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Three-dimensional ankle kinematics of the full gait cycle in patients with chronic ankle instability: A case-control study

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ABSTRACT

Objectives: The ankle kinematic characteristics of chronic ankle instability (CAI) at different gait phases and dimensions were not directly and overall explained. These characteristics have yet to be established. This study aimed to observe ankle kinematic changes of CAI, and explore their mechanisms, at different gait phases and dimensions in full gait cycle.

Methods: A three-dimensional (3D) motion capture system measured the 3D ankle movements of 53 individuals with CAI ($\text{mean}_{\text{age}} = 25.11 \pm 6.01$years, $\text{mean}_{\text{height}} = 170.77 \pm 7.80$ cm, $\text{mean}_{\text{mass}} = 64.28 \pm 9.28$ kg) and 53 healthy controls ($\text{mean}_{\text{age}} = 24.66 \pm 6.32$ years, $\text{mean}_{\text{height}} = 169.98 \pm 9.00$ cm, $\text{mean}_{\text{mass}} = 63.11 \pm 9.62$ kg) during barefoot walking overground at a self-selected speed. Once the acquisition results were processed with visual 3D software, the kinematics data were exported, and the eight phases of the gait cycle were identified.

Results: As compared with the control group, individuals with CAI displayed a significantly smaller plantarflexion in toe off ($P = 0.049$, Cohen's $d = 0.387$), a significantly increased inversion in heel strike ($P = 0.007$, Cohen's $d = 0.271$) and initial swing ($P = 0.035$, Cohen's $d = 0.233$), mid-swing ($P = 0.019$, Cohen's $d = 0.232$) and end-swing ($P = 0.021$, Cohen's $d = 0.214$), and significantly smaller eversion in mid stance ($P = 0.010$, Cohen's $d = 0.288$) and heel off ($P = 0.033$, Cohen's $d = 0.089$). Significant between-group differences in ankle kinematics were observed in the sagittal and frontal planes, but not in the horizontal plane, during walking.

Conclusion: When walking, patients with CAI have altered sagittal- and frontal-plane kinematics during different stance and swing phases. These kinematic changes require multi-dimensional, dynamic, continuous functional assessment and specialized rehabilitation intervention.

1. Introduction

Chronic ankle instability (CAI) is a sequela of ankle sprains, of which the lateral ankle sprain is the most common [1]. The incidence rate of CAI has been estimated as being upwards of 70 % after ankle sprain [2]. Common symptoms of CAI include recurrent sprain, the ankle "giving way", chronic pain, and functional limitations. The development of CAI also increases the risk of ankle osteoarthritis [3]. Functional and structural lesions of the ankle stability system are contributing factors for CAI [4]. Individuals with CAI often experience long-term limitations in sports and daily activities [5] and reduced quality of life [6]. Decreased function in the ankle (e.g.

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proprioception, neuromuscular control, postural control and strength [7])and adjacent joints may be the primary contributors to these adverse outcomes.

The functional deficits associated with CAI not only lead to abnormal ankle kinematics, but since the lower extremity moves in a kinetic chain, they also result in compensation patterns in adjacent joints [8]. A recent study found that CAI can impact lower extremity joints kinematics [9]. Many studies have demonstrated that changes in ankle kinematics may cause compensatory actions in the lower extremity joints [10–12]. Changes in ankle kinematics influence the transfer of energy [13] and the distribution of loading [14] on the lower limb joints. It is proposed that the increased ankle inversion and altered kinematics associated with CAI may increase the risk of ankle degeneration. Concomitantly, CAI also increases the risk of proximal joint injury. Koshino et al. [15] have also found

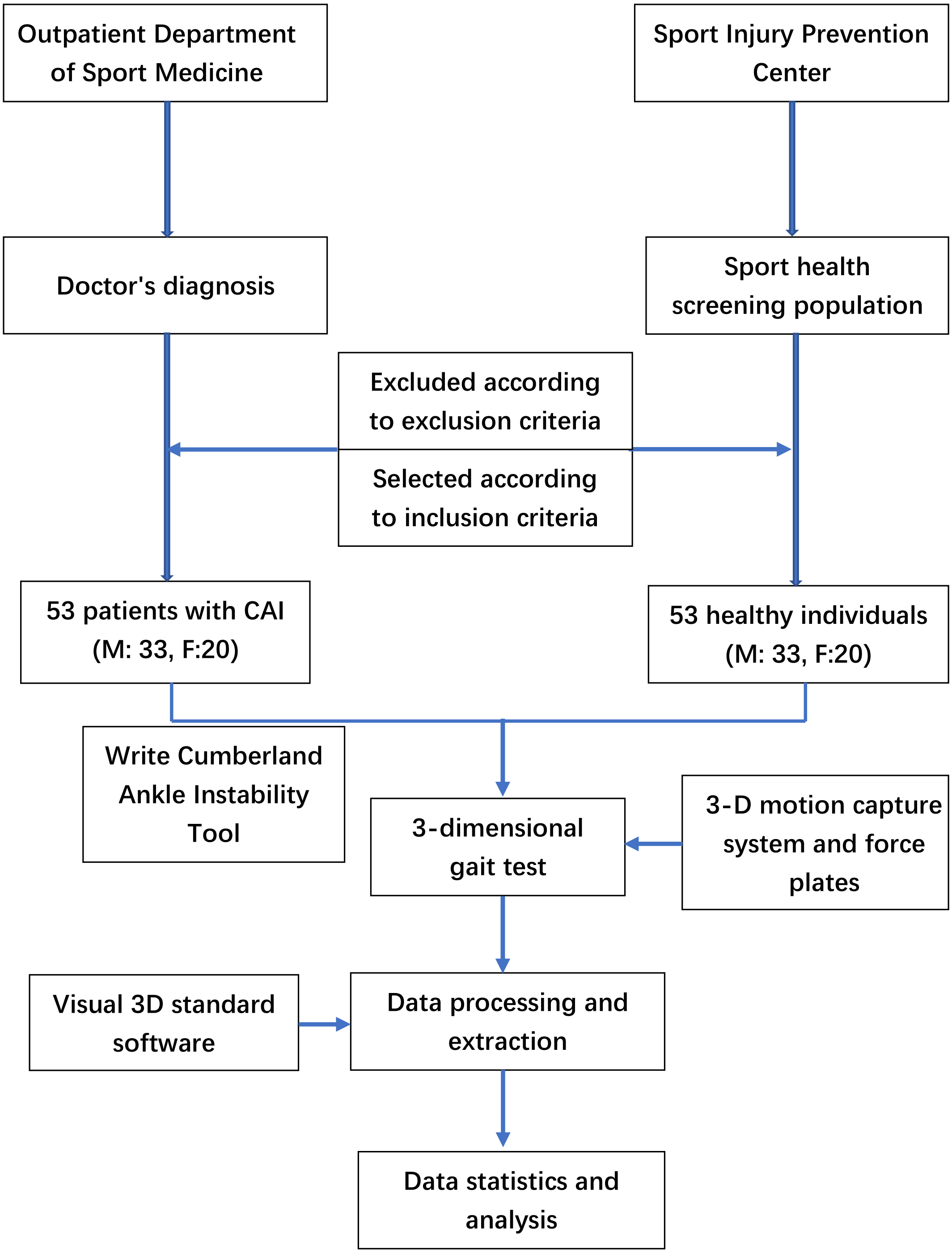

Fig. 1. Flow chart of subjects collection and test analysis.

that CAI results in lower extremity kinematic changes, which contribute to an increased risk of lower limb injury.

Previous studies have investigated the kinematics of CAI using a variety of movement tasks (e.g. walking, running [16], side-cutting [17], and jump-landing [18]). They found that participants demonstrated abnormal kinematics when engaging in these tasks. However, movement patterns and functional performances vary across tasks. Walking is the most basic and vital movement in activities of daily living. It can also better reflect changes in movement function in a natural state than more challenging tasks because it does not typically produce strong stimulation to the affected limb. It has been proposed that individuals with CAI have abnormal ankle kinematics during walking. Moisan et al. [16] determined that participants with CAI have increased ankle and rearfoot inversion and increased ankle plantarflexion during walking. Yen et al. [19] studied ankle dynamics of CAI individuals used recurrence quantitative analysis (RQA) and three-dimensional (3D) motion capture system. They found more frequent switch of ankle position in the frontal plane during walking on treadmill, but the RQA result cannot reflected directly the kinematic fluctuations of the original ankle inversion-eversion trajectory and difficult to use in clinical practice now. Monaghan et al. [20] investigated 3D lower limb function of CAI used CODA mpx30 integrated with a forceplate and found that CAI patients existed a significant inversion posture in the ankle from 100 ms before heel-strike to 200 ms after heel-strike during walking. However, in previous studies, abnormal ankle kinematics of CAI were not directly and overall explained at different gait phases and in different dimensions during walking on ground. The 3D ankle kinematic characteristics of the full gait cycle have yet to be established. These characteristics are integral to the dynamic, accurate evaluation of ankle function.

It is generally believed that the ankle muscles and ligaments dynamically support changes in joint position during walking. Abnormal ankle kinematics may be found in different gait phases and dimensions and help with the accurate assessment of abnormal function in pathological tissues. Some researchers have also suggested that ankle assessments should be conducted at different joint positions [21] to gain detailed and in-depth insight into motor function [22]. Consequently, it is important to study the 3D ankle kinematics of CAI for the full gait cycle to accurately evaluate the functional movement of the ankle and determine precise interventions to help prevent the recurrence of ankle sprains and reduce the negative effects on the lower limb joints.

Therefore, the purpose of this study was to observe changes in ankle kinematics at different gait phases and dimensions of the full gait cycle. The result of this study will inform functional movement assessments and interventions for CAI.

2. Methods

2.1. Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the hospital Ethics Committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Ethics Review Committee of hospital (No.2019-11-15-1).

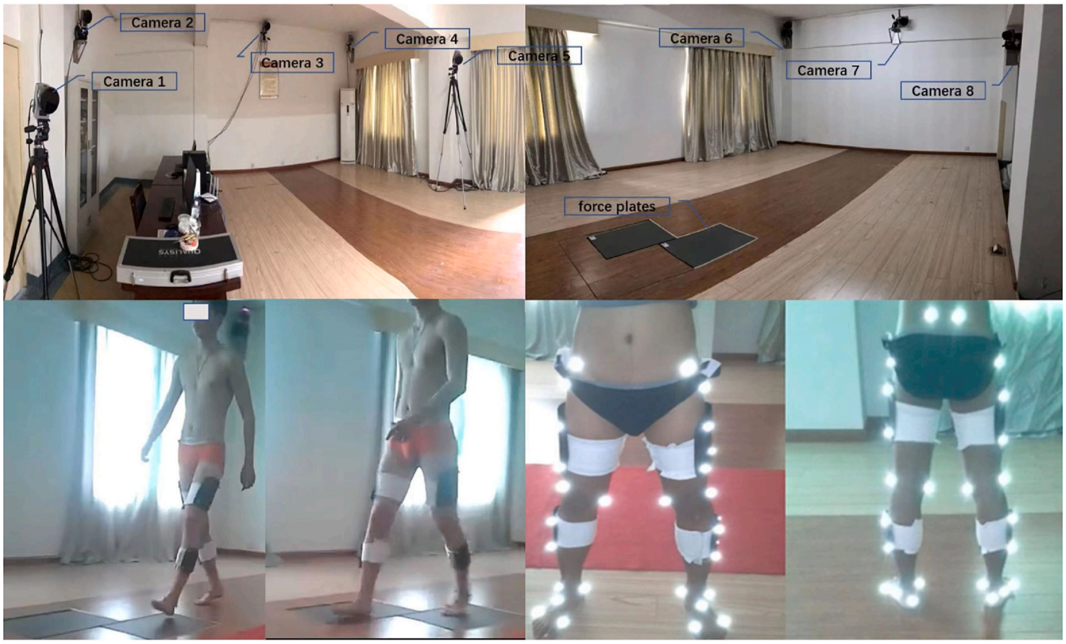

Fig. 2. The 3D motion capture system and the measurement conditions.

2.2. Participants

Individuals with CAI were recruited from an outpatient sports medicine departmentfrom December 2019 to December 2020. The sample size was ascertained using G*Power software ($\alpha = 0.05, 1\text{-}\beta = 0.95, d = 0.8$ [23]). To ensure adequate power owing technical difficulties of data acquisition and extraction, total of 106 participants were included in this study. Fifty-three unilateral individuals aged 20–40 years with lateral CAI were selected according to the methods outlined by Gribble et al. [24]. The total number of affected limbs was 53. The Cumberland Ankle Instability Tool (CAIT), a patient-reported outcome tool, was administered prior to the 3D assessment to measure the severity of CAI. Briefly, we included individuals who had a history of at least one significant ankle sprain, with the most recent injury occurring more than three months prior to study enrollment; a previously injured ankle joint “giving way” and/or recurrent sprain and/or “feelings of instability”; and a CAIT score ≤ 24. Fifty-three healthy individuals aged between 20 and 40 years with no history of ankle sprain or instability and no abnormal lower limb function were recruited from a sports health screening at hospital (Chengdu, China) and served as age-, body mass-, and height-matched controls. For both groups, the exclusion criteria (as measured by self-report and screening) were: obviously abnormal lower limb or spine posture, lower back or lower limb injury affecting gait, cardiovascular disease, nervous system disease, overweight (BMI ≥ 25 kg/m^2), pregnancy, or engaging in intensive exercise within 24 h of the study assessment. All participants provided written informed consent prior to participating in the study (Fig. 1).

2.3. Instrumentation

The kinematics of the full gait cycle were studied using a 3D motion capture system based on infrared photoelectric cameras and reflective markers, which have been considered as the critical standard for gait analysis in clinical [25]. The system included eight cameras (Oqus300+, 200 Hz, Qualisys. Inc., Sweden), a Qualisys track manager software (Version2.15, Qualisys Inc., Sweden), and two force plates (Model4060-08, 550 Hz, Bertec. Inc., USA) that were embedded into a 10-m walkway and synchronized with the Qualisys system to identify gait events and kinetics along with trajectory analysis. The indicator data were processed and calculated using standard visual 3D software (Version4.96.13, C-motion. Inc., USA) (Fig. 2).

2.4. Procedures

Each participant walked barefoot across walkway at a self-selected speed. The test was conducted in a quiet environment, with a room temperature of approximately 26 °C. The camera system’s walkway trajectory space was calibrated with L frame and T wands so that the standard deviation was less than 1.0 mm. Participants wore tight pants and tied their tops to prevent the markers from being covered.

Infrared retro-reflective markers were attached to participants’ skin at anatomical landmarks (i.e., pelvis, hip, knee, ankle, and foot) with double-sided adhesive tape, and marker cluster boards were fixed to the thigh and shank with elastic bandages. A total of twenty-two markers were fixed to the following anatomical landmarks: anterior superior iliac spine ($n = 2$), posterior superior iliac spine ($n = 2$), trochanter of the femur ($n = 2$), medial condyle of the tibia ($n = 2$), lateral condyle of the tibia ($n = 2$), medial malleolus ($n = 2$), lateral malleolus ($n = 2$), calcaneal tubercle ($n = 2$), scaphoid ($n = 2$), first metatarsophalangeal joint ($n = 2$), and the fifth metatarsophalangeal joint ($n = 2$). Next, participants stood in front of the force plate (with feet shoulder-width apart and facing forward in parallel, head straight, palms forward), and static posture data were collected prior to the walking test. The joint markers were removed after the static data acquisition was completed, and participants were instructed to walk at a normal and comfortable pace (Fig. 2). Once the walking gait was stable, the formal test was carried out. Participants were required to walk normally six times per trial, and their trajectories were obtained using an automatic identification of markers model. The motion tracks obtained from each test were then manually checked, labels were manually processed, and the gaps of each track were filled. Gait characteristics and the ground reaction force (GRF) were concurrently used to determine the frame numbers of key points. The processed acquisition

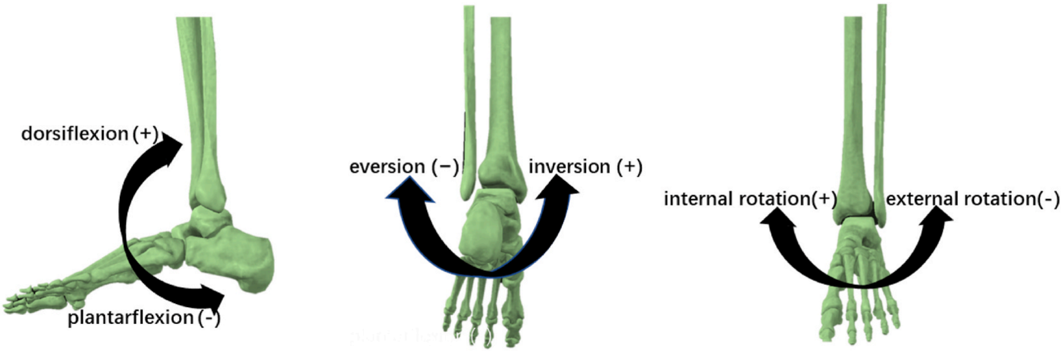

Fig. 3. The movements of ankle in three-dimensional plane. Plantarflexion and dorsiflexion in the sagittal plane; Inversion and eversion in the frontal plane; Internal rotation and external rotation in the horizontal plane.

results were analyzed with visual 3D software, and the kinematics data were exported to a computer. The data were extracted according to the frame numbers of key points by a single researcher (GPM).

The GRF is comprehensive force of body weight and acceleration during walking which was collected and recorded at a sampling rate of 550 Hz by force plates. The vertical GRF was used to determine the stance and swing phase of the gait cycle, and the threshold of 10 N was utilized to identify initial contact and toe off. Five key points (i.e., heel strike, HS; foot flat, FF; mid stance, MS; heel off, HO; toe off, TO) were selected from the stance phase according to the changes in the GRF and foot. Three key points (i.e., initial swing, ISW; mid swing, MSW; and end swing, ESW) were selected from the swing phase according to the characteristics of the lower limb. The 3D kinematics data of ankle movement (Fig. 3) were extracted from the key points of the gait phase. The following key points were selected (Fig. 4): HS: Heel contacts the ground, and there is a reaction force; HF: Foot fully contacts the ground; MS: Line of gravity is vertical to the ground; HO: Heel of the foot leaves the ground; TO: Ground reaction force moves to the forefoot; ISW: Both thighs overlap in the sagittal view; MSW: Shank is perpendicular to the ground; ESW: Before heel strike, with no ground reaction force.

2.5. Statistical analysis

Quantitative data were summarized using means ± standard deviations. The 3D kinematics data of the key point in the full gait cycle were extracted and collected from affected lower limber of CAI and paired ipsilateral lower limber of control. The final results were averaged data from three high-quality walking (Data curve integrity, no obvious abnormal data, left and right foot full contact with force plate respectively). The Kolmogorov-Smirnov test was used to verify data distribution, and confirming the kinematics data, height and mass conform to normal distribution, except age. Independent-t tests was applied to compare the normally distributed data of CAI and control group, and Mann-Whitney U tested the age between-group. All statistical analyses were performed using SPSS software version21.0 software. Statistically significant differences were set at $P \leq 0.05$.

3. Results

Participants' demographic characteristics are displayed in Table 1. In this study, 53 individuals with chronic ankle instability (33 males and 20 females) were included in cases, the mean CAIT score of participants with CAI was 14.85 ± 4.05 points. 53 healthy subjects (33 males and 20 females) were age-, body mass-, and height-matched controls. Baseline characteristics between-group were well matched. There were no significant differences between-group in age ($P = 0.68$), height ($P = 0.63$), and mass ($P = 0.52$).

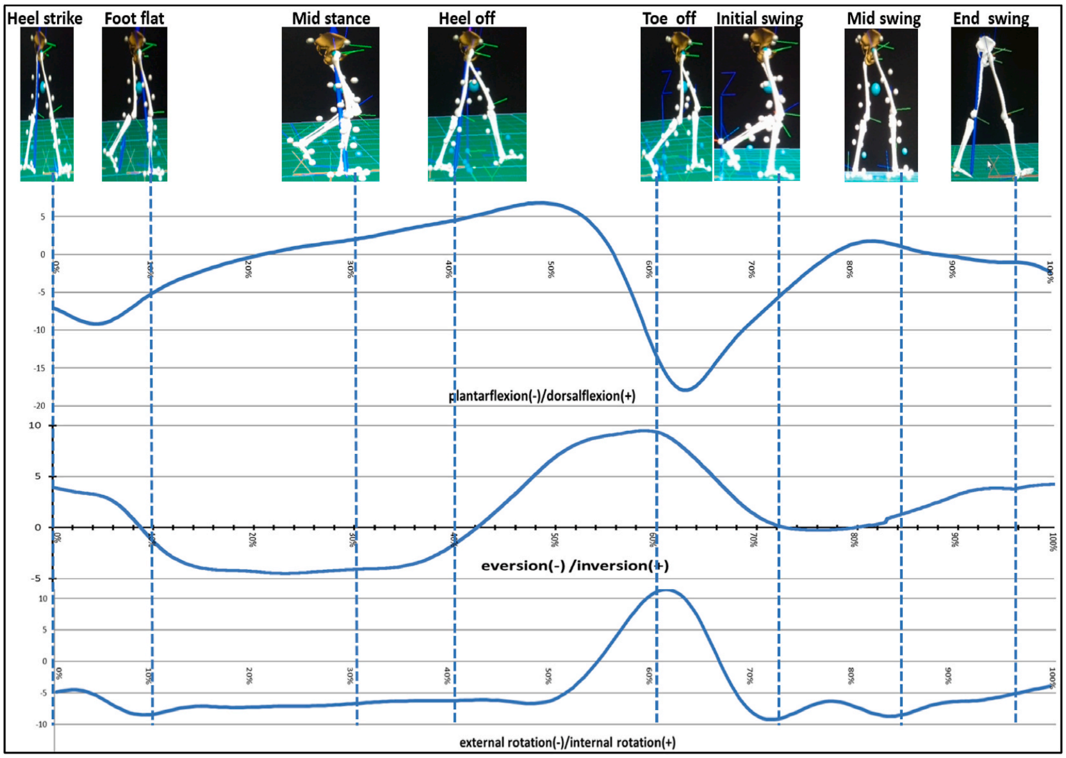

Fig. 4. Key points in the full gait cycle and 3-D kinematics curve of the ankle (e.g. right limber). Note: HS: Heel contacts the ground, and there is a reaction force. FF: Foot fully contacts the ground. MS: Line of gravity is vertical to the ground. HO: Heel of the foot leaves the ground. TO: Ground reaction force moves to the forefoot. ISW: Both thighs overlap in the sagittal view. MSW: Shank is perpendicular to the ground. ESW: Before heel strike, with no ground reaction force.

Table 1
Demographic and CAIT data.

Group	Sex (M:F)	Age (Years)	Height (cm)	Mass (kg)	CAIT
Control (n = 53)	33:20	24.66 ± 6.32	169.98 ± 9.00	63.11 ± 9.62	*NA*
CAI (n = 53)	33:20	25.11 ± 6.01	170.77 ± 7.80	64.28 ± 9.28	14.85 ± 4.05
p-value	*NA*	0.68	0.63	0.52	*NA*

Note: M = Male; F = Female.

Changes in sagittal plane ankle kinematics during walking are shown in Table 2. In the stance phase, the ankle was in plantarflexion at heel strike, and increased plantarflexion during foot flat. There were no significant differences ($P > 0.05$) in kinematic changes in the points of heel strike and foot flat between the CAI and control groups. From mid stance to heel off, the ankle exhibited continuously increasing dorsiflexion. There were no significant differences ($P > 0.05$) in kinematic changes in the points of mid stance and heel off between-group. In toe off, the ankle turned to plantarflexion, and the angle CAI group (−16.01° ± 7.32°) was significantly smaller ($P = 0.049$, Cohen's d = 0.387) than the control group (−18.82° ± 7.22°). In the swing phase, ankle plantarflexion was decreased in the initial swing, turned to dorsiflexion in mid-swing, and plantarflexion in the end swing in preparation for landing again. The angle of ankle in these points were not significant differences ($P > 0.05$) between-group.

Changes in frontal plane ankle kinematics are displayed in Table 3. In the stance phase, the ankle was in an inverted position in heel strike, and the angle of the CAI group (4.58° ± 2.82°) was significantly greater ($P = 0.007$, Cohen's d = 0.271) than the control group (3.83° ± 2.72°). An almost neutral position was achieved in foot flat. Then the ankle displayed an eversion movement from mid stance to heel off, which turned to inversion in toe off. In mid stance and heel off, the angle of the CAI group (−3.61° ± 1.75°, −3.60° ± 2.80°, respectively) was significantly smaller ($P = 0.010$, 0.033, Cohen's d = 0.288, 0.089, respectively) than the control group (−4.16° ± 2.06°, −3.88° ± 3.47°, respectively). In the swing phase, the ankle inversion position and the ankle angle were significantly higher in the CAI group (2.40° ± 5.68°, 2.11° ± 3.88° and4.44° ± 3.65°, respectively) than the control group (1.21° ± 4.44°,1.27° ± 3.35° and 3.69° ± 3.34°, respectively) in the initial, mid and end of the swing phase ($P = 0.035$, 0.019 and 0.021, Cohen's d = 0.233,0.232 and 0.214, respectively).

Changes in horizontal plane ankle kinematics during walking are shown in Table 4. In the stance phase, the ankle was in external rotation from heel strike to heel off, and changed to internal rotation in toe off. In the swing phase, the ankle was in external rotation from the initial swing to the end swing phase. There were no significant differences ($P > 0.05$) in kinematic changes between the CAI and control groups.

4. Discussion

This study focused on 3D ankle kinematics in key points of the full gait cycle, in order to explore the dynamic characteristics of ankle kinematics during walking in individuals with CAI. The results indicated that, compared with healthy controls, individuals with CAI have altered sagittal- and frontal-plane kinematics. Specifically, individuals with CAI exhibited decreased plantarflexion in toe off, increased inversion in heel strike and initial, mid and end swing, and decreased eversion in mid stance and heel off. We did not find any significant changes in horizontal plane kinematics during walking.

When walking, the ankle displays plantarflexion/dorsiflexion in the sagittal plane. Concomitantly, it also needs to coordinate motion in the frontal and horizontal planes during normal gait [26] to maintain the coordinated, stable, and efficient shifting of the human body [27,28]. The ankle stability system, which includes static (i.e., ligaments, bones, and joints) and dynamic (i.e., muscles and tendons) structures, is the main factor affecting normal ankle kinematics during walking. The lateral ligament complex of the ankle is composed of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL). Approximately 85 % of all ankle sprains result in injury to the lateral ligamentous complex [29], of which injury to the ATFL and CFL are most common [30]. The ATFL primarily prevents internal rotation, anterior translation of the talus, and restrains plantarflexion. The CFL is the primary constraint to ankle inversion while the ankle is in a dorsiflexed or plantarflexed position.

When the ankle is in a plantarflexion position, the ATFL becomes taut and begins to experience strain in order to maintain ankle stability. Deficiency in the ATFL will reduce restraint to plantarflexion and increase anterior translation, internal rotation, and superior translation of the talus [31]. In addition, the bony anatomy of the ankle provides less stability and constraint in plantarflexion. We found that patients with CAI had decreased plantarflexion in toe off. This suggests that the kinematic changes in the ankle associated with CAI manifest as decreased plantarflexion in toe off during walking. This may reflect an attempt to relieve the strain on the impaired ATFL, and avoid instability. In contrast to what we found, Chinn et al. [32] reported that ankle plantarflexion was increased

Table 2
Ankle kinematic changes in the sagittal plane (Degree, Mean ± SD) .

Group	HS	FF	MS	HO	TO	ISW	MSW	ESW
Control (n = 53)	−3.19 ± 3.16	−6.89 ± 3.13	0.87 ± 2.35	8.46 ± 3.13	−18.82 ± 7.22	−12.17 ± 7.79	2.36 ± 3.86	−2.99 ± 3.40
CAI (n = 53)	−3.79 ± 2.74	−6.65 ± 3.11	0.84 ± 2.89	8.56 ± 4.06	−16.01 ± 7.32*	−10.63 ± 7.46	1.43 ± 3.06	−3.83 ± 3.02
p-value	0.295	0.689	0.952	0.897	0.049	0.302	0.170	0.186
Cohen's d	–	–	–	–	0.387	–	–	–

Note: * indicates compare with control $P < 0.05$, ”-” means plantarflexion.

Table 3
Ankle kinematic changes in the frontal plane (Degree, Mean ± SD) .

Group	HS	FF	MS	HO	TO	ISW	MSW	ESW
Control (n = 53)	3.83 ± 2.72	0.48 ± 0.29	−4.16 ± 2.06	−3.88 ± 3.47	3.55 ± 4.82	1.21 ± 4.44	1.27 ± 3.35	3.69± ± 3.34
CAI (n = 53)	4.58 ± 2.82$^{\#}$	0.53 ± 0.26	−3.61 ± 1.75*	−3.60 ± 2.80*	4.59 ± 5.50	2.40 ± 5.68*	2.11 ± 3.88*	4.44 ± 3.65*
p-value	0.007	0.092	0.010	0.033	0.051	0.035	0.019	0.021
Cohen's d	0.271	–	0.288	0.089	–	0.233	0.232	0.214

Note: * indicates compare with control $P < 0.05$, $^{\#}$ indicates compare with control $P < 0.01$ "-" means eversion.

Table 4
Ankle kinematic changes in the horizontal plane (Degree, Mean ± SD) .

Group	HS	FF	MS	HO	TO	ISW	MSW	ESW
Control (n = 53)	−1.09 ± 5.59	−5.05 ± 5.69	−4.64 ± 4.49	−3.45 ± 4.88	6.63 ± 6.40	−0.46 ± 6.18	−3.14 ± 4.95	−1.19 ± 4.79
CAI (n = 53)	−0.20 ± 5.59	−3.77 ± 5.54	−3.15 ± 4.94	−2.37 ± 5.24	7.20 ± 7.00	−0.83 ± 5.69	−1.72 ± 4.86	−0.13 ± 5.74
p-value	0.295	0.243	0.107	0.276	0.662	0.262	0.138	0.202

Note: "-" means external rotation.

in individuals with CAI while walking in shoes on a treadmill. This inconsistency in findings may be due to the different walking surfaces. Yao et al. [33] determined that the maximum gastrocnemius force was greater during treadmill walking. Walking on a treadmill may require individuals to increase the plantarflexion force and plantarflexion movement.

In movement function, decreased plantarflexion results from a decrease in plantarflexor function. Many studies have claimed that CAI existed decreased eccentric and concentric plantarflexor strength [34]. However, the plantarflexors engage in concentric contraction to produce the propulsive force in toe off. Decreased plantarflexion was found to reduce the propulsive force at the ankle and increase force generation at the hip. Waterval et al. [35]found that plantarflexor weakness reduced ankle push-off, which was compensated by the ipsilateral hip and/or contralateral leg. However, the plantarflexors consist of the triceps surae, tibialis posterior, flexor halluces longus, flexor digitorum longus, peroneus longus and brevis, all of which contribute differently from heel off to toe off in the gait phase. Clancy et al. [36] reported that the major peak in gastrocnemius firing occurred at 40–45 % of the gait cycle. This suggests that the maximum contraction of the gastrocnemius likely occurs in heel off. But, the other components contributing to plantarflexion during walking were not reported. Therefore, the contributions of muscle function deficits to abnormal plantarflexion in individuals with CAI warrant further study. This will contribute to the development of more precise assessments and accurate interventions in individuals with CAI.

We also found that individuals with CAI experienced increased ankle inversion in heel strike and the initial, mid and end swing of the gait cycle, and decreased eversion in mid stance and heel off. Similarly, Koldenhoven et al. [37]also reported greater ankle inversion during the heel strike and swing phases in individuals with CAI. Our results also indicate that CAI is associated with significant eversion changes in the mid stance and heel off. Thus, the structural factors contributing to these kinematic changes are likely a result of injury to the lateral ligamentous complex. Cao et al. [38]also found the FAI results in greater inversion of the subtalar joints, which is mainly affected by CFL injury. However, the dynamic kinematics changes in different gait phase may be mainly effected by the functional factors.

In movement function, individuals with CAI displayed deficits in joint proprioception [39] and decreased eccentric and concentric evertor strength [34]. Proprioceptive receptors are located in the muscles, tendons, ligaments, and articular capsules. Injuries to the lateral ligaments and muscles contribute to proprioceptive sensor deficits and ankle sprain. The decreased proprioception leads to the body cannot perceive the ankle position and is too slow to respond to sudden inversion. However, the evertor engages in eccentric contraction in heel strike and swing phase. This suggests that eccentric evertor strength deficits may be the main contributing factor for increased ankle inversion. The evertor produces concentric force in mid stance and heel off. Thus, the decreased eversion in mid stance and heel off should be result from concentric evertor strength deficits. The abnormal ankle kinematics in the frontal plane and gait phases suggest that eccentric and concentric evertor strength deficits of CAI could effect of ankle dynamic function in different gait phases [20], which should be studied more closely during movement function assessments and interventions. These findings have implications for the design of movement interventions in individuals with CAI.

Thus, the changes of ankle kinematics at different gait phases and dimensions in full gait cycle are mainly affected by different movement function of ankle. These abnormal ankle 3D kinematics of patients with CAI during walking on ground at a self-selected speed will contribute to directly, all-round, dynamic, continuous and accurate evaluate the movement function deficit, identify the dysfunction tissue of CAI patients, which will provide reference for precise treatment in clinical.

A limitation is that the study did not distinguish the severity of chronic ankle instability. This may have biased the study results. Another limitation of this study is that it not identified dominance leg of individuals. This may not fully reflect the gait characteristics of individuals with CAI, and impacted the effect size of results.

5. Conclusions

In summary, individuals with CAI exhibited decreased plantarflexion in toe off, increased inversion in heel strike and initial, mid and end swing, and decreased eversion in mid stance and heel off when walking. These abnormalities mainly due to different movement function deficits. They may also increase the risk of ankle and proximal joint injury and require accurate functional assessment and specialized rehabilitation interventions.

Data availability statement

Data associated with the study has not been deposited into a publicly available repository and data will be made available on request.

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CRediT authorship contribution statement

Gao Piming: Writing – original draft, Validation, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Yu Yaming:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Shen Hai:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Li Xia:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Luo Xiaobing:** Writing – review & editing, Software, Resources, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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