Biomechanical Characteristics of the Support Leg During Side-Foot Kicking in Soccer Players With Chronic Ankle Instability

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Investigation performed at the International University of Health and Welfare, Narita, Chiba, Japan

Background: Chronic ankle instability (CAI) in soccer players can increase the risk of recurrent ankle varus sprains and damage the articular surface of the ankle joint, thus increasing the risk of osteoarthritis. It is important to understand the biomechanical characteristics of the support leg during kicking in soccer players with CAI.

Purpose/Hypothesis: The purpose of this study was to clarify the kinematics of the kicking motion of soccer players with CAI. It was hypothesized that at the point before ball contact when the support leg makes flat-foot contact with the ground, soccer players with CAI will land with ankle inversion in the support leg during a side-foot kick compared with players without CAI.

Study Design: Controlled laboratory study.

Methods: The study cohort included 19 male college soccer players (mean age, 20.5 ± 0.9 years) with greater than 8 years of soccer experience who were recruited from August 2019 to March 2020. Of these athletes, 10 had CAI and 9 had no CAI in the support leg, as diagnosed according to the Cumberland Ankle Instability Tool. Kinematic data for the trunk, hip, knee, and foot of the support leg during a side-foot kick were obtained using a 3-dimensional, motion-analysis system. The Mann-Whitney *U* test or Student *t* test was selected to identify differences in variables between the CAI and non-CAI groups.

Results: There were no significant differences in physical characteristics between the CAI and non-CAI groups. At the point when the support leg made flat-foot contact with the ground, the players with CAI had more eversion of the hindfoot with respect to the tibia (-28.3° ± 12.1° vs -13.9° ± 14.2°; $P = .03$), a more varus alignment of the knee (26.0° ± 10.7° vs 13.7° ± 10.5°; $P = .03$), and a lower arch height index (0.210 ± 0.161 vs 0.233 ± 0.214; $P = .046$) compared with non-CAI players.

Conclusion: Significant differences between players with and without CAI were seen in the support leg kinematics at flat-foot contact with the ground during the kicking cycle.

Clinical Relevance: The biomechanical alignment of the support leg during a side-foot kick in players with CAI may reflect a subconscious attempt to avoid inversion of the foot and further ankle sprains.

Keywords: ankle injury; biomechanics; joint instability

The most frequent kicking motions in soccer are the side-foot and in-step kicks. The side-foot kick is a strong and accurate motion during which the large medial area of the foot makes contact with the ball. This motion is often selected to maximize the accuracy of short passes and shooting. Therefore, the dynamic stability of the support leg during a kicking motion is an essential physical and functional factor to maintain or improve kicking performance. In a previous study,[22] the support leg attenuated the impact of landing on the initial ground during a kicking motion. In addition, the dynamic stability of the knee joint of the support leg contributes to the swing velocity of the kicking leg.[22] As a result, it was observed that, while the support leg plays a significant role in transferring mechanical energy to the proximal segment, it also contributes to a proximal-distal sequential motion of the swing leg.[1,22,] Thus, the ability to balance solely on the support leg influences kicking accuracy.[6]

Soccer players experience high rates of ankle sprain injuries and reinjuries.[36,41,42] The ankle sprain incidence in soccer is 2.52 per 1000 person-hours,[12] and the ankle sprain recurrence rate (defined as an injury of the exact nature and location involving the same player in the same season) is 9%; in contrast, the average reinjury rate for all injuries is 7%.[42] In the 2010 Fédération Internationale de Football Association (FIFA) World Cup, ankle sprain was the most common of all ankle disabilities and injuries. As a result, approximately 66% of players with an ankle sprain could not participate in training and match play.[11] Furthermore, players with this type of injury required an average convalescence period of 43.4 days

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from the time of the injury to return to play.[23] Therefore, preventing ankle sprains and their subsequent recurrence is an important consideration.

Structural and functional failure of the ankle after a sprain can result in persistent ankle joint instability.[17,18,38] In a previous epidemiological survey, 81 (46.3%) of 175 ankle sprains were associated with chronic ankle instability (CAI).[17] Furthermore, the instability of the ankle joint alters the ability to control posture and has been associated with an increased risk of acute ankle sprains.[3,32] Previous studies have reported that CAI is associated with greater ankle inversion during the landing phase of the gait.[7,25,33] As observed, when the evertor muscles could not counteract the external inversion torque while landing on the ground, hyperinversion was likely to result in trauma to the lateral ankle ligaments.[10,40] Similarly, soccer players with CAI may land with ankle inversion of the support leg during kicking due to poor evertor muscle contraction. Therefore, CAI in soccer players can increase the risk of recurrent ankle varus sprains and damage the articular surface of the ankle joint, thus increasing the risk of osteoarthritis.[20] However, no study has yet to investigate the effect of residual CAI after an ankle sprain of the support leg on kinematic dysfunction during the kicking motion.

In the current study, we aimed to clarify the kinematic characteristics of the support leg of soccer players with CAI, with a focus on side-foot kicking. It was hypothesized that soccer players with CAI would land with the ankle inversion of the support leg during a side-foot kick.

METHODS

Study Participants

The study cohort consisted of 19 male college soccer players (mean age, 20.5 ± 0.9 years; mean height, 172.2 ± 4.9 cm; mean weight, 65.0 ± 4.6 kg) with more than 8 years of soccer experience (mean playing experience, 9.7 ± 2.1 years) who were recruited from August 2019 to March 2020 at the International University of Health and Welfare, Narita Campus, Chiba, Japan. For all participants, the preferred (dominant) leg for kicking a ball was the right leg, with the left leg acting as the support leg; 4 participants were strikers, 5 were midfielders, and 10 were defenders.

The inclusion criteria included patients aged >18 years with soccer experience of >6 years and an absence of current pain in the lower extremities and trunk during daily activities and soccer practice. The exclusion criteria included any history of orthopaedic surgery to the trunk, hip, knee, or ankle or any serious injury. The study protocol received ethics committee approved, and the study was conducted following the tenets of the Declaration of Helsinki. All participants submitted written informed consent before testing.

Instrumentation and Measurement Protocols

Before inclusion in this study, the participants completed a questionnaire regarding physical characteristics, current medical information, and medical history, including ankle sprain. In addition, they completed the Cumberland Ankle Instability Tool (CAIT).[19] The CAIT is a valid and reliable measure of the severity of functional ankle instability used widely by researchers and physicians,[19,27,28] with a cutoff score of <27 to indicate femoroacetabular impingement.[18] All participants were divided into a non-CAI (CAIT score ≥28) and a CAI (CAIT score ≤27 and a history of ankle sprain) group, as described in previous studies.[8,17]

All experiments in this study were conducted in the motion analysis laboratory of our university. All participants wore closely fitted, dark shorts for data collection. Six force plates (MSA-6 Mini Amp; AMTI) were used to record ground-reaction forces (GRFs) during testing at a sampling rate of 1000 Hz; GRFs were recorded in 3 directions: vertical, anterior-posterior, and medial-lateral. A 3-dimensional motion analysis system equipped with 8 cameras (Vicon MX system; Oxford Metrics) was used to record lower extremity and trunk kinematics during testing at a sampling rate of 250 Hz. The data were filtered digitally using a fourth-order zero-lag low pass Butterworth filter with a cutoff frequency of 16 Hz. A Vicon Plug-in-Gait Full Body model (Oxford Metrics) and an Oxford foot model of the left (support) foot were used to obtain foot kinematic values (Figure 1).[5,35]

Reflective markers (14 mm) were placed so as to create coordinate systems of the head (left/right front head and back head), the torso (7th cervical vertebrae, 10th thoracic vertebrae, clavicle, sternum, and right scapula), the upper arm and forearm (left/right acromion, upper arm, lateral epicondyle, forearm, radial styloid, ulnar styloid, and the head of the second metacarpal), the pelvis (left/right anterior superior iliac spine and posterior superior iliac spine), and the thigh and tibial segments (left/right lower lateral third of the thigh, lateral epicondyle, lower third of the shank, second metatarsal head, calcaneus), according to the Vicon Plug-in-Gait Full Body model. In addition, reflective markers (9.5 mm) were added to create hindfoot and forefoot segments and placed on the left/right lateral head of the fibula, tibial tuberosity, anterior aspect of the shin, medial malleoli, posterior end of the calcaneus, posterior calcaneus proximal, lateral

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Ethical approval for this study was obtained from the International University of Health and Welfare (approval No. 19-Io-59).

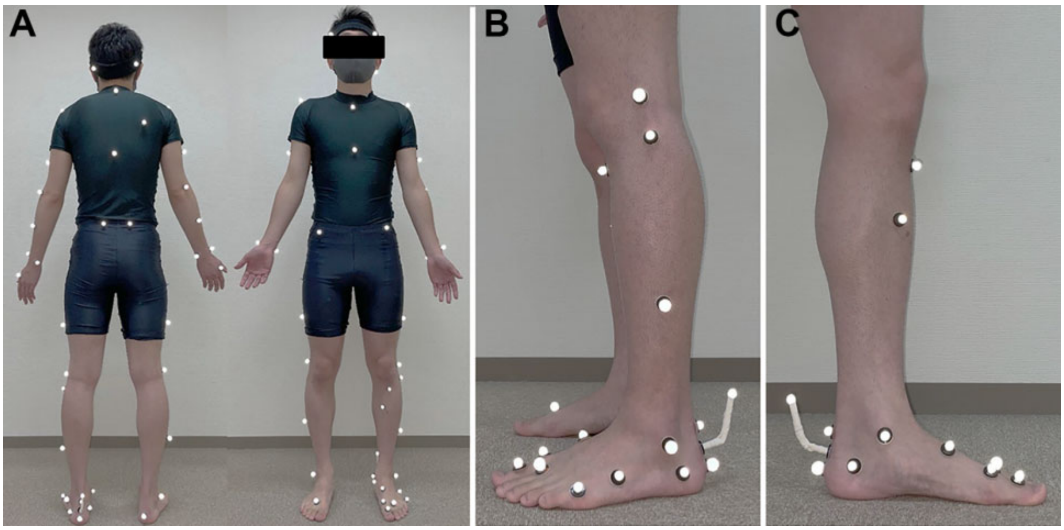

Figure 1. Marker placements for (A) the Vicon Plug-in-Gait Full Body model and (B, C) the Oxford foot model of the left (support) foot.

calcaneus, sustentaculum tali, first metatarsal (proximal dorsal), first metatarsal (distal medial), fifth metatarsal (proximal dorsal), fifth metatarsal (distal lateral), and hallux (proximal end of first distal phalanx), according to the Oxford foot model of the left foot. Vicon Nexus software (Oxford Metrics) was used to calculate the angle of the lower extremity joints and trunk based on kinematic and GRF data.

After a standardized warm-up, including jogging slowly and stretching for approximately 10 minutes, the participants performed 5 side-foot kicks on a stationary ball (size 5). All participants were instructed to kick the ball with the medial side of the foot with as much force as possible toward a net (width 60 cm, height 60 cm) positioned 2 m in front of the stationary ball. The approach velocity was arbitrary for them, and the approach angle was controlled at 45°. Intervals between trials were set at 3 minutes, and off-target kicks were excluded. The middle 3 kicks of 5 successful kicking trials were used for data analysis.

Data Analysis

The GRF in all 3 directions and the trunk, hip, knee, and foot angles were obtained for the support leg during a single kicking cycle, defined as the point of initial ground contact (when the vertical GRF first exceeded 10 N) to the frame when the center of mass of the kicking foot reached the highest vertical position in the follow-through phase after ball contact. For analysis purposes, the kicking cycle was normalized as a percentage, and the GRF data for each participant were normalized to body weight (N/kg). For each participant, we also calculated the kinetic and kinematic data at the point in the kicking cycle before ball contact when the support leg made flat-foot contact with the ground (flat-foot contact point). This point was chosen because it is when a large ground impact is applied to the bottom of the support foot for the first time in the kicking cycle.

The output angles for the lower extremity and trunk were calculated from the *y*-*x*-*z* Cardan angles derived by comparing the relative orientations of the 2 segments. The trunk, hip, and knee angles were calculated from the torso and the pelvic segments, the pelvic and the thigh segments, and the thigh and the tibial segments, respectively. Foot angles included the angle of the hindfoot with respect to the tibia (HFTBA) and the angle of the forefoot with respect to the hindfoot (FFHFA). HFTBA dorsiflexion and inversion angles and FFHFA inversion angle were also calculated. Finally, we calculated the arch height index of the support foot,[31] measured as the perpendicular distance between the first metatarsal (proximal dorsal) marker and the plane defined by the first metatarsal (distomedial), fifth metatarsal (proximodorsal), and fifth metatarsal (distolateral), divided by the foot length (second metatarsal head – calcaneus). The arch height index is a measure of the rigidity of the forefoot segment and an estimate of arch height.[9]

Statistical Analysis

All data are reported as means and standard deviations. The Kolmogorov-Smirnov test confirmed that the data were normally distributed ($P < .05$). Depending on whether the data were normally distributed, the Mann-Whitney *U* test or Student *t* test was selected to identify differences between the CAI and non-CAI groups. Differences with a *P* value of <.05 were considered statistically significant. Data analyses were conducted using IBM SPSS Statistics for Windows Version 24.0. (IBM).

RESULTS

Based on the mean CAIT score in the support leg, 10 players (CAIT score, 25.2 ± 2.1; age, 20.4 ± 1.0 years; height, 173.0 ± 4.8 cm; weight, 66.6 ± 2.7 kg; playing

TABLE 1
GRF Components and Trunk, Hip, Knee, and Foot Angles at the Flat-Foot Contact Point of the Support Leg During a Side-Foot Kick[a]

	CAI Group (n = 10)	Non-CAI Group (n = 9)	MD (95% CI)	*t*	*P*	Effect Size (Cohen *d*)
GRF, N/kg						
Vertical	16.6 ± 6.3	15.8 ± 6.7	-0.77 (-7.27 to 5.72)	-0.25	.80	-0.17
Anterior (−)/posterior (+)	2.1 ± 1.9	1.7 ± 1.1	-0.33 (-1.92 to 1.26)	-0.44	.67	-0.21
Medial (−)/lateral (+)	3.9 ± 1.7	3.5 ± 2.0	-0.42 (-2.28 to 1.44)	-0.48	.64	-0.20
Trunk angle, deg						
Flexion (+)/extension (-)	5.4 ± 11.6	6.3 ± 11.9	0.86 (-10.94 to 12.67)	0.16	.88	0.07
Rotation, right (+)/left (-)	12.5 ± 11.8	19.8 ± 7.3	7.34 (-2.80 to 17.47)	1.54	.14	0.73
Side-flexion, right (+)/left (-)	-9.7 ± 4.5	-12.2 ± 5.5	-2.46 (-7.44 to 2.53)	-1.05	.31	-0.50
Hip angle, deg						
Flexion (+)/extension (-)	34.7 ± 8.5	38.2 ± 15.3	3.55 (-8.49 to 15.58)	0.63	.54	0.30
Adduction (+)/abduction (-)	-7.2 ± 9.2	-8.6 ± 5.4	-1.39 (-9.20 to 6.41)	-0.38	.71	-0.18
Rotation, internal (+)/external (-)	16.6 ± 20.5	1.5 ± 18.9	-15.12 (-35.02 to 4.77)	-1.61	.13	-0.76
Knee angle, deg						
Flexion (+)/extension (-)	36.3 ± 8.5	36.0 ± 10.9	-0.25 (-9.91 to 9.41)	-0.05	.96	-0.03
Varus (+)/valgus (-)	26.0 ± 10.7	13.7 ± 10.5	-12.30 (-22.94 to -1.65)	-2.45	**.03**	-1.16
Rotation, internal (+)/external (-)	0.3 ± 8.7	2.3 ± 21.3	2.03 (-13.59 to 17.66)	0.28	.79	0.13
Foot angle, deg						
HFTBA dorsiflexion (+)/plantarflexion (-)	-9.5 ± 11.5	4.4 ± 30.1	13.90 (-11.74 to 39.54)	1.23	.25	0.64
HFTBA inversion (+)/eversion (-)	-28.3 ± 12.1	-13.9 ± 14.2	14.41 (1.27 to 27.54)	2.33	**.03**	1.10
FFHFA inversion (+)/eversion (-)	-12.4 ± 4.7	-10.6 ± 13.8	2.28 (-7.58 to 12.13)	0.49	.63	0.23

[a]Values are reported as mean ± SD unless otherwise indicated. Bolded *P* values indicate statistically significant difference between the CAI and non-CAI groups ($P < .05$). CAI, chronic ankle instability; FFHFA, angle of the forefoot with respect to the hindfoot; GRF, ground-reaction force; HFTBA, angle of the hindfoot with respect to the tibia; MD, mean difference.

experience, 9.3 ± 1.9 years) were assigned to the CAI group and 9 players (CAIT score, 29.2 ± 1.0; age, 20.7 ± 0.9 years; height, 171.3 ± 5.1 cm; weight, 63.3 ± 5.7 kg; playing experience, 10.2 ± 2.3 years) were assigned to the non-CAI group. There were no significant differences in any physical characteristics between the groups.

Table 1 shows the mean values for the GRF components and for the trunk, hip, knee, and foot angles at the flat-foot contact point of the support leg. There were no differences on any GRF variables between the CAI and non-CAI groups. The knee varus angle was significantly larger in the CAI group than in the non-CAI group (26.0° ± 10.7° vs 13.7° ± 10.5°; $P = .03$), and the HFTBA was significantly more everted in the CAI group than in the non-CAI group (-28.3° ± 12.1° vs -13.9° ± 14.2°; $P = .03$) (Table 1). The time-series data of the support leg during a single kicking cycle are shown for the GRF components in Figure 2; for the trunk, hip, and knee joint angles in Figure 3; and for the HFTBA and FFHFA in Figure 4. The arch height index of the support leg was significantly lower in the CAI versus the non-CAI group at the flat-foot contact point (0.210 ± 0.161 vs 0.233 ± 0.214; $P = .046$).

DISCUSSION

Results showed that, compared with those without CAI, players with CAI had a significantly larger knee varus angle, a more everted HFTBA, and a lower arch height index at the flat-foot contact point in the support leg during a side-foot kick. Therefore, our hypothesis that soccer players with CAI land with the ankle inversion of the support leg during a side-foot kick was not supported.

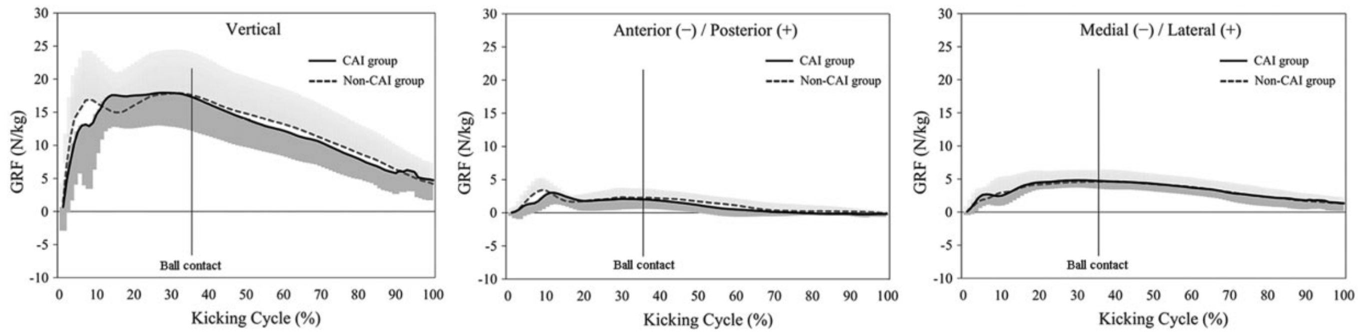

Figure 2. Time-series data of the vertical, anterior-posterior, and medial-lateral GRF components of the support leg for the CAI group (solid line) and non-CAI group (dashed line) during the kicking cycle. The shaded areas indicate SDs. The kicking cycle was normalized from the initial contact of the support leg (0%) to the top of the kicking foot position in the follow-through phase (100%). The vertical line in each graph shows the time of ball contact (when the center of the ball began to move; 36.7% ± 7.3% of the kicking cycle). CAI, chronic ankle instability; GRF, ground-reaction force.

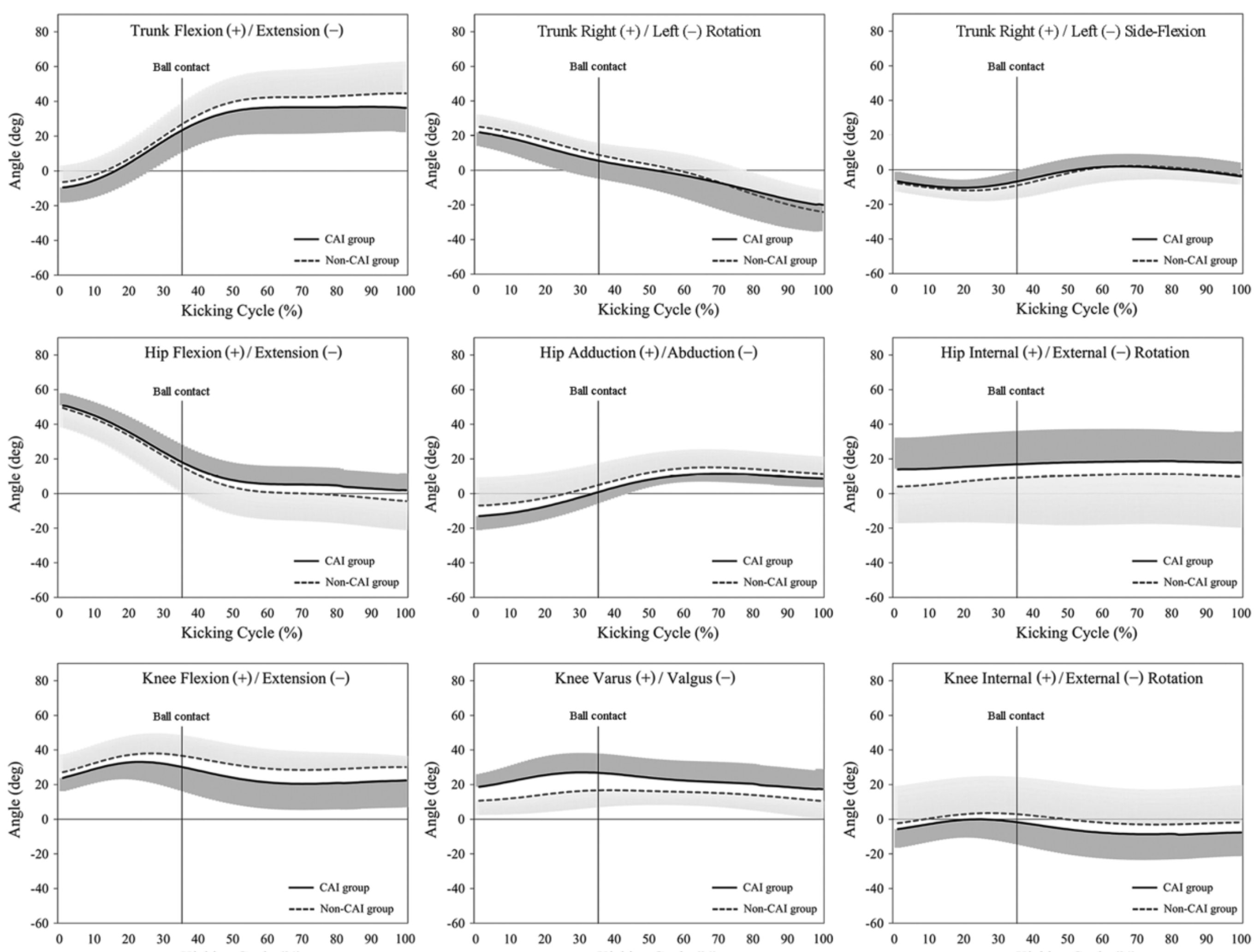

Figure 3. Time-series data of the trunk, hip, and knee angles of the support leg for the CAI group (solid line) and non-CAI group (dashed line) during the kicking cycle. The shaded areas indicate SDs. The kicking cycle was normalized from the initial contact of the support leg (0%) to the top of the kicking foot position in the follow-through phase (100%). The vertical line in each graph shows the time of ball contact (when the center of the ball began to move; 36.7% ± 7.3% of the kicking cycle). CAI, chronic ankle instability.

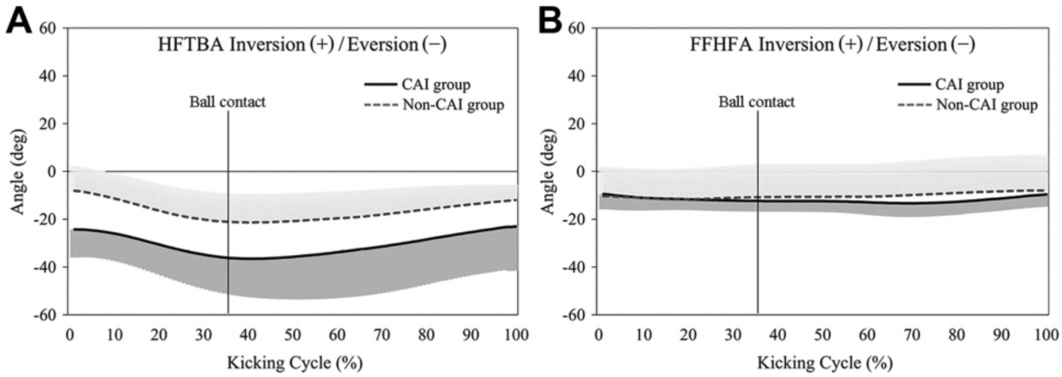

Figure 4. Time-series data of foot inversion/eversion angle of the support leg for the CAI group (solid line) and non-CAI group (dashed line) during the kicking cycle. (A) Angle of the left hindfoot with respect to the tibia (HFTBA) and (B) angle of the forefoot with respect to the hindfoot (FFHFA). The shaded areas indicate SDs. The kicking cycle was normalized from the initial contact of the support leg (0%) to the top of the kicking foot position in the follow-through phase (100%). The vertical line in each graph shows the time of ball contact (when the center of the ball began to move; 36.7% ± 7.3% of the kicking cycle). CAI, chronic ankle instability.

Studies have proposed that the instability of the ankle joint is caused by a lack of primary neuromuscular conditioning,[14,15] involving the ligaments and intrinsic foot muscles in the ankle,[21,30,34] or lower extremity malalignment.[39] Hence, it is considered that the static and dynamic stabilizers of the ankle joint play important roles in dynamic and static postural control during landing. However, CAI is associated with poor rigidity of the ankle joint and foot due to lower activities of the intrinsic foot muscles or lateral ankle instability. In this study, we found eversion of the hindfoot with respect to the tibia in CAI players. In addition, the lower arch height of the support leg can be considered to result from a decrease in the first metatarsal position caused by hindfoot eversion. This characteristic foot alignment indicates that soccer players with CAI may be trying to avoid risky foot alignment during the side-foot kick with eversion of the hindfoot and a lateral tilt of the tibia (as the result of greater knee varus) to prevent trauma to the lateral ankle ligaments.

Lin et al[29] also reported that, compared with uninjured athletes, those with CAI had a significantly greater ankle eversion angle upon initial landing during a single-leg forward jump. However, Kunugi et al[26] showed that landing in the lateral direction exhibits a more inverted ankle and supinated rearfoot. These reports indicate that landing with greater loads or in the lateral direction could generate greater foot inversion. Therefore, soccer players with CAI may experience foot inversion depending on the direction of stepping or kicking.

The results of our study also showed that the GRF components with the flat foot of the support leg acted in the posterior, lateral (ie, toward the support leg), and vertical directions. Of the 3 GRF components, the vertical component was the largest and exhibited the steepest increase, reaching peak magnitudes. Studies have reported that the ankle, knee, and hip joints are crucial to attenuate the impact of landing.[37,43] Specifically, after the ankle absorbs the first load of the lower extremity joints, the periarticular joint structures then absorb the landing energy.[13,37] Regarding our finding of significantly lower arch height in the support leg of CAI players, a study by Kirby[24] suggested that maintaining the height and shape of the medial longitudinal arch is essential to attenuate the impact force of GRF acting on the plantar foot.

Limitations

Some limitations to this study should be noted. First, foot kinetic measurements with a multisegment foot model, such as the Oxford foot model, are hampered by measurement limitations and modeling assumptions.[2,4] In this study, joint moments of the ankle and foot were not evaluated during side-foot kicking. Therefore, we focused on only the lower extremities and foot kinematics. Second, all kicking trials were conducted barefoot to minimize measurement errors by shifting reflective markers while kicking. In addition, all kicking trials were conducted in the laboratory, unlike the environment in daily practices and games. Therefore, these results were not considered the effects of the shock absorption by shoes or protection/fixation of the foot shape and the measurement environment differences from the actual sports situations. Third, mechanical ankle instability was not evaluated because this study focused on the functional mechanism of side-foot kicking specific to soccer. In a previous study, the CAIT measured the severity of CAI due to mechanical or functional instability or, most likely, a combination of these 2 phenomena.[16] As a result, the ankle's mechanical instability was proposed to be affected by the CAI severity and CAIT score. Hence, although it has been confirmed as valid and reliable to evaluate the severity of functional instability of the ankle, it should be considered a self-reported evaluation tool and not equivalent to a physician's evaluation.

CONCLUSION

Soccer players with CAI landed with eversion of the hindfoot, a varus alignment of the knee, and a lower arch height of the support leg during a side-foot kick. These characteristic biomechanical alignments may be the result of soccer players with CAI attempting to avoid inversion of the foot, which is a risk factor associated with recurrence of ankle sprain, during a side-foot kick.

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