J. Phys. Ther. Sci. 30: 405–410, 2018

The Journal of Physical Therapy Science

Original Article

Postural stability for taekwondo athletes with repetitive ankle sprains during a single-leg stance

Minji Son[1)], Changhong Youm, PhD[2)*], Jehwan Woo[1)], Myeounggon Lee[1)], Youkyung Kim[1)], Jinhee Kim[1)]

[1)] *Biomechanics Laboratory, College of Health Sciences, Dong-A University, Republic of Korea*
[2)] *Department of Health Care and Science, College of Health Sciences, Dong-A University: 37 Nakdong-Daero 550 beon-gil, Saha-gu, Busan 49315, Republic of Korea*

Abstract. [Purpose] The purpose of this study is to investigate postural stability in such group of taekwondo athletes by measuring the center-of-pressure variables in both the injured limb and uninjured limb during a single-leg stance with eyes closed. [Subjects and Methods] The study includes eleven taekwondo athletes with repetitive ankle sprains (RASs) and eleven healthy taekwondo athletes (the controls) at the college level participating in taekwondo training sessions. For the controls, the "injured" limb was taken to be the left limb. [Results] The postural stability measured in both the anteroposterior and mediolateral directions using center-of-pressure variables was lower in the uninjured limb of the RAS group than in the control group during a single-leg stance with eyes closed. However, for the injured limb, there were no significant differences between the two groups. Furthermore, compared to the RAS group, the control group had higher stability in the injured limb than in the uninjured limb. [Conclusion] Individuals with RASs should ensure improvements in their proprioceptive and neuromuscular functions, as well as muscle strength, through an adequate period of rehabilitation to reduce the risk of re-injury.
Key words: Instability, Center of pressure, Lateral ankle sprain

(This article was submitted Nov. 10, 2017, and was accepted Dec. 12, 2017)

INTRODUCTION

Taekwondo is characterized by dynamic kicking techniques requiring strength, speed, stamina, balance, flexibility, and coordination. These kicking combinations include advanced kicks, such as jumping, spinning, and sliding kicks[1)]. In addition, a taekwondo athlete requires dynamic stability on the supporting limb to execute fast and jerky movements of the kicking limb. As in many sports, there is a high potential for injury that can affect elite athletic performance in taekwondo[2)]. The mean injury incidence rate in taekwondo athletes has been reported to be 79.3 injuries per 1,000 athletes from the beginning of electronic information records to 2008[1)]. Frequently injured body parts for taekwondo athletes include the head, neck, and lower limbs[3)]. Among these, the lower limbs were found to be the most commonly injured body regions[1)]. Approximately 46% of taekwondo athletes with lower limb injuries were reported to have experienced a second injury, and one of the most common injuries was an ankle sprain[3)].

Lateral ankle sprains accounted for approximately 80% of all ankle sprains, and they have a very high recurrence rate[4)]. In addition, 72% of individuals who sustain lateral ankle sprains have been reported to have residual symptoms and develop chronic ankle instability (CAI)[5, 6)]. CAI is defined as having repetitive ankle sprains on the same ankle after an acute ankle sprain along with pain, swelling, the ankle giving out, and decreased function[7)], all of which are linked to limitations in physical and daily activities[5)]. CAI can cause sprain recurrence, mechanical ankle instability, and functional ankle

*Corresponding author. Changhong Youm (E-mail: chyoum@dau.ac.kr)

Table 1. Demographics of the participants

	RASs (n=11)	Controls (n=11)
Age (yrs)	19.6 ± 0.8	19.3 ± 0.7
Height (cm)	178.8 ± 6.6	177.6 ± 7.6
Body mass (kg)	68.4 ± 8.3	66.3 ± 7.1
BMI (kg/m^2)	21.4 ± 1.8	21.0 ± 1.4
Gender (male/female)	9/2	9/2
Frequency of ankle sprain (repetitions)	2.9 ± 0.7	-

All data represent means and standard deviations.
BM: body mass index; RASs: repetitive ankle sprains.

instability[7]. Functional insufficiencies include impairments in proprioception, neuromuscular control, postural control, and strength[6]. Previous meta-analyses have suggested a significant decrease in postural stability in individuals with repetitive ankle sprains[8, 9]. These deficits undermine the success of taekwondo athletes as well as athletes in other sports where postural stability and control play a significant role[10].

A history of ankle injury is also known to be associated with an increased risk of future injuries. Hiller et al.[8] suggested that people with recurrent ankle sprains show a distinguishing feature of greater postural sway when standing with their eyes closed. Friden et al.[11] found diminished postural control in the injured and uninjured limbs of athletes after acute ankle sprains compared to a reference group. Evans et al.[12] also identified postural control deficits in both the injured and uninjured limbs of individuals after unilateral ankle sprains. Furthermore, Wikstrom et al.[9] suggested that balance is bilaterally impaired after an acute lateral ankle sprain, and patients with acute lateral ankle sprains should undergo balance training on both limbs. However, side-to-side differences within injured participants have not been consistently presented in previous studies. In particular, there have been no previous studies on postural stability that compared the injured limb (IL) and the uninjured limb (UIL) of taekwondo athletes with repeated ankle sprains who regularly participated in training sessions after completing a rehabilitation program.

Therefore, this study aims to investigate postural stability in taekwondo athletes with repetitive ankle sprains by measuring the center-of-pressure variables (COPs) in the IL and UIL for each athlete during a single-leg stance with eyes closed (EC). We hypothesized that postural stability would be lower in the repetitive ankle sprains (RASs) group than in the controls for both limbs and that postural stability would be lower in the IL than in the UIL of the RASs during a single-leg stance.

SUBJECTS AND METHODS

The study involved a case-control trial after an arbitrary sampled comparing taekwondo athletes in two groups: those with RASs and those without an ankle sprain (the controls). The groups included 11 taekwondo athletes with RASs (nine male athletes, two female athletes) and 11 taekwondo athletes without RASs (Controls; nine male athletes, two female athletes), all of whom had been participating in taekwondo competitions at the college level (Table 1). A priori estimated sample sizes for β=0.80 with α=0.05 were calculated. All participants were matched for gender, limb dominance (which was always the right limb), age, height, body mass, and body mass index. Thus, demographics did not differ between the groups ($p>0.05$).

The inclusion criteria for the RASs were a minimum of two ankle sprains of the left ankle within the prior three years. They were screened for inclusion using a Cumberland Ankle Instability Tool (CAIT) score of no more than 27 (ICC=0.96)[13]. All participants have been participating regularly in taekwondo training sessions at least four to five times per week. The exclusion criteria for both groups were: a history of ankle sprain injury or lower limb injury in the last six months; a history of lower limb fracture or surgery; a history of neurological dysfunction, vestibular or visual impairment; or any other pathology that would impair postural stability. All participants signed an informed consent form approved by the Institutional Review Board (IRB No. 2015-HR-018-04).

All participants were required to attend two experimental sessions, and they were asked to refrain from performing physical exercise and to maintain their regular daily activity level during the experimental period. In the first session, participants completed an assessment of physical characteristics, anthropometric measurements, and a CAIT assessment to quantify the functional ability of their ankles by a physical therapist[13]. Furthermore, all participants completed the visual analog scale (VAS), which is a simple and frequently used tool for the assessment of variations in the intensity of pain, with participants measuring their own pain on a 10 cm scale[14]. In addition, for each ankle, the inversion and eversion peak torques were measured at angular velocities of 120°/s and 300°/s, respectively, and a range of motion of 50° for eccentric and concentric contractions using an isokinetic dynamometer (Cybex HUMAC NORM, USA). Measurements were carried out after placing the participants in the supine position with the hip and knee angles at 60° and 90°, respectively, and with the pelvis and thighs secured using a seatbelt and thigh stabilizer pad, respectively. The bare feet of the participants were placed and secured on a footplate with 10° of plantarflexion. The inversion-to-eversion peak torques were defined as the highest torques achieved during five successive maximal eccentric-to-concentric contractions. The participants were familiarized with the study's procedures for a single-leg stance with EC.

In the second session, the participants warmed up by stretching and cycling for 5 min, followed by a 3-min rest before the single-leg stance trials. All participants sustained each single-leg stance trial for over 25 s, standing with the IL and the UIL on a force plate in random order, with the two trials separated by a 2-min rest period. The participants were required to complete a minimum of 3 practice trials prior to data acquisition[15]. During the single-leg stance, participants were instructed to stand barefoot with arms crossed at the chest and the knee of the non-standing leg flexed. Visually, they were told to fixate on a target in front of them, after which their eyes were closed. In addition, the participants were instructed to sway as little as possible during the single-leg stance.

Three infrared cameras (Oxford Metrics Vicon MX-T10, UK) and one force plate (AMTI OR6-7, USA) were used to collect motion and ground reaction force data. The force plate was synchronized to the motion capture system. The sampling frequencies were set at 100 Hz for motion capture data and 200 Hz for force plate data. The collected data was filtered using fourth-order Butterworth low-pass filters at a cut-off frequency of 5 Hz[9]. Reflective markers (14-mm spherical type) were attached to the heel of the gesture leg and at a point 10 cm below the center of the knee joints of both legs to monitor the position of the gesture leg. A trial was defined as failed whenever the heel marker of the gesture leg moved beneath the marker attached 10 cm below the center of the standing knee. All markers were secured with athletic tape to reduce motion artifacts. We established a global reference system, with the positive x-axis rightward, the positive y-axis forward, and the positive z-axis upward. The force platform was used to measure displacements of the COP during a single-leg stance. To avoid considering any initial sway, only data from 5 s to 25 s after the start of a trial was collected and analyzed. The validity and reliability of the force platform measurements for stance stability have been previously verified[16]. The intra-class correlation coefficients revealed a high test-retest reliability for sway measurements (ICCs >0.90)[16].

Table 2. Results of CAIT and peak torque within injured ankle and uninjured ankle

	RASs (n=11)	Controls (n=11)
CAIT of IA (score)	16.4 ± 4.4	28.0 ± 1.0[a,b]
CAIT of UIA (score)	16.6 ± 5.8	28.6 ± 1.3[b]
%PTIA (120°/s)	25.1 ± 10.3	27.3 ± 4.3
%PTUIA (120°/s)	30.8 ± 9.8[a, c]	26.7 ± 6.1
%PTIA (300°/s)	24.8 ± 7.8	23.2 ± 3.3
%PTUIA (300°/s)	28.6 ± 10.9	25.4 ± 4.1

[a]Results of two-way ANOVA with repeated measures between groups and ankles.
[b]Results of independent sample t-test between groups.
[c]Results of the paired sample t-test within ankles.
CAIT: Cumberland ankle instability tool; PTIA: Peak torque injured ankle; PTUIA: Peak torque uninjured ankle.
[a, b, c]$p<0.05$.

The COP data was used to calculate all dependent variables separated into the time and frequency domains using MATLAB (2012a, MathWorks Inc., USA). The variables of the time domain were the mean velocity (the path length divided by the sampling time, in cm/s) and the root mean square (the standard deviation of the time series, in cm) in the anteroposterior (AP) and mediolateral (ML) planes[17, 18]. The variables of the frequency domain were the total power frequency (the integrated area of the power spectrum, in cm^2), the 95% power frequency (the frequency at 95% of the total power, in Hz), and the 50% power frequency (the frequency at 50% of the total power, in Hz) in the AP and ML planes[18]. These variables have been previously assessed in postural control studies and have demonstrated good validity and reliability[18]. Higher values of these variables indicate poor postural stability.

A descriptive statistical analysis was used to characterize all variables. After confirming normality, a two-way repeated measures analysis of variance was employed to test the interactions and main effects of the groups (RASs and controls) and limbs used (IL and UIL) with respect to the COP variables. When appropriate, t-tests for independent samples (RASs and controls) and paired samples (IL and UIL) were performed to determine significant differences. All statistical analyses were performed using SPSS for Windows (version 22.0, SPSS Inc., USA). The significance level was set at 0.05.

RESULTS

As seen at the Table 2, the main effect of being in the RAS group (versus the controls) was significant on the CAIT scores: $p<0.05$ for the injured ankle (IA). Post-hoc analysis showed that the RAS group scored significantly lower than the controls for both ankles ($p<0.05$). The main effect of the RAS group on %PT was significant within ankles ($p<0.05$) and for the interaction effect ($p<0.05$). The %PT of the IA was significantly lower than the %PT of the UIA at an angular velocity of 120°/s ($p<0.05$).

We observed no significant differences in the results of AP variables (Table 3). However, the AP RMS revealed that the RAS values were significantly greater than for the controls for the UIL ($p<0.05$). In addition, the AP RMS of the RASs was not significantly different within limbs, but the AP RMS of the controls showed that the IL was significantly greater than the UIL ($p<0.05$).

The ML RMS showed a significant group effect ($p<0.05$), as presented in Table 4. The ML RMS of the RASs was significantly greater than that of the controls for the UIL ($p<0.05$). In addition, the ML RMS of the RASs was not significantly different within limbs, but the ML RMS of the controls showed that the IL was significantly greater than the UIL ($p<0.05$). We observed no significant differences in the ML total power frequency, but the ML total power frequency of the RASs was significantly greater than that of the controls for the UIL ($p<0.05$), as presented in Table 4. Furthermore, Table 4 illustrates that the ML 95% power frequency showed a significant interaction between group and limb effects ($p<0.05$). The ML 95% power frequency of the RASs was not significantly different within limbs, but the ML 95% power frequency of the controls

Table 3. Results of anteroposterior variables

		IL	UIL
Velocity (cm/s)	RASs	5.67 ± 2.44	5.53 ± 2.41
	controls	4.87 ± 1.06	4.47 ± 0.86
RMS distance (cm)	RASs	1.29 ± 0.45	1.31 ± 0.38
	controls	1.24 ± 0.29	0.92 ± 0.33[b,c]
Total power frequency (cm^2)	RASs	1.51 ± 1.58	1.54 ± 1.01
	controls	1.15 ± 0.59	1.11 ± 0.89
95% edge frequency (Hz)	RASs	2.08 ± 0.54	2.34 ± 0.75
	controls	2.06 ± 0.58	2.46 ± 0.58
50% edge Frequency (Hz)	RASs	0.46 ± 0.24	0.48 ± 0.23
	controls	0.43 ± 0.22	0.54 ± 0.22

[a]Results of two-way ANOVA with repeated measures between groups and limbs.
[b]Results of the paired sample t-test within limbs.
[c]Results of independent sample t-test between groups.
IL: Injured limb; UIL: Uninjured limb; RMS: Root mean square.
[b,c]$p<0.05$.

Table 4. Results of mediolateral variables

		IL	UIL
Velocity (cm/s)	RASs	5.97 ± 0.97	6.36 ± 1.20
	controls	5.77 ± 1.00	5.52 ± 1.09
RMS distance (cm)	RASs	1.32 ± 0.43	1.35 ± 0.56
	controls	1.17 ± 0.26	0.95 ± 0.14[a,c]
Total power frequency (cm^2)	RASs	1.25 ± 0.72	1.40 ± 0.32
	controls	1.20 ± 0.45	0.93 ± 0.41[c]
95% edge frequency (Hz)	RASs	2.80 ± 0.42	2.63 ± 0.55
	controls	2.50 ± 0.43	2.83 ± 0.61[b]
50% edge Frequency (Hz)	RASs	0.62 ± 0.22	0.61 ± 0.22
	controls	0.55 ± 0.22	0.67 ± 0.18

[a]Results of two-way ANOVA with repeated measures between groups and limbs.
[b]Results of the paired sample t-test within limbs.
[c]Results of independent sample t-test between groups.
IL: Injured limb; UIL: Uninjured limb; RMS; Root mean square.
[a,b,c]$p<0.05$.

showed that the IL was significantly lower than the UIL ($p<0.05$).

DISCUSSION

The major findings of this study showed that the AP RMS, ML RMS, and ML total power frequency of the UIL were significantly higher in the RASs than in the controls, but there were no significant differences between groups in the IL. The AP RMS, ML RMS, and ML total power frequency for the IL were higher than the UIL in the controls compared to the RASs. Therefore, the RASs in this study were presumed to have decreased postural stability in the UIL during the eyes-closed single-leg stance.

Postural stability has been assessed by analyzing the COP trajectories in the time and frequency domains separately, and any increase in these COP parameters is interpreted as a weakening of static stability or postural control[19]. This type of postural sway testing on stable force plates is useful for identifying deficits that are associated with an increase in the risk of ankle sprain[20]. In addition, postural sway has been shown to predict susceptibility to ankle sprains[21]. Furthermore, reduced postural control during single-leg balance has been shown repeatedly to indicate heightened risk of injury in healthy ankles[21].

Wikstrom et al.[22] suggested that mediolateral and anteroposterior COP velocity was greater in individuals with CAI relative to both copers and controls. Doherty et al.[23] reported that individuals with CAI also exhibited a decrease in the fractal dimension of the COP path during an eyes-closed single-leg stance compared with both non-injured controls and lateral ankle sprain copers (12 months after sustaining an acute first-time lateral ankle sprain). As mentioned above, previous studies suggested that postural control is impaired in individuals with acute lateral ankle sprains and in CAI individuals[22–24]. However, even when there is a history of lateral ankle sprain, most athletes should return to the field. Some individuals may develop

CAI following severe or repeated ankle sprains[25], whereas other active individuals may return to high-level activities such as jumping and cutting without developing CAI[22, 25].

In the results of this study, the AP and ML directions of the UIL were significantly higher in the RASs than in the controls, although CAIT scores showed a significant difference between groups for both ankles. These results differ somewhat from the previous studies mentioned above. The reason is that after completing a rehabilitation program, the participants in this study regularly participated in training sessions. Furthermore, several studies[26–28] have reinforced the prophylactic use of balance training for the prevention of future ankle sprains in individuals with acute ankle sprains; these studies have also shown that improvements in balance and postural control measures are the strongest indicators of successful treatment for patients with CAI.

In addition, previous studies proposed that central impairments lead to bilateral postural control deficits after acute lateral ankle sprains[11, 12, 29]. In particular, they suggested that side-to-side differences within acutely injured participants were not consistently present in the studies because central impairments led to bilateral postural control deficits after acute lateral ankle sprains[11, 29]. Therefore, bilateral impairments in postural control are of significant importance because of their role in increased risk of re-spraining the injured ankle[29]. They suggested that the uninjured limb should not be used as a control limb when making side-to-side comparisons for impaired postural control after acute ankle sprains. Instead, they recommended making comparisons with baseline measures from the injured limb or comparisons with a healthy reference group[20]. In addition, Wikstrom et al.[30] indicated that bilateral balance deficits were a viable explanation for the lack of significant findings between the involved and uninvolved limbs in previous studies. They suggested that a study of these aspects would enable better clinical decisions on restoring or rehabilitating postural control after both acute lateral ankle sprains and the onset of CAI. The results of the studies mentioned above seem to support the findings of this study.

Some studies have shown deficits of ankle evertor strength in participants suffering from chronic ankle instability compared to healthy participants[31], while other studies have found no significant difference[32]. Witchalls et al.[33] found that weaker eccentric inversion strength is associated with an increased occurrence of ankle injury at testing speeds lower than 110 °/s. This study used 120 °/s and 300 °/s to measure the muscle peak torque. The results showed that during the eyes-closed single-leg stance for the RAS group, the %PT of the IA was significantly lower than the %PT of the UIA at an angular velocity of 120 °/s; however, there was no significant difference between the groups for either the IA or the UIA, although the controls had higher values for the IL than the UIL.

In addition, clinically determining the status of an athlete's rehabilitation and determining the period before an athlete should return from rehabilitation are complex issues. Addressing these issues solely on an assessment of muscle strength would increase the risk of re-injury. Conducting single-leg stance tests with eyes closed is considered an effective technique for quantifying the extent of injury and functional stability in individuals with repetitive ankle sprains[34]. The stability of an eyes-closed single-leg stance is best characterized via the displacement of the center-of-pressure (COP) measurement while standing on a force platform[18, 35].

We have a limitation that all participants were recruited based on prior power analysis, but our sample size may be too small to determine significant group differences. Most of the available competitive taekwondo athletes had sustained a lower limb injury within the last six months or had a history of lower extremity fracture or surgery, making it difficult to recruit the necessary taekwondo athletes.

In summary, despite finding no significant differences in the strength of ankle evertors and invertors for both legs between both groups, postural stability was lower in the UIL of the RASs than for the controls in both the AP and ML directions of the center-of-pressure variables during single-leg stances with eyes-closed. However, there were no significant differences in the IL between the two groups. Compared to the RASs, the control group was higher in the IL than the UIL. Individuals with repetitive ankle sprains should ensure improvements in their proprioceptive and neuromuscular functions, as well as muscle strength, through an adequate period of rehabilitation to reduce the risk of re-injury. These findings will enable clinicians and sports trainers to more appropriately measure specific deficits in athletes and train them for better prevention of ankle injuries.

Funding

This study was supported by the Dong-A University research fund.

Conflict of interest

The authors declare that no personal relationship exists that could have influenced this manuscript.

REFERENCES

1) Lystad RP, Pollard H, Graham PL: Epidemiology of injuries in competition taekwondo: a meta-analysis of observational studies. J Sci Med Sport, 2009, 12: 614–621. [Medline] [CrossRef]
2) Altarriba-Bartes A, Drobnic F, Til L, et al.: Epidemiology of injuries in elite taekwondo athletes: two Olympic periods cross-sectional retrospective study. BMJ Open, 2014, 4: e004605. [Medline] [CrossRef]
3) Schlüter-Brust K, Leistenschneider P, Dargel J, et al.: Acute injuries in *Taekwondo*. Int J Sports Med, 2011, 32: 629–634. [Medline] [CrossRef]
4) Kobayashi T, Gamada K: Lateral ankle sprain and chronic ankle instability: a critical review. Foot Ankle Spec, 2014, 7: 298–326. [Medline] [CrossRef]
5) Braun BL: Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. Arch Fam Med, 1999, 8: 143–148. [Medline] [Cross-

Ref]
6) Hertel J: Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athl Train, 2002, 37: 364–375. [Medline]
7) Delahunt E, Coughlan GF, Caulfield B, et al.: Inclusion criteria when investigating insufficiencies in chronic ankle instability. Med Sci Sports Exerc, 2010, 42: 2106–2121. [Medline] [CrossRef]
8) Hiller CE, Nightingale EJ, Lin CW, et al.: Characteristics of people with recurrent ankle sprains: a systematic review with meta-analysis. Br J Sports Med, 2011, 45: 660–672. [Medline] [CrossRef]
9) Wikstrom EA, Naik S, Lodha N, et al.: Bilateral balance impairments after lateral ankle trauma: a systematic review and meta-analysis. Gait Posture, 2010, 31: 407–414. [Medline] [CrossRef]
10) Hrysomallis C: Balance ability and athletic performance. Sports Med, 2011, 41: 221–232. [Medline] [CrossRef]
11) Fridén T, Zätterström R, Lindstrand A, et al.: A stabilometric technique for evaluation of lower limb instabilities. Am J Sports Med, 1989, 17: 118–122. [Medline] [CrossRef]
12) Evans T, Hertel J, Sebastianelli W: Bilateral deficits in postural control following lateral ankle sprain. Foot Ankle Int, 2004, 25: 833–839. [Medline] [CrossRef]
13) Hiller CE, Refshauge KM, Bundy AC, et al.: The Cumberland ankle instability tool: a report of validity and reliability testing. Arch Phys Med Rehabil, 2006, 87: 1235–1241. [Medline] [CrossRef]
14) Hawker GA, Mian S, Kendzerska T, et al.: Measures of adult pain: Visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap). Arthritis Care Res (Hoboken), 2011, 63: S240–S252. [Medline] [CrossRef]
15) Doherty C, Bleakley C, Hertel J, et al.: Inter-joint coordination strategies during unilateral stance 6-months following first-time lateral ankle sprain. Clin Biomech (Bristol, Avon), 2015, 30: 129–135. [Medline] [CrossRef]
16) Hageman PA, Leibowitz JM, Blanke D: Age and gender effects on postural control measures. Arch Phys Med Rehabil, 1995, 76: 961–965. [Medline] [CrossRef]
17) Doyle RJ, Hsiao-Wecksler ET, Ragan BG, et al.: Generalizability of center of pressure measures of quiet standing. Gait Posture, 2007, 25: 166–171. [Medline] [CrossRef]
18) Prieto TE, Myklebust JB, Hoffmann RG, et al.: Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Trans Biomed Eng, 1996, 43: 956–966. [Medline] [CrossRef]
19) Adlerton AK, Moritz U, Moe-Nilssen R: Forceplate and accelerometer measures for evaluating the effect of muscle fatigue on postural control during one-legged stance. Physiother Res Int, 2003, 8: 187–199. [Medline] [CrossRef]
20) McKeon PO, Hertel J: Systematic review of postural control and lateral ankle instability, Part I: Can deficits be detected with instrumented testing? J Athl Train, 2008, 43: 305–315. [CrossRef]
21) Trojian TH, McKeag DB: Single leg balance test to identify risk of ankle sprains. Br J Sports Med, 2006, 40: 610–613, discussion 613. [Medline] [CrossRef]
22) Wikstrom EA, Fournier KA, McKeon PO: Postural control differs between those with and without chronic ankle instability. Gait Posture, 2010, 32: 82–86. [Medline] [CrossRef]
23) Doherty C, Bleakley C, Hertel J, et al.: Lower limb interjoint postural coordination one year after first-time ankle sprain. Med Sci Sports Exerc, 2015, 47: 2398–2405. [Medline] [CrossRef]
24) Arnold BL, De La Motte S, Linens S, et al.: Ankle instability is associated with balance impairments: a meta-analysis. Med Sci Sports Exerc, 2009, 41: 1048–1062. [Medline] [CrossRef]
25) Brown C, Padua D, Marshall SW, et al.: Individuals with mechanical ankle instability exhibit different motion patterns than those with functional ankle instability and ankle sprain copers. Clin Biomech (Bristol, Avon), 2008, 23: 822–831. [Medline] [CrossRef]
26) Eils E, Rosenbaum D: A multi-station proprioceptive exercise program in patients with ankle instability. Med Sci Sports Exerc, 2001, 33: 1991–1998. [Medline] [CrossRef]
27) McKeon PO, Hertel J: Systematic review of postural control and lateral ankle instability, part II: is balance training clinically effective? J Athl Train, 2008, 43: 305–315. [Medline] [CrossRef]
28) Ross SE, Arnold BL, Blackburn JT, et al.: Enhanced balance associated with coordination training with stochastic resonance stimulation in subjects with functional ankle instability: an experimental trial. J Neuroeng Rehabil, 2007, 4: 47. [Medline] [CrossRef]
29) Tropp H, Ekstrand J, Gillquist J: Factors affecting stabilometry recordings of single limb stance. Am J Sports Med, 1984, 12: 185–188. [Medline] [CrossRef]
30) Wikstrom EA, Naik S, Lodha N, et al.: Balance capabilities after lateral ankle trauma and intervention: a meta-analysis. Med Sci Sports Exerc, 2009, 41: 1287–1295. [Medline] [CrossRef]
31) Willems T, Witvrouw E, Verstuyft J, et al.: Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. J Athl Train, 2002, 37: 487–493. [Medline]
32) Kaminski TW, Buckley BD, Powers ME, et al.: Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. Br J Sports Med, 2003, 37: 410–415, discussion 415. [Medline] [CrossRef]
33) Witchalls J, Blanch P, Waddington G, et al.: Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. Br J Sports Med, 2012, 46: 515–523. [Medline] [CrossRef]
34) Doherty C, Bleakley C, Hertel J, et al.: Postural control strategies during single limb stance following acute lateral ankle sprain. Clin Biomech (Bristol, Avon), 2014, 29: 643–649. [Medline] [CrossRef]
35) Doherty C, Bleakley C, Hertel J, et al.: Balance failure in single limb stance due to ankle sprain injury: an analysis of center of pressure using the fractal dimension method. Gait Posture, 2014, 40: 172–176. [Medline] [CrossRef]