example, articles in which the task presented was different from the research inclusion criteria). After quality evaluation of the articles, 15 articles that exclusively investigated the kinematics of the lower limb during single-leg jump-landing were selected for comprehensive review (Figure 1).

Result of quality evaluation

The results of the quality assessment are presented in Table 1. All studies were evaluated based on the modified checklist of Downs and Black, and the quality index score for all articles was higher than 7, so the selected articles had acceptable quality levels.

Characteristics of the included studies

Fifteen studies included in this review examined the kinematics of the lower limb during a unilateral jump-landing task. In 10 studies, a height of 30 to 50 cm was used to perform the single-leg landing task [9, 14, 22-24, 35-39]. In one study, the investigated task was jump landing, which included jumping 2 feet from the ground and landing with the test leg from a distance of 75 to 90 cm from the center of the force plate [26]. Single-leg forward jump from a height of 15 cm followed by a single-leg landing was utilized in one study [25]. Single-leg landing (double□leg forward jump from 70 cm distance from the center of the force plate and landing with the test leg) and then keeping the balance for 5 second were used in two studies [40, 41]. In one study, a single-leg landing task (from a box with 15 cm height) with 2 feet and landing with 1 foot was investigated [42].

Out of the 10 studies that reported lower extremity kinematic parameters, 6 studies reported ankle, knee, and hip kinematics [14, 24-26, 36, 39-41], 3 studies reported ankle and knee kinematics [9, 22, 42], 3 studies reported only ankle kinematics [23, 35, 37], while the remaining one study reported ankle and foot kinematics [38].

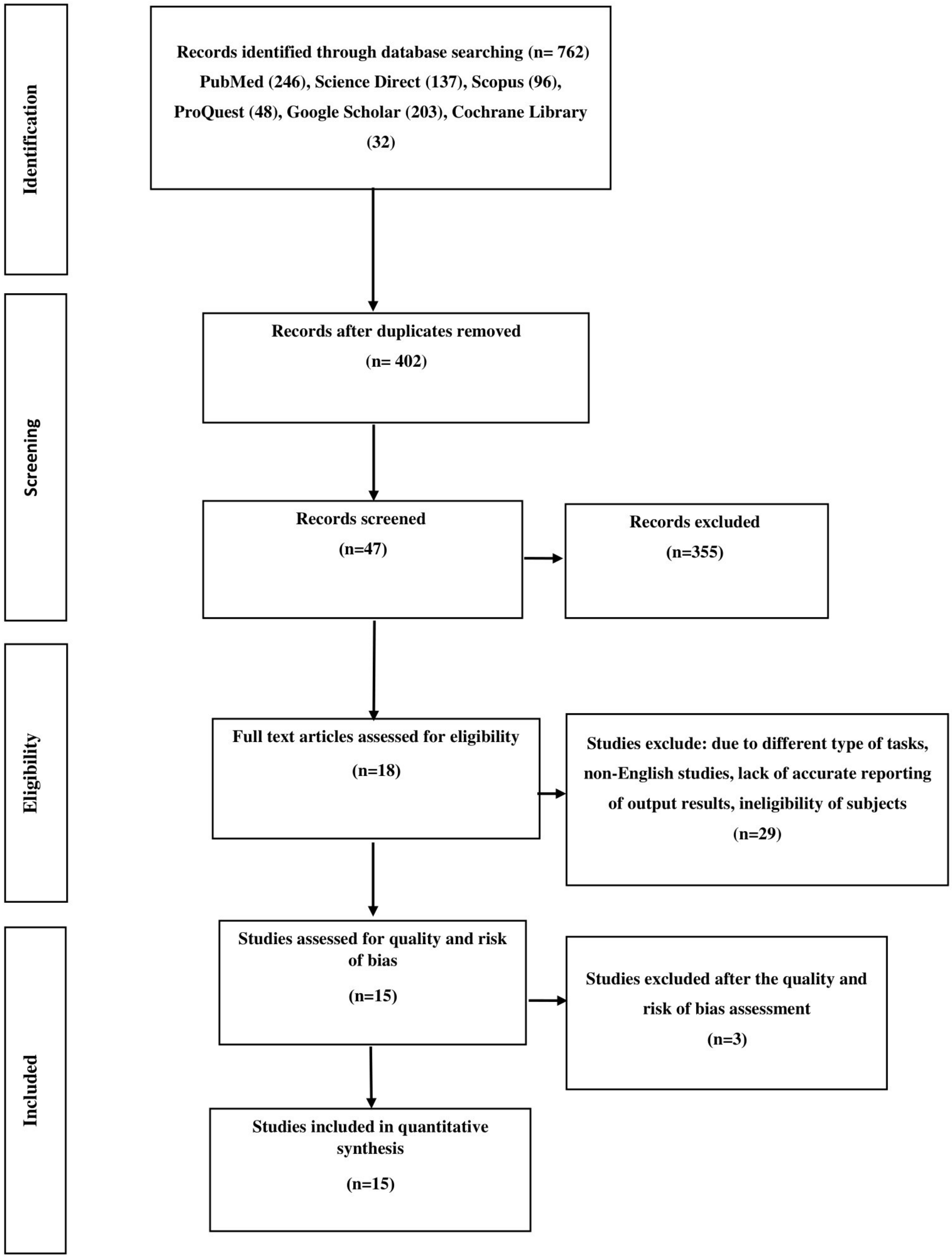

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Figure 1. Flow diagram of the study selection process (based on the preferred reporting items for systematic reviews and meta-analyses [PRISMA]).

Table 1. Summary of study characteristics and results

Studies	MQA Score	Study Design	Participants	Age (y)	Task	Measurement	Time Measurement	Comparison	Main Result
Wright et al. (2016) [23]	10	Cross-sectional	n=69 Control=23 Coper=23 FAI:23	Control: 23.17±4.01 Coper: 23.52±3.68 FAI: 30.23±3.84	Single-leg drop jumps (From a box with a 40 cm height)	Kinematics of the ankle in sagittal and frontal planes	Initial contact and maximum vertical ground reaction force	FAI group, Coper group, and control groups	-Individuals with FAI displayed more dorsiflexion in the hind foot than the coper and control groups
Kunugi et al. (2018) [14]	11	Cross-sectional	n=30 Control=15 CAI=15	Control: 20.07±1.03 CAI: 19.8±0.94	Diagonal single-leg rebound jump (From a box with 30 cm height)	Kinematics of Hip, knee, and ankle in sagittal, frontal, and transverse planes	300 ms before initial contact (IC) to 300 ms after initial contact	CAI group with a control group	-The CAI group had decreased hip adduction, knee flexion, external rotation, and ankle dorsiflexion angle compared to the control group
Kim et al. (2018) [26]	9	Cross-sectional	n=200 Control=100 CAI=100	Control: 22±3.3 CAI: 22±2.3	Jump landing/cutting task (Double leg maximum vertical forward jump and single leg landing)	Kinematics of hip, knee, and ankle in sagittal and frontal planes	-	CAI group with a control group	-The CAI group showed a decrease in ankle dorsiflexion angle, and an increase in knee and hip flexion, hip adduction, and ankle inversion compared to the control group.
Lin et al. (2019) [25]	10	Cross-sectional	n=30 Control=10 Coper=10 CAI=10	Control: 20.1±2 Coper: 19.6±1.6 CAI: 20.1±1.2	A single leg the forward jump was followed by a single-leg landing	Kinematics of hip, knee, and ankle in sagittal and frontal planes	The pre-landing Phase: 100 ms before the initial contact The landing: Initial foot contact with the force plate	CAI group with the coper and control groups	-The CAI group showed increased hip flexion and adduction angle, ankle eversion at the initial landing - The CAI group showed an increase in ankle inversion velocity during the descending phase.
Delahunt et al. (2006) [35]	10	Cross-sectional	n=48 Control=24 FAI=24	Control: 22±0.84 FAI: 25±1.3	Single-legged drop jumps (From a box with 35 cm height)	Kinematics of hip, ankle in sagittal, and frontal planes	Two 200-ms periods on either side of initial contact	FAI group with a control group	- The FAI group had more ankle inversion during 200 to 95 ms before initial contact and less dorsiflexion angle in the period of 90 to 200 ms after the initial contact. -The FAI group had less external rotation of the hip
Caulfield et al. (2002) [22]	11	Cross-sectional	n=24 Control=10 FAI=14	Control: 22.6±4.6 FAI: 26.6±6.3	Single leg jump (From a box with a 40 cm height)	Kinematics of the knee, and ankle in the sagittal plane	From 100 ms before landing to 200 ms post landing	FAI group with a control group	- The FAI group showed an increase in ankle dorsiflexion from 10 ms pre-landing to 20 ms post-landing, they also exhibited an increase in knee flexion angle in the period of 20 ms pre-landing to 60 ms post-landing

Studies	MQA Score	Study Design	Participants	Age (y)	Task	Measurement	Time Measurement	Comparison	Main Result
Brown et al. (2008) [9]	13	Cross-sectional	n=63 Coper=21 FAI=21 MAI=21	Coper: 21.71±4.85 FAI: 22.14±3.83 MAI: 22.38±4.3	Drop jump, and stop jump (From a box with 32 cm height)	Kinematics of the knee, and ankle in the sagittal and frontal planes	During the drop jump trials, those variables were identified in the 250 ms after initial contact	FAI group with the coper and MAI groups	-The MAI group landed with less plantar flexion (More dorsiflexion) at initial contact and maximum than the coper group, MAI group also landed with a greater maximum eversion than the FAI and coper groups
McCann et al. (2019) [40]	11	Cross-sectional	n=76 Control=25 Coper=25 CAI=26	Control: 23±3.6 Coper: 24±5.2 CAI: 24.2±4	Single-leg landing (Double-leg jump from 70 cm distance and landing with the test leg)	Kinematics of hip, knee, and ankle in sagittal, frontal, and transverse planes	From 200 ms before the initial contact to 50 ms after the initial contact	CAI group with the coper and control groups	-The CAI group exhibited less hip abduction during landing compared to the Cooper and control groups -The CAI group showed a decrease in external rotation strength compared to the control and Cooper groups
Herb et al. (2018) [24]	8	Cross-sectional	n=47 Control=23 CAI=24	Control: 21.7±2.9 CAI: 21.4±3.1	Drop-vertical jump (From a box with 30 cm height)	Kinematics of hip, knee, and ankle in the sagittal and frontal planes	100 ms before to 200 ms after force-plate contact	CAI group with a control group	-The CAI group showed an increase in inversion angle from 107 to 200 ms after the contact and a decrease in plantar flexion from 11 to 71 ms after the contact. -The CAI group showed a decrease in knee flexion angle from 95 to 200 ms after the contact.
Doherty et al. (2016) [36]	10	Cross-sectional	n=70 Coper=42 CAI=28	Coper: 22.7 CAI: 23.2	A drop land task (From a box with 40 cm height)	Kinematics of hip, knee, and ankle in sagittal, frontal, and transverse planes	From 200 ms before the initial contact (IC) to 200 ms after the initial contact	CAI group with coper group	-The CAI group showed an increased hip flexion during the landing descent on their involved limb and a decrease in the hip flexion pattern in the after the initial contact phase -The CAI group showed an increased internal rotation of the hip joint 200 to 50 ms before landing compared to the coper group -In the ankle and knee, the results were not significant.

Studies	MQA Score	Study Design	Participants	Age (y)	Task	Measurement	Time Measurement	Comparison	Main Result
Watabe et al. (2021) [37]	11	Cross-sectional	n=36 Control=12 Coper=12 CAI=12	Control: 19.7±1.3 Coper: 19.8±1.9 CAI: 20.1±1.2	normal and inversion single-leg landing (From a box with 30 cm height(	Kinematics of the ankle in the sagittal and frontal planes	200 ms before the initial contact to 200 ms after the initial contact	CAI group with the coper and control groups	-The CAI group displayed an increased maximum inversion angle at post-landing during inversion single-leg landing compared to the Cooper and control groups -No significant difference was observed among the CAI and coper groups during normal single-leg landing
Gribble et al. (2010) [41]	9	Repeated-measures case-control design	n=38 Control=19 CAI=19	Control: 23.1±3.9 CAI: 20.3±2.9	10 single-limb jump landing (Double-leg jump from 70 cm height and landing with the test leg)	Kinematics of hip, knee, and ankle in sagittal, frontal, and transverse planes	100 ms before the impact as well as peak and time-to-peak kinematic position after the impact	CAI group with a control group	- The CAI group showed a decrease in the knee flexion angle compared to the control group in the before the impact phase -The results were not significant for the ankle and hip
Kipp et al. (2013) [42]	10	Cross-sectional	n=22 Control=11 CAI=11	Control: 22.6±4.2 CAI: 22.4±3.2	Single-leg landing task (From a box with a 15 cm height)	Kinematics of knee and ankle in the sagittal and frontal planes	100 ms before to 200 ms after the touchdown	CAI group with a control group	- The CAI group showed more variation in the main components of the sagittal plane and the change in plantar flexion of the ankle in the period pre-contact compared to the control group -In addition, the CAI group showed more variation in the main components of the frontal surface in the entire movement length
Ridder et al. (2015) [38]	11	Cross-sectional	n=96 Control=30 Coper=38 CAI=38	Control: 25.7±1.8 Coper: 20.3±1.9 CAI: 22.1±3.4	A vertical drop and side jump task (From a box with a 40 cm height)	Kinematics of ankle and foot in the sagittal, frontal and transverse planes	-	CAI group with the coper and control groups	-CAI group showed more inversion-eversion range of motion in vertical jump than the coper group - The CAI and coper groups showed less inversion during 10-100% of the impact phase than the control group -The CAI and coper groups showed a decrease in plantar flexion in the touch-down phase compared to the control group -CAI group showed lower plantarflexion-dorsiflexion range of motion in the ankle area than the control group
Moisan et al. (2019) [39]	9	Case-control stud	n=63 Control=31 CAI=32	18-35 years	-side jump landing -unilateral drop landing on (even (DROP) (From a box with 46 cm height)	Kinematics of hip, knee, and ankle in the sagittal plane	-	CAI group with a control group	-The CAI group showed an increase in dorsiflexion during the landing phase when landing on the foam. -On the even surface, the results were not significant

Abbreviations: MQA: Modified quality assessment; CAI: Chronic ankle instability; FAI: Functional ankle instability; MAI: Mechanical ankle instability.

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Moreover, 5 studies reported kinematics in the sagittal, frontal, and transverse planes [14, 36, 38, 40, 41], 8 studies reported sagittal and frontal plane kinematics [9, 23-26, 35, 37, 42], while the remaining 2 studies only reported sagittal plane kinematics [22, 39].

The time frame of the measurements was between 50 and 300 millisecond (ms)before and after the initial contact, while most studies examined 200 ms before and 200 ms after the initial contact (Table 1).

4. Discussion

This research systematically evaluated the studies that investigated the kinematic changes of the lower limb in people with CAI during unilateral landing tasks. The results were discussed separately for lower limb joints (ankle, knee, and hip) to facilitate interpretation and conclusions.

Ankle joint

In the ankle joint, individuals with CAI and functional ankle instability (FAI) showed a greater dorsiflexion angle [9, 22-24, 38] during various phases of jump-landing, especially at the moment of initial impact [9, 23, 38] and post-landing [22, 24]. There is a hypothesis that an increase in dorsiflexion in individuals with FAI may be a protective adaptation that creates a more stable position for the lateral ligaments and the talocrural joint. In other words, in the case of more dorsiflexion, the lateral ligaments are in a less stretched position, which leads to more protection of the lateral ligament complex of the foot [22]. Increase in dorsiflexion was done unconsciously by individuals with ankle instability to reduce the effects of ground reaction force (GRF) on the ligaments during landing [22]. Reducing the plantar flexion of the ankle can be a compensatory strategy to protect the ankle from the re-injury of lateral ankle sprain. This strategy due to the inverse relationship between a stiffer landing pattern (smaller range of motion) and a higher load can make individuals prone to ankle instability [38]. In contrast to the previous studies, in 3 studies, a reduction in ankle dorsiflexion was observed in people with CAI during [26] and after the initial impact [14, 26, 35]. The authors' justification was that reducing the dorsiflexion angle of the ankle leads to less bone stability and capacity to absorb shock to control the body [14]. In other words, the reduction in dorsiflexion decreases the ability to absorb GRF and an increase in the posterior GRF, which makes the person prone to repeated ankle sprain injuries [35].

In the ankle, individuals with CAI showed a greater inversion angle [24, 26, 35, 42] during various phases before and after unilateral landing. Some studies reported increased inversion angle in subjects with FAI and CAI compared to healthy subjects during various phases before and the initial compact moment [35] and post-impact phases [24, 42]. In two studies by Delahunt et al. (2006) and Herb et al. (2018), the ankle of healthy people tended toward eversion after impact, but in people with chronic instability, the ankle tended toward inversion [24, 35]. It has been found that eversion causes the absorption of energy at the moment of landing and modifies GRF. Therefore, in people with CAI with the inclination of the ankle to inversion, there is an inability to absorb landing energy (loading), which is likely to be related to an increase in vertical GRF [24]. A more inverted position may place the ankle in a harmful position that requires more activation of the peroneal muscles to move the foot out of this position and prevent inversion [24]. Only in Lin et al. (2019) research, an increase in ankle eversion angle at the moment of initial impact was reported in people with CAI and coper [25]. According to the findings of this research, people with CAI and coper often show an increase in ankle eversion at the moment of impact as the main change in movement, to reduce the effect of excessive inversion. This increase in eversion is considered a protective mechanism, although this mechanism only occurs in the initial phase [25]. Reducing the amount of ankle inversion can be considered a protective mechanism to reduce the risk of ankle sprain [25]. Other studies reported no significant difference in ankle kinematics in the frontal and sagittal plane between CAI and control groups [36, 37, 39-41].

Regarding the ankle kinematics in people with CAI at the sagittal and frontal levels, the results seem to be conflicting. Several articles observed an increase in dorsiflexion, and some others observed a decrease in dorsiflexion. Also, at the frontal plane, several studies reported an increase in inversion and some others reported a decrease.

Knee joint

Some studies reported an increase in the knee flexion angle in the initial contact phase [26] and 20 ms before and 60 ms after the initial contact [22] in people with CAI during landing. Previous studies show that when the mechanical demand increases, eccentric energy is absorbed by the knee and hip during landing by increasing flexion [38]. The increase in knee flexion can be due to the increase in GRF, which people with CAI distribute and neutralize with knee flexion [14]. In the study of Caulfield et al. (2002), the reason for the increase in knee flexion before the contact, while there are no external forces, was the difference in the feedforward-motor program. They also stated that the changed movement pattern that was observed in people with CAI indicates the adaptation created as a result of a previous injury [22]. Several studies have also reported a decrease in knee flexion in different phases of jump-landing in patients with CAI. Kunugi et al. (2018) and Herb et al. (2018) reported a decrease in the knee flexion angle in the post-impact phase [14, 24]. Gribble et al. (2010) also reported a decrease in knee flexion in the pre-impact phase [41]. It has been found that the reduction of knee flexion is a risk factor for non-contact knee injuries [29]. Previous research has shown that the reduction of knee flexion, especially 10-30 degrees, is when the quadriceps muscle exerts the most anterior shearing force on the tibia [43].

The more ankle, knee, and hip flexion, the better ability they have to absorb GRF energy, which leads to less force being transferred to the knee [44]. When the knee is in an extended position, the force resulting from the contraction of the hamstring muscles is parallel to the anterior cruciate ligament, which reduces the ability of the hamstrings to limit the anterior displacement of the tibia [29]. Despite the above, in another study, more knee extension before impact was mentioned as a contributing factor in compensating for the decrease in dynamic knee stability in individuals with CAI during sports activities such as jump-landing.

It has also been reported that increased knee extension in the pre-impact phase may be due to creating a long time to distribute and control the GRF after landing [41]. It should be mentioned that in one of the studies where the knee flexion angle was not reduced, the subjects performed a different jumping task [26].

Knee rotations have been investigated in very few articles, and only one study reported a reduction in knee external rotation in the CAI group 250 to 300 ms before the initial contact [14]. This result indicates a changed strategy in the transverse plane in people with CAI during landing [45]. In general, regarding the knee, most studies have reported the reduction of knee flexion in various phases before and after the impact.

Hip joint

Regarding the hip joint, studies reported an increase in hip flexion [25, 26, 36]. Increasing hip flexion is a mechanism that people use to help dissipate force in the lower limb [44]. One of the reasons for the increase in hip flexion can be a preparation mechanism to help distribute force during impact in people with CAI. Probably, this is a feedforward pattern that occurs due to the body's awareness of the instability in the ankle joint [20]. In the frontal plane, only one study reported a decrease in the hip adduction angle [14], but in other studies, an increase in hip adduction [25, 26, 40] was observed. Also, in the transverse plane, studies reported an increase in the internal rotation of the hip [35, 36] in the pre-landing phase.

Research has shown that increased adduction and internal rotation of the hip is a risk factor for non-contact knee injuries because they can cause knee valgus [35]. The decrease in hip abduction angle (increase in adduction) in the CAI group may be due to a change in the internal-external positioning of the foot, but more research is needed [40]. Because of the lower range of motion of the hip joint compared to the knee in the frontal plane, lateral instability of the ankle joint can be compensated by movements in the hip joint [46].

It has been determined that the change in the movement patterns of the hip in individuals with CAI is potentially caused by the change in the movement programs in the central nervous system following peripheral joint injury (ankle) and contributes to recurrent injury and CAI development [40, 47]. Altogether, regarding the hip, most studies have reported a decrease in flexion, adduction, and internal rotation.

5. Conclusion.

In summary, the limitations caused by CAI on the sensory-motor system change the dominant landing strategies in the proximal parts of the lower limb (knee and hip) and it seems that these adaptations are also affected by the type of jump-landing task. According to the results of the studies, people with CAI showed kinematic changes in the lower limbs (ankle, knee, and hip) during single-leg landing jumps. Considering the effect of different parts of the lower limb on each other and the effect of the forces on the joints, these changes are possible factors for the reoccurrence of ankle sprain injury in people with CAI. The important point is that none of the mentioned studies provided sufficient information on the cause-and-effect relationship between the kinematic changes of the lower limbs and CAI. Thus, it is unclear whether these kinematic changes in the lower limbs lead to ankle sprains and instability or whether CAI has caused kinematic changes in the lower limb over time. It seems that prospective research can clear the above ambiguity. The findings of this study can assist specialists and clinicians to identify abnormal movement patterns associated with frequent lateral ankle sprains and develop an effective rehabilitation program to restore motor sensory deficits that occur after a primary ankle sprain injury that can lead to CAI.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the University of Tehran (Code: IR.UT.SPORT.REC.1398.070).

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Authors' contributions

Conceptualization, Invesigation, Funding acquisition and Resources: All authors; Methodology: Mahsa Hakimi Poor and Reza Rajabi; Writing original draft: Mahsa Hakimi Poor; Writing, reviewing, and editing: Reza Rajabi and Mohammad hosein Alizadeh.

Conflict of interest

The authors declared no conflict of interest.

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