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# The effectiveness and sustainability of supervised balance training in chronic ankle instability with grade III ligament injury: a one-year prospective study

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## Abstract

**Background:** To determine the effectiveness and sustainability of supervised balance training in people with chronic ankle instability (CAI) with grade III ligament injury.

**Methods:** Twenty young adults (12 males and 8 females) diagnosed with CAI with grade III ligament injury underwent 3 months of supervised balance training. The self-reported functional questionnaire, plantar pressure (walking and single leg standing), and isokinetic ankle strength were consecutively evaluated at pre-training, 3 months, 6 months and one year. Paired T tests were used to explore changes in muscle strength and plantar pressures following the supervised balance training. According to whether the patient had sprain recurrence, the patients were divided into sprain recurrence group and control group. The risk factors of sprain recurrence were explored with univariate analysis and multivariable logistic regression.

**Results:** The self-reported functional scores, the plantar pressure distribution and the muscle strength showed significant immediate improvements after 3 months of supervised balance training. At 6 months post-training, peak force under 2nd metatarsal, time to peak force under the medial hindfoot, time to boundary measurements and dorsiflexion, and eversion strength were partly declined to the pre-training level. 16 patients (80%) resumed the daily life and sports without sprain recurrence during the follow-up. Four patients (20%) reported ankle sprain during the follow-up, and the sprain recurrence group showed significantly higher Beighton scores ( $p = 0.012$ ) and weaker initial inversion strength ( $p = 0.022$ ) than the control group.

**Conclusions:** Three months' of supervised balance training could effectively improve postural control and muscle strength of CAI cases with grade III ligament injury, although these improvements would partially decreased over time. Additional strength exercises for dorsiflexion and eversion should be supplemented from 6 months. Higher Beighton score and initial inversion muscle strength weakness might increase the risk of sprain recurrence.

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**Keywords:** Chronic ankle instability, Rehabilitation, Plantar pressure, Muscle strength

## Introduction

Lateral ankle sprain is a common musculoskeletal injury in sports [1]. Although most patients resume daily life after the primary sprain, about 34% of individuals can suffer from chronic ankle instability (CAI), which is characterized as recurrent sprain, episodes of giving-way of the ankle joint, pain, deficits of postural control and muscle strength [1]. Treatment strategy includes conservative or operative solutions, mainly depending on the severity of ankle sprains, which are classified from grades I to III (mild, moderate, or severe) [2]. Conservative treatment is more effective for CAI patients with Grade I and Grade II ligament injuries while treatment for chronic ankle instability (CAI) with grade III injuries is controversial [3]. Surgery is commonly recommended to CAI patients, especially to those with combined intra-articular lesions (osteochondral lesions (OCLs), osteophyte, impingement, loose body, etc.) causing obstructive symptoms [4–6]. However, considering the invasiveness and potential complications of the surgery, conservative treatment could be the first choice for CAI cases with isolated lateral ankle ligament but without intra-articular lesions.

Balance-training programs have been shown to be effective in improving postural control and muscle strength in CAI patients [7] in the short term. However, some research suggests that the effectiveness of conservative treatment (such as subjective symptoms [8] and eversion muscle strength [9]) might be temporary, and about 21.4% of CAI patients still had re-sprains [8] and the postural stability deficits at 6 months post-intervention [9]. However, previous studies merely targeted some single treatment (such as resistance tubing [8] and wobble board [9]), and the follow-up period was only 6 months. In addition, those studies included CAI cases with varying degree of ligament injury but did not distinguish the CAI cases with grade III ligament injury. At present, there is limited evidence for long-term effectiveness and continuity of systematic rehabilitation training for CAI patients with grade III ligament injury.

In terms of the post-training functional evaluation, most of the studies focused on the subjective feeling instead of objective evaluation, thus, make it difficult to guide clinical practice. In fact, the foot pressure measures, such as center-of pressure (COP) excursion, time-to-boundary (TTB) and peak plantar analysis have been commonly used to identify the postural control deficits of those with CAI. CAI cases have significantly less time

to make postural corrections to meet the stability demands [10] and a significantly increased lateral loading [11] compared with healthy controls. These objective parameters might be important predictors for the effectiveness and sustainability and help treatment decision making.

In the present study, 20 CAI patients with isolated lateral ankle ligament injury were included and accepted 3 months of supervised balance training and consecutive follow-up for 1 year. The purpose of the present study was to determine the mid-term effectiveness and the sustainability of a balance training program and preliminarily explore the risk factors of sprain recurrence in the CAI cases. We hypothesized that balance training would improve the muscle strength, foot pressure distribution and postural stability, but some improvements would be weakened with time. These results may help us optimize rehabilitation strategies to improve the effectiveness of balance training for the CAI cases with grade III ankle ligament injury.

## Materials and methods

### Design

From September 2018 to April 2019, 20 CAI patients who were diagnosed as grade III ligament injury and ready for rehabilitation were included in the study. A priori power analysis was completed using data from a previous study in which the researchers examined the effects of a similar balance-training program [12]. The study was approved by the IRB Medical Committee of our hospital (IRB00006761-M2019164) and the written consent was obtained from all patients. The study was registered in Chinese Clinical Trial Registry (ChiCTR), and the number was [ChiCTR1900023999](https://www.chictr.org.cn/edit.aspx?pid=39984&htm=4).

### Patient enrollment

The inclusion criteria were (i) aged 18 to 40 years, (ii) unilateral injury with a history of at least one significant lateral ankle sprain (at least 12 months prior to study enrolment) that caused inflammatory symptoms and disrupted activity, (iii) the most recent ankle sprain occurred > 3 months prior to study participation, (iv) reports of the previously injured joint “giving way” and/or recurrent sprain and/or “feelings of instability” (v) scoring < 24 on the Cumberland Ankle Instability Tool (CAIT) [13], (vi) the first time sprain was diagnosed as grade III [14, 15] injury of anterior talofibular ligament (ATFL) and/or calcaneofibular ligament (CFL) confirmed by both

MRI and positive anterior drawer test (increased translation of 3 mm compared to the uninjured side or an absolute value of 10 mm of displacement) [16] and talar tilt test (10° of absolute talar tilt or 5° difference compared to the contralateral side) [17] by TELOS SD 900 Stress Device (Austin & Associates, inc. USA). All patients presented without a history of neurological or orthopedic impairment. Patients with combined intra-articular lesions (OCLs, osteophyte, impingement, loose body, etc.), any history of surgery, fracture requiring realignment and/or acute injury to the musculoskeletal structures (bone, joint structure and/or nerve) in either lower limb were excluded.

Upon enrollment, all the patients' basic information was collected and evaluated, including gender, age, height, weight, involved side, pre-duration, sprain time and the Beighton score (Table 1). The Beighton score  $\geq 4$  was defined as the generalized joint hypermobility (gJHM). The postintervention data-collection session occurred within 48 h after the intervention ended. A follow-up session was performed 3 months, 6 months and 1 year since the pre-intervention data-collection session. Participants were instructed to cease all interventions during the follow-up session. During each data-collection session, we administered the patient-oriented outcomes (Foot and Ankle Ability Measure (FAAM), Cumberland Ankle Instability Tool (CAIT)) before evaluating the disease-oriented outcomes (isometric ankle strength, foot pressure and static and dynamic postural control).

#### Plantar pressure and posture control evaluation

The patients underwent three trials of single-limb stance on each leg with eyes closed on a force plate (AMTI; Watertown, MA, USA) for 10s [10, 18]. COP data were calculated from the three-dimensional force and moment signals and sampled at a rate of 50 Hz<sup>18</sup>. Subjects were instructed to stand as still as possible during testing with arms folded across their chests, holding the opposite limb at approximately 45° of knee flexion and 30° of hip flexion in accordance. If a subject touched down onto the ground, contacted the stance limb, or was unable to maintain standing posture during the 10-s trial, the trial was terminated and repeated. TTB measures and COP measures were computed separately in the ML and the AP directions using previously described methods and smaller TTB and larger COP indicated shorter time to reach the balance boundaries and more risk to fall [10, 18].

Following the standard calibration trial, the subjects were asked to walk barefoot at a self-chosen, comfortable, moderate velocity along the walkway. All subjects were allowed to familiarize themselves with the procedures before data collection. Subjects walked six times

over the pressure plate (Footscan, RSscan International, Olen, Belgium) with 120 Hz sampling rate [19]. Three valid left and three valid right stance phases were measured. A trial was considered to be valid when the following criteria were met: stance phase registered as a heel strike pattern and no visual adjustments in step length or step frequency to aim on the pressure plate. Each print consisted of a time peak-force curve for eight regions of interest on the foot. The regions of interest, which were analyzed automatically by the system software, were medial heel (HM), lateral heel (HL), 1st to 5th metatarsal heads (M1 ~ M5), and toes (T1). The time variables were calculated as the ratio of time from the start of the stance to peak force under the region of interest and the total stance time (%). The peak force variables were calculated as the ratio of the peak force under the region of interest and were normalized by the body weight (N/kg) [20].

#### Isokinetic strength measurement

As described in TW Kaminski's research [21], isokinetic strength was assessed with a Biodex isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY). Each subject's foot was securely fastened on the Biodex chair, with the hip angle 80° flexion (0° neutral position) and 20° to 30° of knee flexion. Each subject was allowed three submaximal (50% capacity) warm-up repetitions at each velocity to become familiar with the isokinetic test procedure, then performed three maximal concentric test repetitions at 60 and 120°/s on both ankles. The resting interval was approximately one minute between tests for each motion, velocity, and side. At the end of testing, peak torque data were extracted from the torque curves.

#### Balance training protocol

As shown in Table 2, the detailed balance training protocol was designed based on the widely used protocol from previously published papers [22, 23]. The protocol includes single-legged stance, wobble board, resistant band and hop exercises. All participants underwent the 3-month balance training intervention. The progressive balance-training program consisted of 24 supervised training sessions (two 60-min sessions per week).

#### Risk factors analysis

Based on the ankle sprain recurrence after the balance training program through one year, the patients were divided into the sprain recurrence group and control group. The pre-training variables for each patient was used to analyze the risk factor for the sprain recurrence after the balance training.

**Table 1** Participants' information

| Characteristics (n = 20) | Values      |
|--------------------------|-------------|
| Age, y                   | 26.4 ± 5.2  |
| Height, cm               | 167.1 ± 8.4 |
| Weight, kg               | 60.3 ± 9.5  |
| No. of sprains           | 8.2 ± 4.1   |
| Months since last sprain | 21.1 ± 21.6 |
| Sex, men: women          | 12: 8       |
| Beighton score           | 3.3 ± 2.3   |
| CAIT                     | 15.4 ± 5.3  |
| FAAM ADL                 | 67.6 ± 10.3 |
| FAAM sport               | 55.9 ± 11.4 |

FAAM Foot and Ankle Ability Measure, CAIT Cumberland Ankle Instability Tool

### Data analysis

The self-reported function (FAAM and CAIT), postural control measures (TTB measures and COP-based measures, plantar pressure measures) were analyzed separately at pre-training, post-training, 3 months, 6 months and 1 year. Paired sample t test was used to assess changes in the dependent measures before and after balance training. Shapiro-Wilk test was used to assess normality of data. Group comparison was only conducted after the formation of both groups (1 year). Univariate analysis and multivariable logistic regression models were used to explore the risk factors of sprain recurrence after the balance training, alpha level was set a priori at  $p < 0.05$ . An a priori power analysis was completed using data from a previous study [23] in which the researchers examined the effects of a similar balance-training program. Based on an  $\alpha$  level of .05, a

**Table 2** The balance training protocol

| Exercise                 | Description   | Progression   |
|--------------------------|---|---|
| Single-legged stance     | Performed up to 60s per repetition for up to 3 repetitions.<br>Performed with eyes opened and eyes closed   | Progressed when participants could complete a 60-s trial without a loss of balance.<br>Increased no. of repetitions by 1<br>Changed surface from floor to using the Dyna-Disc <sup>a</sup> .  |
| Wobble board             | Slowly moved the board in the plantar- flexion/dorsiflexion and inversion/eversion directions without letting the board contact the floor.<br>Performed up to 10 repetitions in each direction.                               | Progressed when participant could complete the task without upper extremity support.<br>Added rotational directions.  |
| Steamboats               | Tied a 48-in Thera-band around the unstable ankle. Positioned stance foot 27-in from where Thera-band was tied.<br>Performed up to 3 sets of 15 repetitions in each direction (hip flexion, extension, abduction, adduction). | Progressed when participants could complete the repetitions without a loss of balance or fatigue.<br>Increased no. of repetitions from 10 to 15.<br>Progressed to next level of resistance with the Thera-band.   |
| Single-legged hop        | Hopped as far as comfortable in the anterior direction.<br>Performed up to 15 repetitions.  | Progressed when participants could perform the task with minimal ankle and hip motion and no loss of balance on landing.<br>Increased no. of repetitions from 5 to 10 to 15.<br>Encouraged increased distance to participants' tolerance.<br>Progressed to medial, lateral, and posterior directions. |
| Quadrant hop             | Hopped in numbered squares clockwise and counterclockwise while maintaining single-legged stance.   | Progressed when participants could complete 2 sets of 5 hops without a loss of balance or fatigue<br>Made unanticipated directional changes where investigator randomly called out numbers.   |
| Single-legged ball catch | Performed up to 3 sets of 20 tosses   | Progressed when participants could perform 20 tosses without a loss of balance.<br>Tossed ball outside participants base of support.<br>Performed during stance on a DynaDisc.  |
| Toe touch down           | Maintained single-legged stance on a step while lowering the unstable ankle in the anterior, posterior, medial, and lateral directions until the foot contacted floor.<br>Performed up to 3 sets of 10 repetitions.           | Progressed when participants could complete all trials without a loss of balance and with good lower extremity alignment (no eversion collapse)<br>Increased no. of repetitions from 5 to 10.<br>Increased height of step from 4 in to 12 in in 2-in increments                                       |
| Hop ups and downs        | Hop off step and landed in single-legged stance on floor.<br>Performed up to 3 sets of 10 repetitions.  | Progressed when participants could complete all hops without a loss of balance or fatigue.<br>Increased no. of repetitions from 5 to 10.<br>Increased height of step from 4 in to 12 in in 2-in increments<br>Changed direction of hop.<br>Hopped up onto step.                                       |

<sup>a</sup> Exertools, Petaluma, CA. <sup>b</sup> The Hygenic Corporation, Akron, OH

power of 0.95, and an effect size of 0.97 determined by the FAAM-Sport, 16 participants were needed. Therefore, we enrolled 20 participants to account for up to 20% attrition.

**Results**

**Self-reported questionnaire**

The changes of self-reported function questionnaires are presented in the Fig. 1. Compared with the pre-training values there was a significant increase for the FAAM ADL ( $p < 0.05$ ) and FAAM Sport ( $p < 0.05$ ) and CAIT ( $p < 0.05$ ) at all follow-up timepoints. Numbers of recurrent sprains decreased from  $3.29 \pm 2.87$  to  $1.63 \pm 2.02$  at one-year follow-up. However, there were four patients (20%) that still reported a sense of instability with at least once sprain recurrence while other 16 patients (80%) patients went back to pre-injury sport and general life.

**Plantar pressure distribution and postural stability**

During walking, a significant increase in the peak force under the M2 ( $2.4 \pm 1.2$  vs  $3.2 \pm 1.9$  N/kg,  $T = 3.79$ ,  $p = 0.011$ ) and HM ( $3.2 \pm 0.9$  vs  $4.0 \pm 1.2$  N/kg,  $T = 3.99$ ,  $p = 0.034$ ) was observed at 3 months follow-up, and the changes of peak force in HM ( $3.6 \pm 0.9$  vs  $5.0 \pm 1.7$ ,  $T = 4.03$ ,  $p = 0.032$ ) lasted until 6 months (Fig. 2. a, b). For the time to peak force (TPF), there was a significant decrease in M2 ( $79.5 \pm 8.5$  vs  $72.3 \pm 7.9\%$ ,  $T = 2.98$ ,  $p = 0.031$ ) and increase in HM ( $12.6 \pm 4.6$  vs  $19.1 \pm 4.9\%$ ,  $T = -2.65$ ,  $p = 0.047$ ) only at 3 months follow-up. No other differences were found at 6 months follow-up compared with the pre-training value. The foot pressure distribution changes in a three-dimension model of two individuals from respective control group and recurrence group are shown in the Fig. 3.

During single leg standing, TTB measurements were found to be significantly different with the pre-training level after 3-month training (Fig. 2. c, d). After 3 months' balance training program, TTBAPa ( $T = 3.58$ ,  $p = 0.02$ )

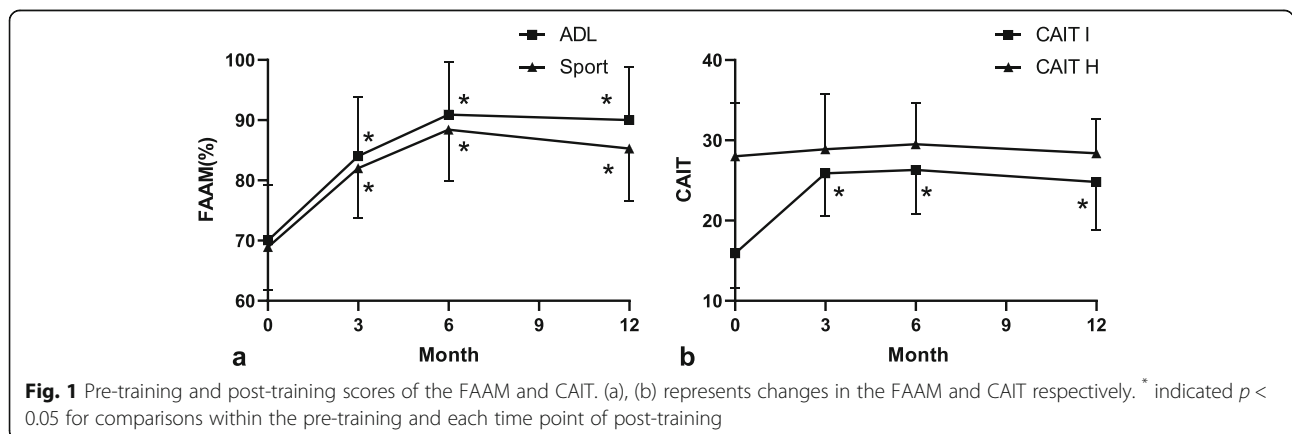
and TTBMLa ( $T = 3.36$ ,  $p = 0.02$ ) temporarily increased and then decreased to the pre-training level while TTBAPm and TTBMLm showed continued improvement at 6 months and one-year ( $p < 0.05$ ). There were no significant differences for the COP measures at all time points ( $p > 0.05$ ).

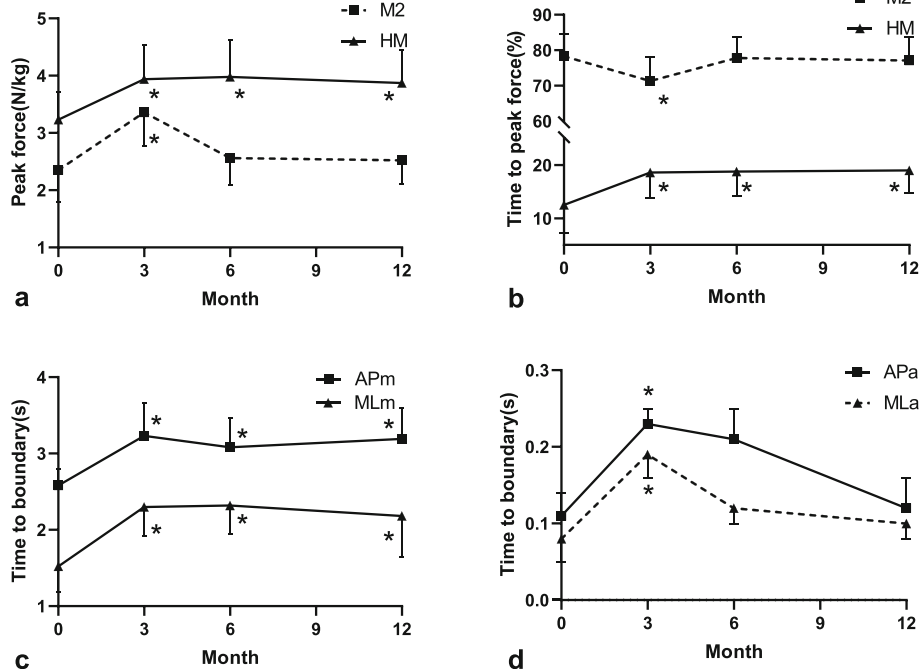
**Muscle strength**

As shown in Fig. 4, all the isokinetic contraction strength was significantly improved after 3 months of balance training ( $p < 0.05$ ). Continuously significant increase in the  $120^\circ/s$ ,  $60^\circ/s$  PF and  $120^\circ/s$  IV strength was observed at the one year follow up ( $p < 0.05$ ), but the dorsiflexion and eversion muscle strength decreased to the pre-training level ( $p > 0.05$ ) after six months until one year. Besides,  $60^\circ/s$  inversion strength decreased slightly after one year.

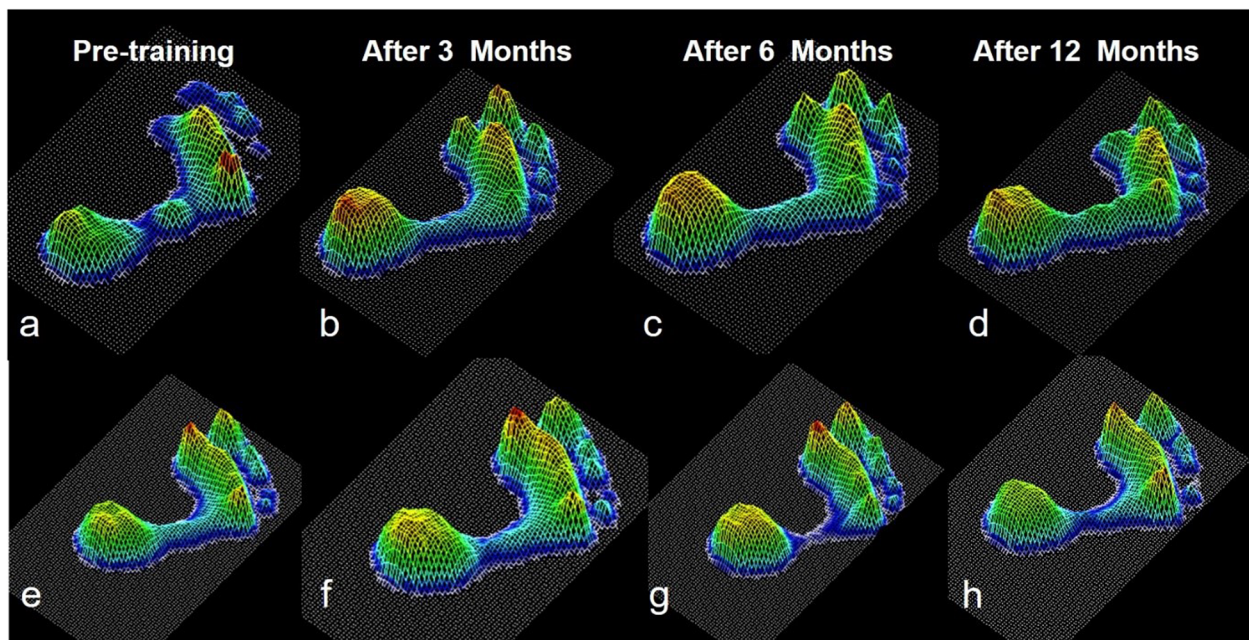
**Risk factors of sprain recurrence**

To preliminarily explore the potential risk factors of recurrence, the univariate analysis and multivariable logistic regression model were used. Based on whether the scores  $< 24$  CAIT or there was an obvious ankle sprain during the follow up, the patients were divided into the sprain recurrence group ( $n = 4$ ) and the control group ( $n = 16$ ). The baseline values in those two type individuals were analyzed with univariate analysis. Significant differences were found in the  $60^\circ/s$  inversion strength, Beighton scores, peak force under first metatarsal, medial hindfoot and lateral hindfoot (Appendix file 1, all  $p < 0.05$ ). Using univariate analysis results (variables  $p < 0.1$ ) and forward selection to create a multivariable logistic regression model, we found that the lower  $60^\circ/s$  isokinetic inversion muscle strength (OR 1.46; 95% CI, 1.23–1.98;  $p = 0.012$ ) and a higher Beighton score (OR 1.27; 95% CI, 1.03–1.32;  $p = 0.032$ ) could be the risk factors (Table 3).

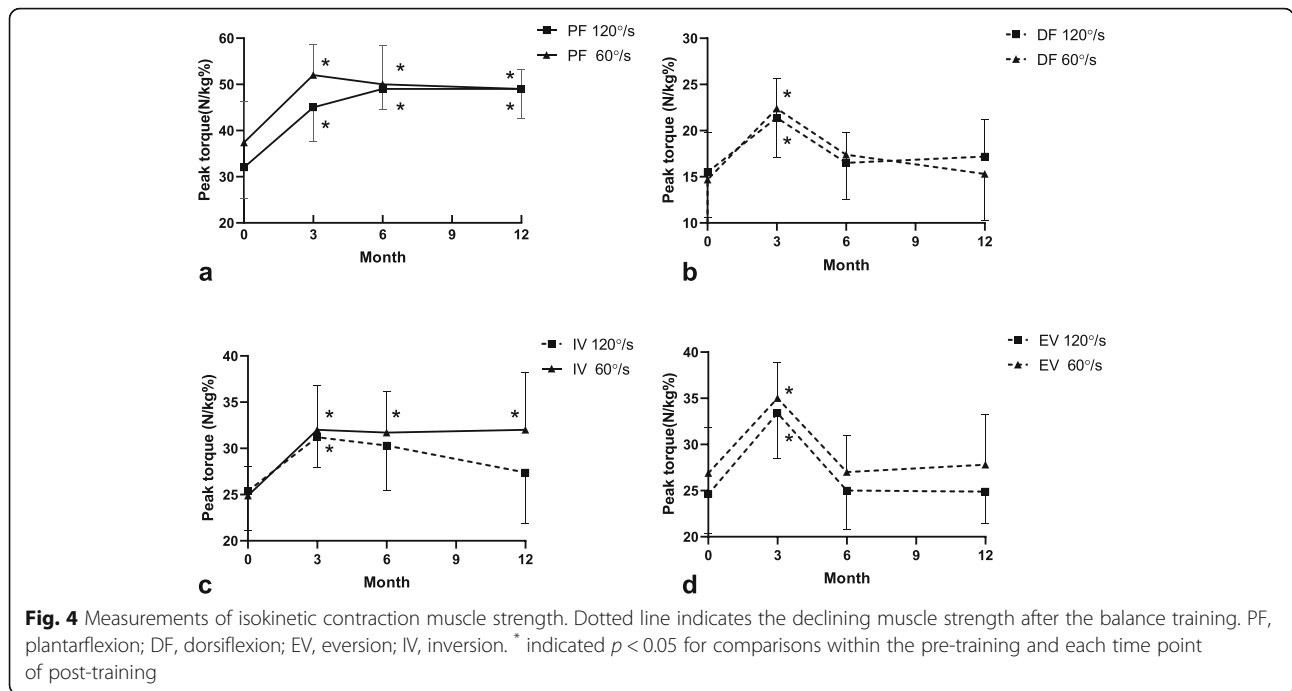




**Fig. 2** Measurements during the walking (a, b) and the single limb standing (c, d). TTbML (AP)m: mean value of the minimum time to boundary in the medial-lateral (anterior-posterior) direction, TTbML (AP)a: absolute minimum time to boundary in the medial-lateral (anterior-posterior) direction. HM, Medial heel; M2, the 2nd metatarsal heads. Dotted line indicates the declining variables after the balance training. \* indicated  $p < 0.05$  for comparisons within the pre-training and each time point of post-training



**Fig. 3** Foot pressure distribution changes of the patient from respective control group(a ~ d) and sprain recurrence group(e ~ h) in three-dimension model (Screenshot from footscan 7.0 software). The figures showed the peak force during the walking at pre-training, 3, 6 and 12 months post training. After the balance training, the foot distribution in the control group turned to the medial side of foot(a ~ d) while the foot distribution in the sprain recurrence group turned to the medial side then reversed to lateral side of foot again (e ~ h)



**Discussion**

The most important finding of the present study was that the 3 months of supervised balance training significantly improved self-reported function, postural control, and muscle strength for CAI patients with isolated ligament injury and most CAI patients with grade III ligament injury (80%) had satisfactory outcomes. However, some improvements on postural control and muscle strength declined after 6 months and 1 year. Additional strength exercises for dorsiflexion and eversion should be supplemented from 6 months. The generalized joint hypermobility (gJHM) and the initial inversion strength weakness could be the potential risk factors for sprain recurrence after balance training.

According to our results, most CAI patients with grade III ligament injury had satisfactory outcomes after the balance training. Similar improvements in self-reported function questionnaire [24, 25] and muscle strength [26, 27] were also found, but none of them investigated the long-term effectiveness of balance training and distinguish the severity of the

ligament injury. The results of the present study implicated that the balance training is still effective even for patients with severe ligament injuries in the long term (i.e., up to 1 year). Although the ligaments are completely disrupted in the acute phase and the joints are obviously unstable in the chronic phase, the feeling of instability is partly improved by increasing the muscle strength and the posture control. However, we found that the strength improvement in dorsiflexion and eversion disappeared at the 6 months follow-up and a similar situation occurs with 60° eversion muscle strength at 1 year. It could be inferred that balance training will provide a short-term muscle strength improvement and additional strength exercises for dorsiflexion and eversion from 6 months and inversion exercise from 1 year might enhance and maintain the effect of balance training again. Further studies are needed to improve the balance training program for CAI cases.

Regarding the plantar pressure evaluation, we found a significant change in the TTB related measures during

**Table 3** Final logistic regression model for the relationship between baseline variables and sprain recurrence at 1-year follow-up

|                  | Sprain recurrence individuals (N = 4) | Control individuals(N = 16) | Odds ratio | 95% CI    | P value |
|------------------|---------------------------------------|-----------------------------|------------|-----------|---------|
| Beighton         | 4.33 ± 1.53                           | 1.43 ± 1.62                 | 1.27       | 1.03–1.32 | 0.032*  |
| 60°/s IV(N*m/kg) | 13.47 ± 1.10                          | 18.27 ± 2.09                | 1.46       | 1.23–1.98 | 0.012*  |
| PF M1(N/kg)      | 2.77 ± 0.54                           | 2.55 ± 1.05                 | 1.02       | 0.88–1.13 | 0.322   |
| PF HM(N/kg)      | 5.53 ± 1.18                           | 5.47 ± 1.21                 | 0.98       | 0.82–1.26 | 0.241   |
| PF HL(N/kg)      | 4.44 ± 1.29                           | 4.31 ± 1.34                 | 0.85       | 0.67–1.23 | 0.085   |

CI, confidence interval. PF M1, HM and HL, Peak force under the 1st metatarsal heads, and medial hindfoot and lateral hindfoot. \* indicates  $p < 0.05$

single leg standing. TTB related measurements involved a spatiotemporal analysis of COP data points, which was a novel approach to assessing postural control deficit in single-limb stance [10, 28]. It quantified the theoretical amount of time an individual had to use to make a postural correction to maintain postural stability. The results indicated that the grade III CAI patients needed longer time to reach the balance boundaries and had a lower risk to fall after the balance training. During walking, we found that the TPF of HM was more delayed and M2 came earlier after the balance training, which means a shorter duration of contact of the heel to central forefoot. The longer duration indicated a slowing down of weight transfer from heel strike to toe off, which was a sign of walking stability improvement [20]. The results also showed that greater loading under the M2 and HM which indicates a medial shift of the COP so as to decrease the susceptibility of ankle sprain [11]. However, improvements on stability during single leg standing and pressure distribution during walking was declined gradually over time.

The present study showed that the sprain recurrence patients had significantly higher Beighton scores, which indicated that the patients with gJHM might have poor rehabilitation effect for balance training. Previous studies [29, 30] have reported generalized joint hypermobility was an intrinsic risk factors related to recurrent lateral ankle sprain, so the hypermobility of ankle joint structure might increase the risk of ankle injury during the rehabilitation process. Similar poor outcomes have been reported for surgery treatment, such as the modified Broström procedure [16, 31]. In those cases, the repaired ligaments would eventually stretch and the patients need a longer period for lateral ligament recovery. However, the impact of gJHM on conservative treatment effect was rarely reported. In theory, the increased muscle strength brought by functional training can enhance joint stability. However, the joint capsule of these patients with gJHM may be compromised, so that the improvement of muscle strength is not enough to restore sufficient stability. This may be the reason for the relatively poor results of these patients. Considering the limited number of cases, the effect and the mechanism of joint hyper-relaxation on conservative training requires further controlled studies.

In this study, we also found the relatively weaker 60°/s inversion strength could be another risk factor of the failure. Several studies have shown that subjects with CAI exhibited strength deficits in their invertor musculature [32–34]. It is suggested that the ankle joint invertors play an integral role in controlling the rate of calcaneal eversion as the body's center of mass is displaced laterally beyond the base of support [35]. The inversion strength weakness lead in uncontrolled weight

transfer to the lateral side of the foot during single leg standing, thus increased frequency of ankle inversion episodes. For patients with inversion strength weakness, more specific and targeted rehabilitation needs to be done.

To our knowledge, this is the first comprehensive study to investigate the long-term effectiveness and its related factors of sprain occurrence for CAI patients with isolated grade III ligament injury. The strength of this study included a relatively long-term follow-up, a detailed systematic balance training protocol and a comprehensive evaluation of the patients and the objective assessment on the postural control improvement in terms of plantar pressure and TTB. It was important to note that although some improvements seem not to last over time, the rehabilitation for the severe type of CAI patients were still effective in the long term. Our results provided more evidence for the use of balance training in CAI cases and would help to optimize rehabilitation plans for this condition. Those with high-risk factors might be prompted to receive early and comprehensive treatment, including the consideration of surgery.

There were still some limitations of the present study. Firstly, the sample size was relatively small in the sprain recurrence group although overall participants enrolled in this study was calculated by the sample size, larger sample are needed to be included in the future research. Secondly, this study focused on patients with lateral ligament injury only while other ligament and syndesmosis injuries also impeded rehabilitation outcomes. So, our results were only suitable for the isolated lateral ankle ligament injury, the balance training for more complex injury type are needed in the future. Thirdly, the patients selected a self-chosen, comfortable walking speed to accomplish the walking task, which might affect the plantar pressure results.

## Conclusion

For the grade III CAI patients with isolated lateral ankle ligament injury, the 3 months' supervised balance training program significantly improved FAAM scores, foot pressure distribution, static postural control, and muscle strength. However, the effectiveness may be partial declined after 6 months and 1 year. Additional strength exercises for dorsiflexion and eversion should be supplemented from 6 months. The high Beighton score and the initial inversion muscle strength weakness might be the potential risk factors of sprain recurrence after balance training.

## Abbreviation

CAI: Chronic ankle instability; ATFL: Anterior talofibular ligament; CFL: Calcaneofibular ligament; OCLs: Osteochondral lesions; COP: Center-of pressure; TTB: Time-to-boundary; gJHM: Generalized joint hypermobility; HM: Medial heel; HL: Lateral heel; M1 ~ M5: 1st to 5th metatarsal heads;



T1: Toes; TPF: Time to peak force; FAAM: Foot and ankle ability measure; CAIT: Cumberland ankle Instability tool; TTbML (AP)m: Mean value of the minimum time to boundary in the medial-lateral (anterior-posterior) direction; TTbML (AP)a: Absolute minimum time to boundary in the medial-lateral (anterior-posterior) direction; PF: Plantarflexion; DF: Dorsiflexion; EV: Eversion; IV: Inversion; SR: Sprain recurrence individuals; C: Control individuals

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13047-022-00514-x>.

**Additional file 1: Appendix 1.** Univariate analysis between sprain recurrence individuals (SR) and control individuals (C). PF, plantarflexion; DF, dorsiflexion; EV, eversion; IV, inversion; HM, Medial heel; HL, lateral heel, M1 to M5, the 1st to 5th metatarsal heads and T1, the hallux.

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Not applicable.

### Authors' contributions

D J designed the study and revised the manuscript. ZC H, L N and HS H analysed and interpreted the patient data regarding the chronic ankle instability. QW G and C J performed the clinical examination of the ankle. X M, YL H, YF J, YF A and D J substantively revised it and ZC H and HS H were major contributors in writing the manuscript. All authors read and approved the final manuscript.

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### Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

### Declarations

#### Ethics approval and consent to participate

The research was approved by the IRB Medical Committee of Peking University Third Hospital (IRB00006761-M2019164), and written informed consents were obtained from the subjects.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare that they have no competing interests.

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