©Journal of Sports Science and Medicine (2026) **25**, 1-15
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2026.1

Research article

Acute Effects of Floss Band at Different Pressures on Multidimensional Ankle Stability in Patients with Chronic Ankle Instability: A Randomized Controlled Trial

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Abstract

This randomized controlled trial investigated the acute effects of floss band (FB) application at different pressures on multidimensional ankle stability in patients with chronic ankle instability (CAI). Forty-two male participants with CAI were randomly assigned to a medium-pressure (MP, 150 mmHg), high-pressure (HP, 200 mmHg), or control group (CG, non-compressive bandage). Outcomes included the Y-Balance Test (YBT), single-leg landing stability (assessed via surface electromyography), ankle proprioception, and static balance, measured at baseline (T0), 5 min (T1), 25 min (T2), and 45 min (T3) post-intervention. The results showed that both MP and HP groups exhibited significant improvements in YBT composite scores, lower limb muscle activation during landing, and joint position sense accuracy at T1 and T2 compared to T0 (all $p < 0.05$), with the MP group demonstrating longer-lasting benefits up to T3. The MP group also significantly outperformed the CG across multiple dynamic stability and neuromuscular metrics at early time points ($p < 0.05$). Improvements in static balance were limited and transient. These findings indicate that a single application of FB, particularly at 150 mmHg, can acutely enhance dynamic stability, neuromuscular control, and proprioception in CAI patients, with effects sustained for up to 45 minutes, supporting its use as an effective pre-activity or pre-rehabilitation intervention.

Key words: Chronic ankle instability; floss band; postural balance; neuromuscular control; randomized controlled trial.

Introduction

Chronic Ankle Instability (CAI) is a common condition that significantly impairs athletic performance and functional mobility (Herzog et al., 2019). It often develops after an initial ankle sprain fails to heal completely, leading to persistent pain, recurrent sprains, and limited functional capacity (Doherty et al., 2017). Lateral ankle sprains are among the most frequent musculoskeletal injuries, characterized by high incidence and recurrence rates, particularly in athletic populations. Studies suggest that up to 50% of individuals with ankle sprains may develop CAI, resulting in long-term deficits in neuromuscular control, proprioception, and dynamic stability (Chandran et al., 2023). These impairments not only diminish athletic performance but also increase the risk of secondary injuries and degenerative joint changes, often leading to missed participation in sports and work, thereby contributing to substantial socioeconomic burden (Herzog et al., 2019). Consequently, there is a pressing need for effective preventive and rehabilitative interventions (Vuurberg et al., 2018).

Current management strategies for CAI typically include strength training, balance exercises, and external support (Doherty et al., 2017). However, such functional training generally requires long-term implementation to yield measurable benefits and often lacks the capacity for immediate functional improvement (McCriskin et al., 2015). Moreover, prolonged use of external support raises concerns about potential compensatory injury risks (Kliethermes et al., 2020). In recent years, Compression Tissue Flossing band (FB) has emerged as a novel non-invasive intervention showing promise for rapidly improving joint function (Yan et al., 2024). This technique involves applying circumferential compression to the joint during active movement. Proposed mechanisms underlying its acute effects include enhanced fascial sliding, pain modulation via the gate control theory, and physiological responses triggered by transient blood flow restriction and subsequent reperfusion (Konrad et al., 2021b). Together, these processes may improve sensorimotor function by elevating stretch tolerance, optimizing afferent input from periarticular mechanoreceptors, and enhancing neuromuscular efficiency—thereby contributing to improved joint stability (Yan et al., 2024).

However, current evidence regarding FB efficacy remains inconclusive, as most studies focus on healthy populations. For example, one study reported that floss band application did not improve knee joint position sense in healthy adults, likely because their intact sensorimotor systems offer limited scope for improvement (Chang et al., 2021). In contrast, individuals with CAI exhibit inherent sensorimotor deficits at the ankle (Chandran et al., 2023), suggesting a potential "therapeutic window" for FB interventions that may not exist in healthy populations. Nevertheless, no studies to date have systematically examined the immediate effects of FB on ankle stability in CAI, and the role of application pressure remains unclear (Galis and Cooper, 2022).

A recent review indicated that the pressure used in clinical studies typically ranges from 100 to 210 mmHg (Yan et al., 2024). More specifically, a study investigating compression bands applied to the calf established 150 mmHg and 200 mmHg as moderate and high pressure levels, respectively, with 150 mmHg significantly improving ankle dorsiflexion peak torque, whereas 200 mmHg showed no benefit and potential adverse effects (Galis and Cooper, 2022). Therefore, to identify the optimal pressure

Received: 20 September 2025 / Accepted: 11 November 2025 / Published (online): 01 March 2026

for clinical application, this study directly compared the effects of 150 mmHg (moderate pressure) and 200 mmHg (high pressure).

Therefore, this study aimed to investigate the acute effects and time-dependent responses of FB (at these two pressures) on ankle stability in CAI patients. Based on the aforementioned mechanisms (i.e., enhanced fascial sliding, pain gating, transient blood flow restriction-reperfusion), we hypothesized that FB would improve CAI patients' dynamic stability, neuromuscular control, and proprioception. Furthermore, we postulated that 150 mmHg would yield superior outcomes compared to 200 mmHg, as it likely balances beneficial physiological responses with patient comfort and tissue tolerance. Findings are anticipated to clarify FB's practical utility and temporal benefits as an adjunct to conventional rehabilitation, while providing evidence-based guidance for selecting optimal pressure parameters in clinical and athletic settings.

Methods

Study design

This open-label RCT investigated the immediate effects of FB in patients with CAI. Eligible patients were randomly allocated to three groups: medium-pressure (MP) flossing group, high-pressure (HP) flossing group, or placebo intervention control group (CG). A single standardized flossing session was administered (excluding controls). Outcomes were assessed at four time points: baseline (T0), 5 min (T1), 25 min (T2), and 45 min (T3) post-intervention. The parallel-group design was chosen for three principal reasons: (1) to eliminate the risk of carryover effects, given the undefined persistence of the acute neurophysiological effects of floss banding in CAI; (2) to prevent learning effects associated with repeated testing of complex dynamic stability tasks; and (3) to minimize participant burden and attrition risk by condensing the protocol to a single session.

The study received ethical approval from the Ethics Committee of Sports Science Experiment at Beijing Sport University (Approval No. 2025318H) and was prospectively registered with the Chinese Clinical Trial Registry (Registration No. ChiCTR2500107140). All procedures adhered to the Declaration of Helsinki. Participants provided written informed consent and retained withdrawal rights.

Participants

Potential participants were recruited from the Beijing Sport University community. Screening was performed by two experienced physical therapists. Only patients with unilateral ankle sprains were included. Eligible participants were male, aged 18-30 years, and met the following inclusion criteria, adapted from the International Ankle Consortium consensus guidelines (Gribble et al., 2014; Delahunt et al., 2018):

1. History of at least one significant ankle sprain causing pain, functional deficit, and interruption of physical activity for ≥1 day.
2. Initial sprain occurring ≥12 months and the most recent significant sprain occurring ≥3 months prior to enrollment.
3. Experience of ≥ 2 episodes of the ankle "giving way" (defined as an uncontrolled, unexpected excessive inversion event not resulting in an acute sprain) and/or recurrent sprains within the 6 months preceding enrollment.
4. Score < 24 on the Cumberland Ankle Outcome Score (CAIT) (Wright et al., 2014).

Exclusion criteria were:

1. Allergy to latex/rubber.
2. History of lower extremity musculoskeletal injury < 3 months prior to enrollment.
3. History of lower extremity musculoskeletal surgery, neurological disorders, cardiovascular disease, or significant skeletal abnormalities (e.g., pes planus, genu varum).
4. Previous experience with tissue flossing therapy.

Intervention

The tissue flossing intervention was administered by a certified physiotherapist with 3 years of clinical experience, who had completed standardized training in the FB application protocol prior to the study commencement. Participants assumed a long-sitting position on the treatment bench with the test limb fully extended and the ankle joint suspended in neutral position. The CompreFloss® standard flossing band (Sanctband; length: 2m, width: 5cm) was applied according to *Flossing* (Kreutzer et al., 2015):

1. Two anchor wraps around the distal forefoot metatarsals;
2. Three figure-8 wraps covering 50% of the preceding band width;
3. Terminal fixation secured beneath the final wrap.

A Kikuhime pressure monitor (sensor positioned at the tibialis anterior midline between medial/lateral malleoli) provided real-time pressure calibration. It has been shown to be a valid (Intraclass Correlation Coefficient, ICC = 0.99, Coefficient of Variation, CV = 1.1 %) and reliable (CV = 4.9 %) tool for measuring interface pressure in sport settings (Driller and Overmayer, 2017). Immediate re-wrapping occurred if pressure drift exceeded 5 mmHg. The MP group (n = 14) received 150 mmHg compression, the HP group (n = 14) received 200 mmHg, while the CG (n = 14) underwent identical wrapping with non-compressive elastic bandage (3M; Material: cotton-spandex blend, width: 5cm). Pressure was calibrated via the Kikuhime device during bandage application to ensure the CG's pressure was maintained within 1 mmHg, avoiding functional compression.

After a standardized warm-up, the FB was applied. Participants then performed the standardized exercise protocol (Table 1), which was designed based on previous established research (Huang et al., 2023) and the ACSM's Guidelines for Exercise Testing and Prescription (American College of Sports Medicine, 2018), supervised by a physiotherapist. FB were removed immediately post-exercise, followed by 1-minute unrestricted walking to promote reperfusion. The total intervention duration of FB was standardized at approximately 4.5 minutes for all participants. A metronome set at 60 beats per minute was used throughout the intervention to control movement rhythm, and a unified exercise protocol was strictly implemented to

Table 1. Standardized exercise protocol.

Exercise Name	Reps × Sets	Execution Details & Standards	Interset Rest
Active Ankle Dorsiflexion/Plantarflexion	12 × 1	Seated with knee extended. Perform full-range motion in a slow, controlled manner (2s dorsiflexion - 1s hold - 2s plantarflexion).	
Bilateral Heel Raises	10 × 2	Standing. Raise heels to full height slowly, hold for 1 second. Lower with control, then actively pull the toes towards the shin (ankle dorsiflexion) upon ground contact.	15 seconds
Forward Lunge	8 × 2	Keep torso upright. Step forward and descend slowly until both knees are bent at ~90°, hold for 1 second at the bottom, then push back to the starting position. Alternate legs.	15 seconds
Single-Leg Deadlift	8 × 2	Hinge at the hips with a slight bend in the stance knee, extending the non-stance leg backwards for balance until torso is nearly parallel to the ground, then return to upright. Alternate legs.	15 seconds

ensure consistency in both intervention duration and movement execution across all participants. Intervention discontinued immediately for neurological symptoms (numbness/parasthesia) or pain (Visual Analogue Scale ≥ 3/10).

Basis for selecting pressure levels

The selection of 150 mmHg and 200 mmHg as the FB intervention pressures in this study is primarily based on findings from previous experimental studies and systematic reviews (Cheatham et al., 2024; Konrad et al., 2021b): both pressures fall within the commonly used range for lower limb FB applications, exhibit good representativeness, and have been directly adopted in multiple prior studies—this study also employs fixed pressures to ensure the reproducibility of results and valid comparisons between groups. Additionally, existing evidence suggests that these two pressures may exert distinct intervention effects; thus, they were included in this study to explore the potential impact of pressure differences on ankle stability in patients with CAI.

Outcome measures

All assessors completed standardized pre-trial training (device operation, workflow optimization, contingency protocols). A fixed two-assessor team per test item implemented a modular rotation protocol to ensure consistency and efficiency across four assessment rounds.

Primary Outcomes

Y-Balance Test

The Y-Balance Test (YBT; Functional Movement Systems, USA) was used to assess dynamic lower extremity stability. This widely recognized method for evaluating dynamic postural stability demonstrates high interrater (ICC 0.81–1.00) and intrarater (ICC 0.85–0.91) reliability (Plisky et al., 2021). After verbal instructions, visual demonstration, and two practice trials per direction (anterior-AN, posteromedial-PM, posterolateral-PL-dir), participants performed three recorded trials per direction with 10-s rests. Barefoot on the stance limb at grid center (hands on iliac crests), participants maximally reached with the non-stance limb along the designated line, lightly touched the device with the toe, and returned. Trials were invalidated/repeated for: stance foot shift/heel lift/balance loss, reach foot ground contact/support, failure to return before next reach, or hands losing iliac contact (Ness et al., 2015).

The maximum reach distance (cm) from three valid trials per direction was recorded. Reach distances were normalized to the stance limb length (anterior superior iliac spine to medial malleolus) (100%). The composite score (COM) was: [(AN + PM + PL-dir) / (3 × limb length)] × 100% (Anguish and Sandrey, 2018).

Single-Leg Landing Stability

Neuromuscular control during single-leg landing was evaluated using synchronized force platform (KWYP-FP6035-7K, Kunwei, China) and wireless surface electromyography (Delsys Trigo, USA). Following SENIAM guidelines, electrodes were placed on tibialis anterior (TA), lateral gastrocnemius (LG), and peroneus longus (PL) after standard skin preparation; sEMG was sampled at 2000 Hz. After demonstration and three practice trials, participants stood on a 30-cm platform, hands on hips. At the "ready" command, they extended the test leg; upon "start," leaned forward to land single-legged on the force platform center. Participants stabilized within 1 s post-landing, maintaining an upright posture (head/trunk vertical, hands on hips, contralateral leg flexed: 45° hip, 90° knee) for 2 s. Trials with balance loss, contralateral limb contact, hand displacement, hopping, or excessive sway were discarded. Three valid trials were collected per participant, separated by 10-s rest intervals (Wang et al., 2020; Taghavi Asl et al., 2022).

Signal processing (EMG works Analysis 4.0, Delsys) included: raw sEMG full-wave rectification and 10-400 Hz band-pass filtering; landing onset defined as vertical ground reaction force >20 N (Bigouette et al., 2016; Chen et al., 2025); and Root Mean Square (RMS) amplitude calculation for two time windows relative to landing onset: a pre-activation window (-100 to 0 ms) and a post-activation window (0 to +100 ms) (Ran et al., 2025; Wu and Hao, 2021). The peak RMS during T0 (-50 to 50 ms window around peak activation in three landings) was set as the normalization baseline (100%) (Yuan et al., 2018). MVC normalization was avoided for two reasons: 1) MVC assesses static strength, mismatching dynamic landing-related muscle activation and potentially distorting intervention effects; 2) Maximal contractions may induce pre-fatigue in CAI patients, confounding subsequent tests. Task-specific normalization to baseline landing RMS better captures neuromuscular changes in functional contexts, enhancing ecological validity (Taghavi Asl et al., 2022;

Yuan et al., 2018).

Secondary Outcome Measures

Ankle proprioception assessment

Active joint position sense was evaluated using an isokinetic dynamometer (Biodex 3, USA). The reliability of this test reaches an excellent level, and the corresponding ICC value range is 0.742-0.964. Seated participants (torso/thighs strapped, hands grasping handles) positioned barefoot on the adapter with ankle-dynamometer axis alignment. Wearing eye masks and headphones for sensory deprivation, the ankle was guided to actively move from neutral (0°) to a 15° target angle (inversion/eversion) for proprioceptive encoding. After returning to neutral, participants actively replicated the target angle. The angular velocity is strictly standardized to 5°/s. Absolute error (mean absolute deviation from target) was calculated via Biodex Advantage V4.26 software across two trials per direction, with higher values indicating poorer proprioceptive acuity (Willems et al., 2002; Taghavi Asl et al., 2022).

Static balance assessment

Static balance was assessed via single-leg stance on a Prokin system (Pro-kin 252, Tecnobody, Italy). Participants stood on the force platform with the test limb aligned longitudinally (heel centered on 2nd-3rd toe axis) and transversely (midfoot line matching platform axis), non-test leg flexed to thigh-parallel position, hands on iliac crests, eyes forward. Center of pressure (COP) trajectories were recorded for 30 seconds during two trials separated by 30-second rests. The COP sway area (mm²) was analyzed as the primary indicator of postural stability, with increased values indicating reduced balance control (Zhang et al., 2024).

Sample size calculation

Sample size was estimated using G*Power 3.1 software, anchored to the minimal clinically important difference (MCID) of the YBT composite score for CAI patients due to limited direct evidence on FB interventions in this population. Based on current CAI rehabilitation research, the YBT MCID is 4.5%(Plisky et al., 2021) with a population standard deviation (SD) of 3.2%(Madsen et al., 2018), yielding a target effect size of Cohen's d= 1.41. For a 3×4 mixed-design ANOVA (groups × time points) with α = 0.05, power = 0.90, and repeated-measures correlation = 0.5, the analysis indicated a minimum requirement of 36 participants. To maintain statistical power against an anticipated 15% dropout rate common in acute intervention trials, the recruitment target was proactively set at 42 participants (14 per group). This constituted a modification from the initially registered protocol (ChiCTR2500107140), pertaining solely to the sample size. It did not alter the core trial design, intervention protocols, eligibility criteria, or participant risk-benefit profile. All outcome measures and statistical analyses were conducted as pre-specified in the original registry.

Randomization and blinding

This open-label randomized controlled trial utilized Microsoft Excel to randomly assign 42 participants into three equal groups: MP, HP, and control groups. Allocation sequence was concealed by an independent coordinator until immediately before intervention. All participants were informed that they would be randomly assigned to one of three different types of elastic bandage, all of which might have therapeutic effects, but were not informed of details regarding pressure differences between groups; the control group received visually identical elastic bandage wrapping. Nevertheless, due to the pressure differences in the intervention measures, we could not completely exclude the possibility that participants in the control group might perceive tactile differences from those in the intervention groups, making effective participant blinding unattainable. Outcome assessors and statisticians remained blinded to group allocation throughout data collection and analysis, with all data anonymized. Interveners could not be blinded due to the requirement for precise pressure control using the Kikuhime monitor but adhered to standardized protocols to minimize bias.

Statistical analysis

All analyses were performed using SPSS 26.0. Normality was assessed with Shapiro-Wilk tests and homogeneity of variance with Levene's tests. A two-way repeated-measures Analysis of Variance (ANOVA) (3×4) examined main effects (group: MP vs. HP vs. CG; time: T0 vs. T1 vs. T2 vs. T3) and their interaction. Greenhouse-Geisser correction addressed violations of sphericity. A hierarchical analysis strategy was followed: specifically, if the group × time interaction was significant ($P < 0.05$), simple effects analysis with Bonferroni-adjusted post hoc comparisons was performed; if the interaction was non-significant, only significant main effects were interpreted, and post hoc tests were conducted exclusively for those significant main effects. Effect sizes were quantified by partial eta-squared (η^2p), interpreted as: small effect ($\eta^2p < 0.06$), medium effect ($\eta^2p = 0.06 - 0.13$), and large effect ($\eta^2p \geq 0.14$) (Fritz et al., 2012). Statistical significance was defined at $P < 0.05$. All analyses were conducted using the intention-to-treat method.

Results

A total of 51 potentially eligible participants were recruited. Following screening, 42 participants met the inclusion criteria and were randomly allocated to three intervention groups (n = 14/group; Figure 1). Baseline demographic and clinical characteristics presented in Table 2. All participants completed the study, with no dropouts reported, and no adverse events or side effects were observed during the trial.

Primary Outcomes

YBT

All YBT measures met normality assumptions ($P > 0.05$). Sphericity was violated for ANT, PM, and COMP ($P < 0.05$), necessitating Greenhouse–Geisser corrections. No baseline differences existed among groups.

Significant main effects of time were detected for all directions (all $P < 0.001$), along with group main effects for PM ($P = 0.044$) and COMP ($P = 0.047$).

Significant group × time interactions were observed across all measures (all $P \leq 0.004$). Simple effects analysis indicated that both MP and HP groups improved significantly over time in all directions (all $P < 0.001$), with between-group differences at T1 and T2 for PM and COMP (all $P < 0.05$).

Post hoc tests revealed that both MP and HP groups achieved higher scores than T0 at T1 and T2 in all directions (all $P < 0.001$), and remained above T0 at T3 ($P < 0.05$). The MP group's scores at T3 were lower than at T1 in PM, PL-dir, and COMP (all $P < 0.05$), while the HP group showed a similar decline in COMP ($P < 0.05$). The MP group significantly outperformed the CG in PM and COMP at T1 and T2 (all $P < 0.05$). The CG only showed a transient improvement in COMP at T1 ($P < 0.05$). Detailed statistics are available in Table 3, and temporal changes are visualized in Figure 2.

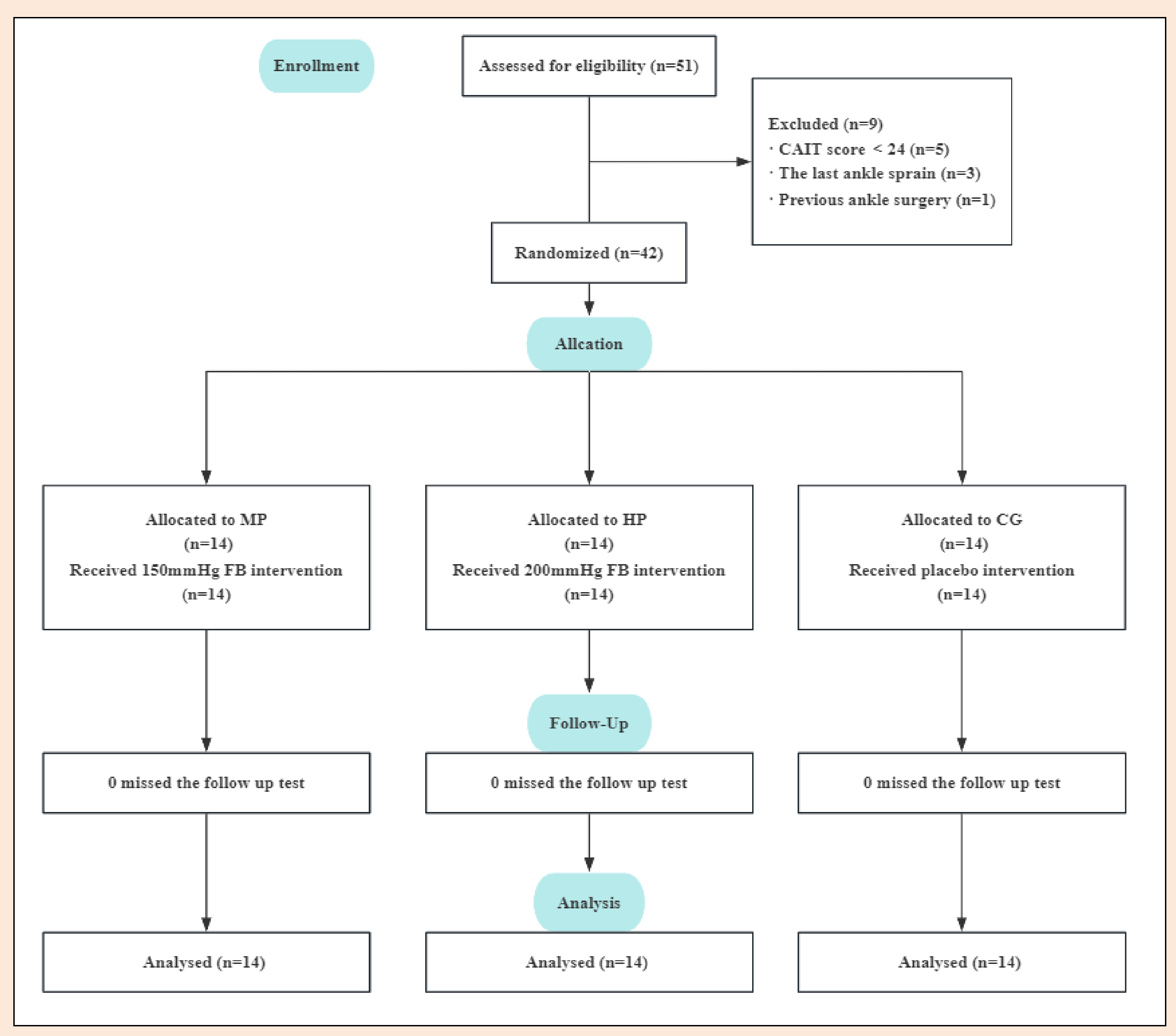

Figure 1. The CONSORT flow diagram. CONSORT, Consolidated Standards of Reporting Trials; CAIT, Cumberland Ankle Outcome Score; MP, medium-pressure; HP, high-pressure; CG, control group; FB, Compression Tissue Flossing band.

Table 2. Baseline demographic and clinical characteristics of participants by group (mean ± standard deviation).

Characteristic	Total (n=42)	MP Group (n=14)	HP Group (n=14)	Control Group (n=14)
Age, years	21.95±2.48	22.00±3.24	21.64±1.78	22.23±2.42
Body mass, kg	75.65±7.85	74.61±7.48	75.50±6.67	76.84±9.39
Height, cm	178.8±9.58	177.15±8.42	179.93±9.76	179.23±11.33
CAIT, score	18.87±2.39	18.69±2.17	19.50±1.82	18.38±3.46
Affected Side (L/R)	24/18	9/5	7/7	8/6
BMI, kg/m²	23.66±5.00	23.77±4.64	23.32±4.59	23.92±5.95
Affected Side* (dominant/non-dominant)	25/17	9/5	8/6	8/6
MET-minutes per week, MET-min**	2217.98 ± 515.63	2102.36±482.78	2352.51 ± 543.45	2199.08 ± 506.33

***Note*:** *The dominant lower limb of the subject was defined as the side that was preferred for the kicking action (An et al., 2022); **Assessed via the International Physical Activity Questionnaire, IPAQ (Craig et al., 2003). CAIT, Cumberland Ankle Instability Tool; MP, Medium-Pressure; HP, High-Pressure; BMI, Body Mass Index; MET, Metabolic Equivalent of Energy.

Table 3. Descriptive statistics for the Y-Blance Test at 4 assessment points in 3 groups (mean ± standard deviation).

		MP (150mmHg)	HP (200mmHg)	Control	F	P	η²p
ANT (%)	T0	69.00±9.30	66.92±4.70	67.73±8.06	0.254	0.777	0.014
	T1	76.41±10.25**	72.45±5.72**	69.58±9.72	2.006	0.15	0.103
	T2	76.22±8.80**	71.81±4.94**	69.51±9.19	2.413	0.104	0.121
	T3	74.91±8.17**	70.69±6.78*	68.65±8.27	2.495	0.097	0.125
	F	55.196	27.321	2.681			
	P	< 0.001	< 0.001	0.063			
	η²p	0.834	0.713	0.196			
			Overall	Time	33.866	< 0.001	0.492
				Group	1.635	0.209	0.085
				Time × Group	3.949	0.004	0.184
PM (%)	T0	99.36±5.78	95.76±10.74	96.85±9.83	0.577	0.567	0.032
	T1	112.37±7.34**	103.64±8.18**	98.78±13.44††	6.351	0.004	0.266
	T2	111.74±9.88**	103.35±7.11**	100.48±11.58††	4.798	0.014	0.215
	T3	108.12±10.17**†§	101.63±7.32*	100.66±11.01	2.356	0.11	0.119
	F	30.705	9.817	0.114			
	P	< 0.001	< 0.001	0.256			
	η²p	0.736	0.472	0.114			
			Overall	Time	38.774	< 0.001	0.526
				Group	3.408	0.044	0.163
				Time x Group	5.552	< 0.001	0.241
PL-dir (%)	T0	99.59±9.72	97.75±4.26	99.03±14.21	0.119	0.888	0.007
	T1	109.14±10.27**	105.39±4.63**	101.20±12.85	2.072	0.141	0.106
	T2	107.97±11.45**	103.12±7.26*	99.73±11.84	2.022	0.148	0.104
	T3	104.97±9.78*†	102.13±6.80*	100.32±14.31	0.633	0.537	0.035
	F	40.222	23.502	1.779			
	P	< 0.001	<0.001	0.17			
	η²p	0.785	0.681	0.139			
			Overall	Time	27.562	< 0.001	0.441
				Group	0.974	0.387	0.053
				Time × Group	3.997	0.001	0.186
COM (%)	T0	89.65±6.44	87.14±5.50	88.21±5.85	0.603	0.553	0.033
	T1	99.65±7.64**	94.16±4.83**	90.18±7.16*††	6.393	0.004	0.268
	T2	98.98±8.67**	93.10±5.20**	90.26±6.76††	5.008	0.012	0.222
	T3	96.33±8.23**‡§	91.81±5.18**†	90.21±7.24	2.625	0.087	0.13
	F	94.002	42.905	2.746			
	P	< 0.001	< 0.001	0.059			
	η²p	0.895	0.796	0.2			
			Overall	Time	82.595	< 0.001	0.702
				Group	3.349	0.047	0.161
				Time × Group	10.902	< 0.001	0.384

Note: *P < 0.05 and **P < 0.01 versus T0; †P < 0.05 and ‡P < 0.01 versus T1; §P < 0.05 versus T2; ††P < 0.05 and ‡‡P < 0.01 versus the Low-Pressure Group; ||P < 0.05 versus the High-Pressure Group. MP, medium-pressure; HP, high-pressure; ANT, anterior; PM, posteromedial; PL-dir, posterolateral; COM, composite score.

Single-Leg Landing Stability Test

All outcome measures from TA, LG, and PL satisfied normality assumptions (P > 0.05). Greenhouse-Geisser corrections were applied for sphericity violations in TA, PL (both phases) and LG pre-activation. No baseline differences existed across groups.

TA

Pre-activation: Significant main effect of time and group × time interaction (both P < 0.05). Both MP and HP groups showed markedly increased RMS at T1 and T2 versus T0 (both P < 0.001). The MP group maintained higher activation than the CG at T1 and T2 (both P < 0.05).

Post-activation: A significant main effect of time was found (P = 0.002). The MP group demonstrated elevated activation at T1 and T2 (both P < 0.05), while the HP group showed an increase only at T1 (P < 0.05).

LG

Pre-activation: A significant main effect of time was observed (P = 0.002). The MP group exhibited increased activation at T1 and T2 (both P < 0.05), whereas the HP group increased only at T1 (P < 0.05).

Post-activation: Significant main effects of time, group, and their interaction were detected (all P < 0.05). Both MP and HP groups showed substantial activation increases at T1 and T2 (both P < 0.001), significantly surpassing the CG (both P < 0.05). The MP group maintained higher activation than the CG even at T3 (P < 0.05).

PL

Pre-activation: Significant main effects of time, group, and their interaction were found (all P < 0.05). Both intervention groups displayed higher activation at T1 and T2 (both P < 0.001), with the MP group outperforming the CG at these time points (both P < 0.05).

Post-activation: Significant main effects of time, group, and interaction were observed (all P ≤ 0.001). MP and HP groups demonstrated increased activation at T1 and T2 (both P < 0.001), and both exceeded the CG (both P <

0.05). The MP group maintained elevated activation at T3 ($P < 0.05$), indicating longer-lasting benefits.

Detailed statistics are available in Table 4, 5 and 6, and temporal changes are visualized in Figure 3.

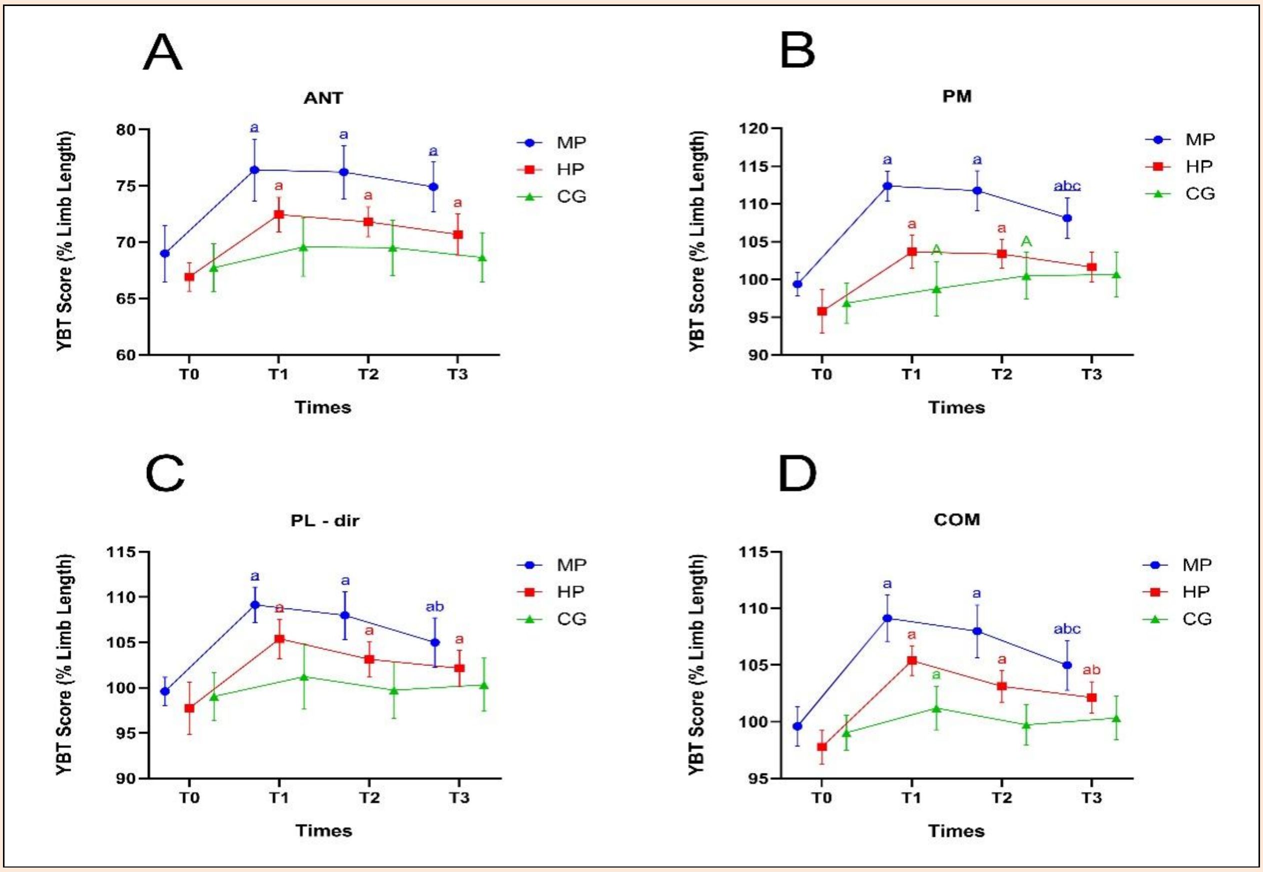

Figure 2. Temporal changes in Y-Balance Test score at different pressures. (A) Temporal changes of ANT; (B) Temporal changes of PM; (C) Temporal changes of PL - dir; (D) Temporal changes of COM. *Note:* Lowercase letters indicate significant differences between time points: a, vs. baseline (T0), P < 0.05; b, vs. T1, P < 0.05; c, vs. T2, P < 0.05; d, vs. T3, P < 0.05. Uppercase letters indicate significant differences between groups at the same time point: A, vs. MP group, P < 0.05; B, vs. HP group, P < 0.05. MP, medium-pressure; HP, high-pressure; CG, control group; ANT, anterior; PM, posteromedial; PL-dir, posterolateral; COM, composite score.

Table 4. Descriptive statistics for the RMS of TA at 4 assessment points in 3 Groups (mean ± standard deviation).

		MP (150mmHg)	HP (200mmHg)	Control	F	P	η²p
Pre (%)	T0	70.06±11.41	68.86±14.63	71.13±14.97	0.083	0.92	0.005
	T1	86.96±8.64**	82.43±11.31**	73.19±12.26††	4.753	0.008	0.224
	T2	83.96±10.39*	78.10±8.77	72.48±16.67††	3.491	0.04	0.172
	T3	77.96±8.27†	73.68±11.42†	69.87±11.07	1.943	0.158	0.1
	F	23.46	14.566	0.59			
	P	< 0.001	< 0.001	0.626			
	η²p	0.681	0.57	0.051	0.083	0.92	0.005
			Overall	Time	15.165	< 0.001	0.302
				Group	2.199	0.126	0.112
				Time × Group	2.854	0.019	0.154
Post (%)	T0	45.97±11.11	47.25±11.19	44.69±8.08	0.177	0.839	0.1
	T1	54.47±8.66**	53.73±11.58*	45.92±7.65	4.059	0.034	0.158
	T2	53.13±13.31*	51.46±9.49	45.73±10.67	3.656	0.038	0.152
	T3	50.14±8.70	49.73±8.46	43.84±8.26	1.741	0.19	0.09
	F	7.412	4.484	0.245			
	P	0.001	0.01	0.865			
	η²p	0.403	0.29	0.022			
			Overall	Time	5.454	0.002	0.144
				Group	2.093	0.139	0.107
				Time x Group	1.632	0.265	0.099

***Note*:** *P < 0.05 and **P < 0.01 versus T0; †P < 0.05 and ‡P < 0.01 versus T1; §P < 0.05 versus T2; ††P < 0.05 and ‡‡P < 0.01 versus the Low-Pressure Group; ||P < 0.05 versus the High-Pressure Group. RMS, Root Mean Square; TA, tibialis anterior; MP, medium-pressure; HP, high-pressure.

Table 5. Descriptive statistics for the RMS of LG at 4 assessment points in 3 groups (mean ± standard deviation).

		MP (150mmHg)	HP (200mmHg)	Control	F	P	η²p
Pre (%)	T0	36.46±9.73	38.06±9.06	38.64±11.13	0.163	0.85	0.009
	T1	48.01±8.83**	46.91±9.43*	40.51±9.05	2.633	0.085	0.125
	T2	46.84±8.29*	44.84±9.75	39.03±12.67	2.167	0.129	0.105
	T3	42.90±6.86	42.66±10.84	36.62±7.59	2.225	0.122	0.107
	F	10.082	5.63	0.551			
	P	< 0.001	< 0.001	0.651			
	η²p	0.478	0.339	0.048			
			Overall	Time	5.640	0.002	0.139
				Group	2.166	0.130	0.110
				Time × Group	0.965	0.445	0.052
Post (%)	T0	75.61±11.23	71.27±8.75	72.86±8.49	0.718	0.495	0.039
	T1	93.92±8.64**	86.10±10.21*	75.49±8.59‡‡||	11.589	<0.001	0.398
	T2	90.84±8.32**	82.21±9.67*	71.64±9.12‡‡||	13.139	<0.001	0.429
	T3	83.50±11.14†	75.89±7.89†	72.44±7.57††	4.722	0.015	0.210
	F	16.916	10.709	0.278			
	P	< 0.001	< 0.001	0.841			
	η²p	0.606	0.493	0.025			
			Overall	Time	12.598	< 0.001	0.265
				Group	18.189	< 0.001	0.510
				Time x Group	2.998	0.011	0.136

Note: *P < 0.05 and **P < 0.01 versus T0; †P < 0.05 and ‡P < 0.01 versus T1; §P < 0.05 versus T2; ††P < 0.05 and ‡‡P < 0.01 versus the Low-Pressure Group; ||P < 0.05 versus the High-Pressure Group. RMS, Root Mean Square; LG, lateral gastrocnemius; MP, medium-pressure; HP, high-pressure.

Table 6. Descriptive statistics for the RMS of PL at 4 assessment points in 3 groups (mean ± standard deviation).

		MP (150mmHg)	HP (200mmHg)	Control	F	P	η²p
Pre (%)	T0	44.77±7.33	42.37±6.32	46.07±8.29	1.527	0.227	0.073
	T1	57.14±7.47**	53.48±12.38**	48.80±9.63††	3.735	0.033	0.161
	T2	55.59±8.76**	51.31±6.23**	47.50±7.00††	5.533	0.008	0.221
	T3	49.08±10.54§	46.39±7.23§	46.13±10.83	1.315	0.363	0.063
	F	15.145	10.467	0.203			
	P	< 0.001	< 0.001	0.823			
	η²p	0.579	0.488	0.019			
			Overall	Time	15.016	< 0.001	0.278
				Group	4.468	0.018	0.186
				Time × Group	2.628	0.039	0.119
Post (%)	T0	68.50±7.91	71.70±11.17	70.12±7.96	0.450	0.641	0.023
	T1	85.83±9.78*	86.48±9.69*	72.05±8.14††||	12.886	< 0.001	0.404
	T2	84.97±10.17*	81.01±7.21*	69.64±13.88††||	6.611	0.003	0.258
	T3	78.13±7.57*	76.81±11.66†	68.52±10.24	3.55	0.039	0.157
	F	22.319	14.736	0.461			
	P	< 0.001	< 0.001	0.711			
	η²p	0.65	0.551	0.037			
			Overall	Time	13.856	< 0.001	0.267
				Group	9.040	0.001	0.322
				Time x Group	3.896	0.010	0.186

Note: *P < 0.05 and **P < 0.01 versus T0; †P < 0.05 and ‡P < 0.01 versus T1; §P < 0.05 versus T2; ††P < 0.05 and ‡‡P < 0.01 versus the Low-Pressure Group; ||P < 0.05 versus the High-Pressure Group. RMS, Root Mean Square; PL, peroneus longus; MP, medium-pressure; HP, high-pressure.

Secondary Outcome Measures

Ankle proprioception assessment

Significant group × time interactions were found for both eversion and inversion (both P < 0.05). The MP group demonstrated sustained improvements in joint position sense from T1 to T3 (all P < 0.05), outperforming the CG across multiple time points. The HP group showed only transient improvements at T1. Detailed results are presented in Table 7.

Static balance assessment

A significant main effect of time was observed for COP sway area (P < 0.001). Post hoc tests revealed that while both intervention groups reduced sway area at T1 (both P < 0.001), only the MP group maintained significantly improved balance at T2 and T3 (both P < 0.05). No other significant effects were found. Results are summarized in Table 8.

Discussion

This study represents the first RCT to systematically investigate the acute effects of FB application on multi-dimensional ankle stability in individuals with CAI. The results demonstrate that a single session significantly improved dynamic stability, neuromuscular control, and proprioception. Both MP and HP interventions markedly enhanced

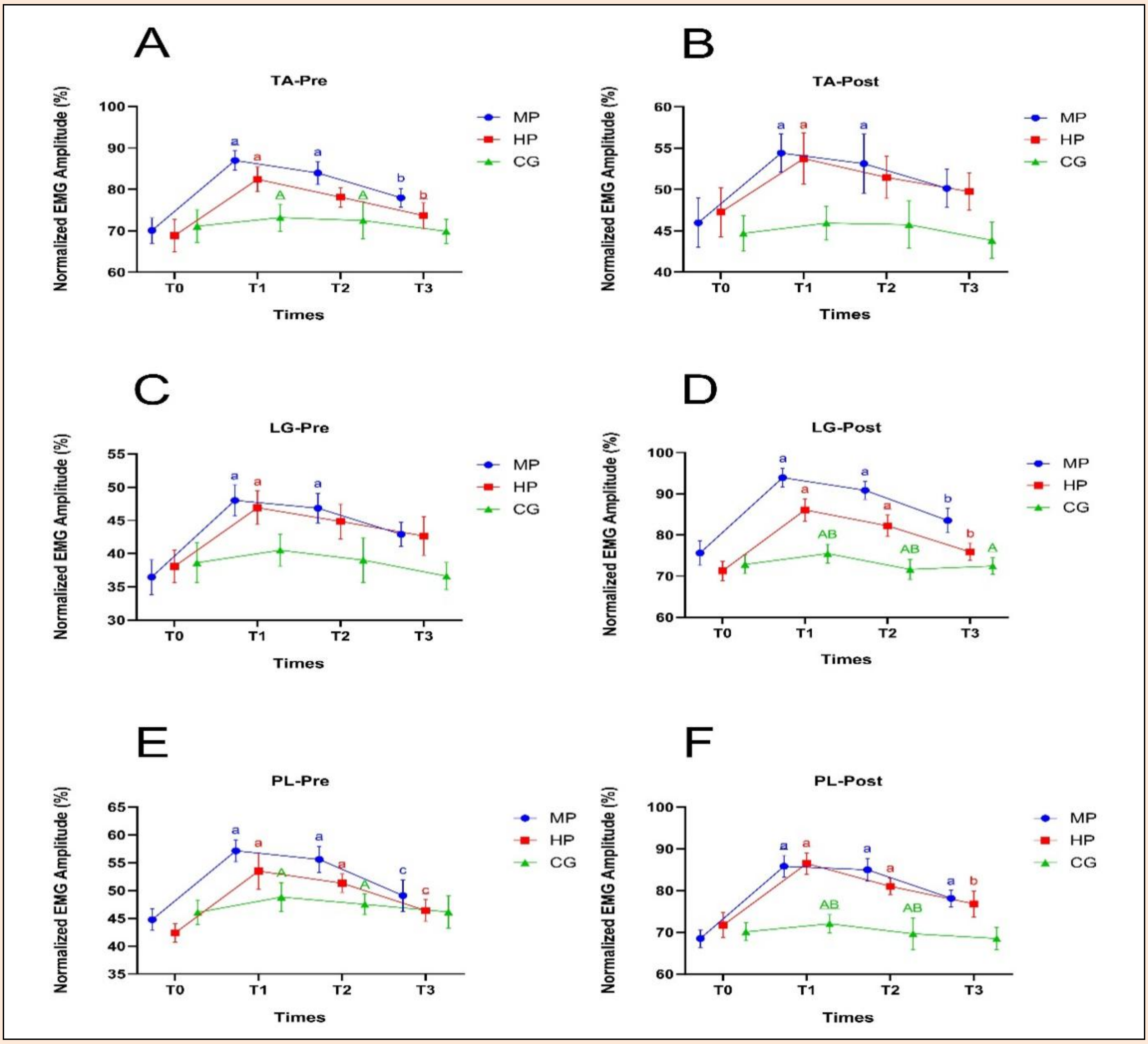

Figure 3. Temporal changes in EMG amplitude (RMS) during pre- and post-activation phases of peri-ankle muscles at different pressures (A) Temporal changes of pre-activation of TA; (B) Temporal changes of post-activation of TA; (C) Temporal changes of pre-activation of LG; (D) Temporal changes of post-activation of LG; (E) Temporal changes of pre-activation of PL; (F) Temporal changes of post-activation of PL. ***Note*****:** Lowercase letters indicate significant differences between time points: a, vs. baseline (T0), $P < 0.05$; b, vs. T1, $P < 0.05$; c, vs. T2, $P < 0.05$; d, vs. T3, $P < 0.05$. Uppercase letters indicate significant differences between groups at the same time point: A, vs. MP group, $P < 0.05$; B, vs. HP group, $P < 0.05$. MP, medium-pressure; HP, high-pressure; CG, control group; RMS, Root Mean Square; TA, tibialis anterior; LG, lateral gastrocnemius; PL, peroneus longus.

YBT performance, activation of peri-ankle muscles during landing, and joint position sense accuracy within 5–25 minutes post-intervention. Notably, the MP group exhibited superior efficacy and longer-lasting benefits across multiple outcomes, with effects sustained for up to 45 minutes, suggesting that the MP protocol offers both sustained effects and a favorable safety profile for acute applications.

To date, no studies have evaluated the acute effects of FB on ankle stability in CAI patients. Existing limited research involving CAI populations reported improvements in ankle dorsiflexion ROM—the sole outcome—after four weeks of intervention (Rosier, 2022) while another trial on patients with recurrent ankle sprains also found positive effects in plantarflexion/dorsiflexion ROM, pressure pain threshold, and single-leg stance stability (Bermúdez-Egidos et al., 2025). Furthermore, most previous studies have focused on healthy participants, demonstrating that acute FB application can effectively increase ankle ROM and may enhance sprint and jump performance (Konrad et al., 2021b; Yan et al., 2024; Tedeschi and Giorgi, 2024).

The improvement in YBT performance suggests an immediate enhancement in lower limb dynamic stability, which may be primarily associated with optimized neuromuscular control (Plisky et al., 2021). Recent studies indicate that the mechanism of FB action is more likely related to neuromodulatory effects rather than changes in fascial mechanical properties alone (Konrad et al., 2021a). Growing evidence supports that FB's effects align with the Pain Gate Theory: mechanical pressure from FB stimulates Aβ afferent fibers in the skin and fascia, activating

Table 7. Descriptive statistics for the ankle proprioception assessment at 4 Assessment points in 3 Groups (mean ± standard deviation).

		MP (150mmHg)	HP (200mmHg)	Control	F	P	η^2p
Eversion (°)	T0	4.33±1.06	3.99±1.33	3.92±1.11	0.474	0.626	0.025
	T1	2.86±0.97**	3.09±0.74*	4.10±1.20††‖	5.712	0.007	0.236
	T2	3.10±1.53*	3.74±1.47	4.11±0.56	2.013	0.148	0.098
	T3	3.28±1.59*	3.78±0.98	3.87±1.01	0.875	0.425	0.045
	F	10.972	3.614	0.171			
	P	< 0.001	0.023	0.915			
	η^2p	0.485	0.237	0.014			
			Overall	Time	4.524	0.005	0.114
				Group	2.118	0.135	0.108
				Time × Group	2.457	0.024	0.127
Inversion (°)	T0	3.85±1.21	3.65±1.299	4.09±1.38	0.357	0.702	0.02
	T1	2.24±0.80**	2.52±1.12*	3.88±1.25††‖	7.804	0.002	0.308
	T2	2.19±0.52**	2.79±0.98	4.10±1.08††‖	14.362	<0.001	0.451
	T3	2.28±0.72**	3.02±0.91	3.82±1.26††	7.487	0.002	0.300
	F	10.870	5.486	0.430			
	P	< 0.001	0.004	0.733			
	η^2p	0.497	0.333	0.038			
			Overall	Time	9.626	< 0.001	0.216
				Group	9.991	< 0.001	0.363
				Time x Group	3.803	0.028	0.161

***Note*:** *P < 0.05 and **P < 0.01 versus T0; †P < 0.05 and ‡P < 0.01 versus T1; §P < 0.05 versus T2; ††P < 0.05 and ‡‡P < 0.01 versus the Low-Pressure Group; ‖P < 0.05 versus the High-Pressure Group. MP, medium-pressure; HP, high-pressure.

Table 8. Descriptive statistics for the static balance assessment at 4 assessment points in 3 groups (mean ± standard deviation).

		MP (150mmHg)	HP (200mmHg)	Control	F	P	η^2p
COP (mm)	T0	470.61±142.52	480.11±177.45	493.03±142.02	0.083	0.92	0.004
	T1	349.00±102.58**	385.96±145.90*	478.81±120.30	3.742	0.033	0.168
	T2	363.31±110.17*	428.53±157.46	486.46±126.91	3.009	0.062	0.14
	T3	373.03±123.11*	440.82±150.47	491.63±149.29	2.642	0.085	0.125
	F	10.385	6.221	0.179			
	P	<0.001	0.002	0.91			
	η^2p	0.471	0.348	0.015			
			Overall	Time	7.64	< 0.001	0.171
				Group	2.393	0.105	0.115
				Time × Group	1.765	0.113	0.087

***Note*:** *P < 0.05 and **P < 0.01 versus T0; †P < 0.05 and ‡P < 0.01 versus T1; §P < 0.05 versus T2; ††P < 0.05 and ‡‡P < 0.01 versus the Low-Pressure Group; ‖P < 0.05 versus the High-Pressure Group. MP, medium-pressure; HP, high-pressure; COP, Center of pressure.

inhibitory interneurons in the spinal dorsal horn, thereby suppressing pain signal transmission, reducing pain perception, and diminishing reflexive muscle tension (Yan et al., 2024; Gao et al., 2024). This mechanism helps improve tissue stretch tolerance and is particularly relevant to patients with CAI, who often exhibit impaired mechanoreceptor function around the ankle (Herzog et al., 2019)—FB may acutely enhance sensorimotor integration through augmented peripheral sensory input (Gao et al., 2024). From a biomechanical perspective, periarticular compression may also alter intra-articular pressure, promote synovial fluid redistribution, temporarily increase joint space, and reduce friction, thereby providing a more favorable mechanical environment for precise joint movement control (Meehan et al., 2019; Gao et al., 2024).

The improvement in YBT performance indicates an acute enhancement of dynamic postural control. Furthermore, this study identified a significant increase in the root mean square amplitude of electromyographic signals from the peri-ankle muscles during the single-leg landing task following the FB intervention. This elevation in muscle activation level demonstrates an improvement in neuromuscular control during a dynamic stabilization task (X et al., 2023). The underlying mechanisms may primarily involve neurohormonal and metabolic modulation induced by soft tissue ischemia, complemented by the pain gate mechanism (Yan et al., 2024).

The pressure applied by the FB induces temporary localized blood flow restriction, eliciting physiological responses similar to blood flow restriction training (Kalc et al., 2021). During the ischemic phase, metabolite accumulation (e.g., lactate, hydrogen ions) stimulates release of growth hormone and norepinephrine and preferentially recruits fast-twitch muscle fibers (Schiaffino and Reggiani, 2011). During reperfusion, nitric oxide-mediated vasodilation further optimizes the local metabolic environment (Hughes et al., 2017). Together, these processes enhance motor unit recruitment and firing rates, leading to marked increases in RMS values and improved muscle contraction efficiency. These findings align with previously reported neurofacilitatory effects, such as reduced muscle contraction time following FB application (Vogrin et al., 2020). The most pronounced increase in RMS immediately post-intervention (T1, T2), followed by a gradual decline, is consistent with the acute and transient nature of ischemia-reperfusion responses (Kielur and Powden, 2020).

Concurrently, FB stimulation of Aβ fibers may inhibit pain signaling via the gating mechanism, alleviating neurally mediated muscle inhibition and creating more favorable central conditions for enhanced muscle activation (Chen et al., 2024).

The mechanisms underlying FB-induced improvements in proprioception primarily involve specific activation of mechanoreceptors in the joint capsule and ligaments, coupled with optimized central sensory integration. CAI patients often exhibit functional inhibition of intra-articular mechanoreceptors due to recurrent sprains, leading to impaired position sense signaling (Herzog et al., 2019). It is plausible that the circumferential pressure from the FB deforms peri-articular soft tissues (e.g., joint capsule, ligaments), which, based on established literature, can directly stimulate mechanoreceptors and enhance afferent signal intensity, thereby contributing to improved position sense accuracy (Schleip, 2003). Concurrently, FB-induced changes in intra-articular hydraulic pressure promote synovial fluid diffusion, optimizing mechanical stimulus transmission (Gao et al., 2024). Moreover, nitric oxide release during brief ischemia-reperfusion may temporarily enhance sensorimotor integration within the central nervous system (Reeves et al., 2006). The synergy between peripheral stimulation and central modulation contributes to the immediate improvement in ankle proprioception in CAI patients.

However, the current study found that FB-induced improvements in static balance (as indicated by COP sway area) were relatively limited. This may be because static balance maintenance relies more heavily on continuous integration of multi-sensory information (visual, vestibular) and fine-tuned feedback regulation by higher central nervous system centers, whereas the acute effects of FB primarily involve peripheral mechanical stimulation and local neuro-metabolic modulation, exerting minimal immediate influence on higher central functions (Horak, 2006; Bednarczuk et al., 2021). This result aligns with previous research indicating that FB's benefits are more pronounced in dynamic tasks requiring rapid neuromuscular coordination and joint stiffness regulation than in static postural tasks that depend on sustained central control (Chen et al., 2024).

Notably, this study further demonstrated the superiority of MP over HP interventions across multiple outcomes, a finding that can be interpreted from several mechanistic perspectives. First, excessive pressure may over-compress soft tissues, prolonging local ischemia and impairing metabolite clearance and reperfusion efficacy, thereby attenuating neuromuscular facilitation—a phenomenon supported by research on ischemic preconditioning (Mouser et al., 2017). Second, excessively high pressure may over-stimulate mechanoreceptors, triggering protective inhibitory reflexes that reduce muscle activation efficiency. Furthermore, high-pressure intervention is more likely to cause discomfort (e.g., skin numbness, pain), compromising patient tolerance and compliance (Wienke et al., 2020) These observations align with a previous study reporting that 200 mmHg pressure may even reduce ankle dorsiflexion ROM and peak torque (Galis and Cooper, 2022). Therefore, medium-pressure FB application may strike an optimal balance among blood flow restriction effects, neuromodulatory benefits, and patient tolerance, proving more advantageous for immediate improvement of ankle function in CAI patients.

Furthermore, compared to other common immediate interventions, FB demonstrates unique clinical application value. For instance, in contrast to traditional taping techniques that primarily provide external support and sensory input, FB requires patients to perform active movements while the band is applied. This "compression-with-movement" paradigm is more focused on actively eliciting and optimizing neuromuscular control patterns (Williams et al., 2012; Yan et al., 2024). Compared to static stretching alone, FB significantly improves joint range of motion without inducing the transient strength reduction often associated with prolonged stretching, making it particularly advantageous for athletes' immediate use pre-competition or during training sessions (Behm et al., 2016). Furthermore, studies have indicated that the acute effectiveness of FB in enhancing ankle range of motion is comparable to that of dynamic stretching and soft tissue mobilization techniques like foam rolling, yet FB offers a more integrated and efficient operational procedure (Kaneda et al., 2020; Konrad et al., 2021a). In summary, FB integrates the multiple acute benefits of improving flexibility, maintaining muscle strength, and optimizing movement patterns, providing clinicians and coaches with a unique and effective tool for the immediate management of CAI.

This study employed a non-compressive bandage as a control to ensure participant blinding. This approach better replicates the appearance and somatic sensation of the active intervention compared to exercise-only protocols (Sawkins et al.,2007). Although bandage contact may provide a perceivable sensory stimulus, previous studies using non-compressive underwrap or sham taping reported no significant benefits, indicating that low-intensity sensory input alone is unlikely to account for the observed effects (Sano et al.,2024; Yin and Wang, 2020). Thus, the significant and sustained differences between the MP group and CG more robustly support the contribution of physiological mechanisms specific to therapeutic compression, such as moderate blood flow restriction/reperfusion and enhanced stimulation of deep mechanoreceptors (Yan et al., 2024). Future studies could employ more inert controls or assess blinding success to further dissociate the unique contributions of sensory and compressive effects.

Limitations and Future Research Directions

This study has several limitations. the lack of direct measurement of hemodynamic changes or fascial sliding during intervention precludes objective quantification of the actual contributions of mechanisms such as 'blood flow restriction' and 'fascial sliding. Second, although including only male participants controlled for sex-related confounding in within-group comparisons, sex differences in fascial properties, ligament laxity, and blood flow distribution may exist (Kubo et al., 2003). Furthermore, this study focused solely on acute effects within 45 minutes post-intervention and did not track the specific time point of effect decay; thus, it cannot inform the optimal intervention frequency in clinical practice.

To address these limitations, future research could develop in the following directions: First, integrating multi-modal ultrasound techniques, surface electromyography, and motion analysis systems to monitor local blood flow, fascial morphology, and joint kinematics in real time during FB application would allow more precise elucidation of its mechanisms. Second, expanding the sample to include participants of both sexes and diverse populations—such as individuals with varying activity levels or pathological conditions (e.g., other forms of joint instability or soft tissue disorders)—would help verify the generality and specificity of FB effects. Third, investigating the combined application of FB with other rehabilitation approaches, particularly embedding FB into phased functional training programs—may reveal its potential additive benefits for warm-up and long-term rehabilitation. Additionally, subsequent studies should extend observation time points to several hours or even days to clarify the trajectory of therapeutic effects and provide an evidence-based foundation for determining optimal intervention timing.

Conclusion

This study demonstrates that a single acute application of FB significantly improves dynamic stability, activation efficiency of the peri-ankle muscles, and proprioception in patients with CAI. The MP (150 mmHg) intervention was more effective than the HP (200 mmHg) application, with benefits sustained for up to 45 minutes post-intervention. These findings confirm that FB intervention, particularly at 150 mmHg, can effectively enhance sensorimotor function in CAI patients during the immediate post-application period.

Acknowledgements

This work was supported by the Fundamental Research Funds for the Central Universities (2024KFZX007). The experiments complied with the current laws of the country in which they were performed. The authors declare no competing interests. The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author, on behalf of the research organization, upon reasonable request.

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Key points

- This RCT demonstrates that a single application of floss band acutely enhances dynamic stability, neuromuscular control, and proprioception in individuals with chronic ankle instability.
- Medium-pressure (150 mmHg) application induced more favorable and longer-lasting improvements across multiple outcomes compared to high-pressure (200 mmHg).
- The observed benefits are likely mediated by neurophysiological mechanisms, such as enhanced sensorimotor integration and stretch tolerance, rather than alterations in fascial mechanical properties.
- Floss band is recommended as an effective adjunctive warm-up modality for rapidly improving ankle function in clinical and athletic settings.

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