Am J Transl Res 2024;16(12):7354-7363
www.ajtr.org /ISSN:1943-8141/AJTR0157090

Original Article

Effects of elastic ankle braces on dynamic stability in patients with functional ankle instability

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Received April 8, 2024; Accepted July 3, 2024; Epub December 15, 2024; Published December 30, 2024

Abstract: Objective: To investigate the protective effects of ankle braces in patients with functional ankle instability. Methods: This retrospective study involved 30 participants recruited from January 2023 to December 2023 at School of Physical Education, Nanchang University. These participants were divided into an ankle brace group wearing braces and a control group without braces. The biomechanical parameters of lower extremity were collected by infrared motion capture and three-dimensional force plate. The parameters were compared between two groups. Results: Regardless of movement patterns, no significant differences were found for vGRF peak, time to peak of vGRF, range of sagittal motion, knee flexion angle at the landing moment, knee varus-valgus angle at the landing moment, knee internal rotation angle at the landing moment, knee range of sagittal motion, knee range of frontal motion, knee range of horizontal motion, knee flexion moment peak, knee extension moment peak, knee varus moment peak, knee valgus moment peak and the knee internal rotation moment peak between ankle brace group and the control group. In addition, peak of ankle varus angle (walking pattern and running pattern: all $P<0.001$), speed of ankle varus angle (walking pattern: $P=0.003$; running pattern: $P=0.023$), the knee external rotation moment peak (walking pattern: $P=0.026$; running pattern: $P=0.031$) and energy absorption of knee joints (walking pattern: $P=0.034$, running pattern: $P=0.029$) in ankle group were significantly lower than those in control group, while peak of ankle valgus torque (walking pattern: $P=0.002$, running pattern: $P<0.001$) in ankle group was obviously more than that in control group. Conclusion: The protective effects of elastic ankle brace for functional ankle instability were more prominent in contrast to that without ankle brace support. Elastic ankle braces could be used as an effective measure to prevent the ankle sprain in patients with functional ankle instability.

Keywords: Elastic ankle brace, biomechanics, kinematics, energy absorption

Introduction

Acute ankle sprain is one of the most common musculoskeletal injuries, occurring in a variety of sports and daily activities [1]. Epidemiologic studies have shown that approximately 32% to 47% of ankle sprain patients progress to functional ankle instability after the initial injury [2]. Once functional ankle instability is confirmed, patients often fall into a vicious cycle of sprains, instability, and re-sprains. Long-term repetitive sprains could lead to degenerative ankle joint disease, such as ankle osteoarthritis, in 78% of these patients, severely limiting their physical activity and quality of life [3].

Patients with functional ankle instability are more prone to recurrent ankle joint sprains. Study has found proprioceptive deficits in patients with functional ankle instability, characterized by larger ankle varus angles, higher varus angular velocities, and smaller eversion moments during exercise [4]. Another study has shown that patients with functional ankle instability have larger vertical ground reaction force (vGRF) peaks and a shorter time to vGRF peak after landing, indicating a more rigid landing pattern [5]. Preventing and treating injuries caused by functional ankle instability is crucial. Studies have shown that protecting the ankle joints can significantly reduce incidence of ankle sprains by 69%, with remarkable effect [6]. Ankle braces have been shown to limit varus and plantar flexion angles of the ankle joints during landing [7]. However, the therapeutic effects of different types of ankle protection remain unclear, and the research on their effects on knee joint biomechanics is limited, with no consensus results.

https://doi.org/10.62347/FPFU4495

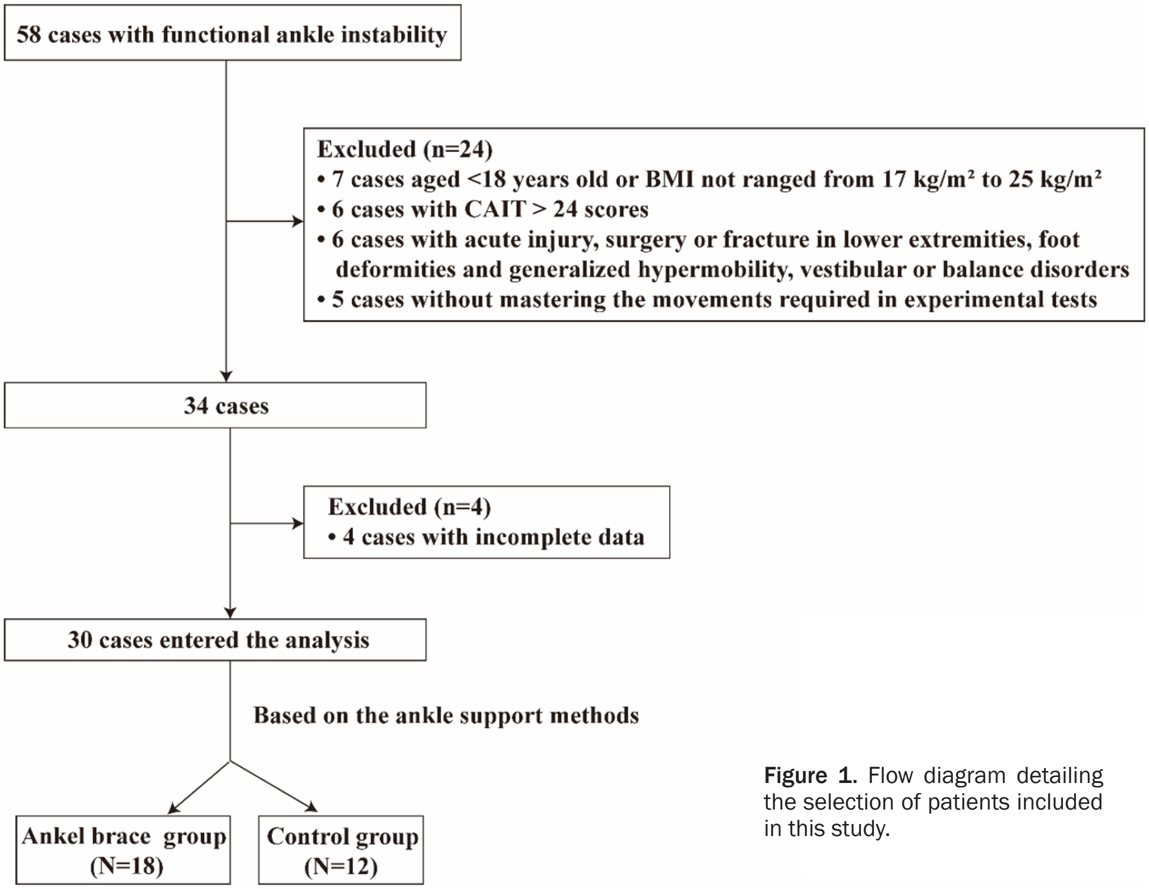

Figure 1. Flow diagram detailing the selection of patients included in this study.

One study showed that restricting the sagittal range of motion of the ankle joint with ankle protection may increase the knee flexion angle and energy absorption, potentially causing knee function compensation and increasing the risk of knee joint injury by 30% [8]. Epidemiological study also found that ankle sprains occurred during walking and running [9], yet few studies focus on these basic activities or specifically on patients with FAI [10]. Moreover, the protective effects of ankle supports may vary with different movements, and focusing solely on landing and stop-redirect movements provides a limited perspective [11]. Elastic ankle braces are commonly applied in the treatment of patients with functional ankle instability, in order to improve stability and to prevent re-injury. These braces provide compression and flexibility to the ankle joint without limiting the normal range of motion. Some studies found that custom-molded foot orthosis combined with elastic ankle braces could improve the postural control and increase the proprioception [12], while other studies revealed that the single application of elastic ankle braces was ineffective in maintaining the dynamic balance [13]. Therefore, the protection mechanism of ankle supports for functional ankle instability during walking and running is worth further investigation.

This study analyzed the differences in lower limb kinematics, dynamics, and energy absorption under walking and running conditions between patients with functional ankle instability wearing elastic ankle braces and those without elastic ankle supports.

Material and methods

General information

This retrospective study involved 30 participants recruited from January 2023 to December 2023 at School of Physical Education, Nanchang University. The eligible participants underwent the experimental tests were shown in **Figure 1**. All the participants received the conservative treatment including alleviation of pain, immobilization, and reduction of weight-bearing [14]. The participants

Figure 2. Elastic ankle brace used in this study.

were informed of the strengths and the limitation of these two treatment methods and were allowed to choose their preferred treatment option. Based on the ankle support methods, these participants were divided into the control group and the ankle brace group. The control group is consisted of 12 participants without wearing ankle brace, and the ankle brace group had 18 participants. The Ethics Committee of School of Physical Education, Nanchang University approved this research (202316).

Inclusion criteria: ① Participants met the diagnostic criteria of functional ankle instability: recurrent ankle sprains in the same ankle were more than twice, with a feeling of giving way or instability during daily life activities in the previously injured ankle [15]; ② Patients with the initial ankle sprains occurred more than 12 months before the treatment; ③ Patients with the Cumberland Ankle Instability Tool (CAIT) score lower than 24 points; ④ Participants with negative talus tilt test and anterior drawer test; ⑤ Participants with an age over 18 years old and a BMI of 17 kg/m^2-25 kg/m^2; ⑥ Participants with complete and standard records including general information and examination results.

Exclusion criteria: ① Participants with a history of acute injury, surgery or fracture in lower extremities; ② Participants with lower limb pain unrelated to ankle sprain; ③ Participants with vestibular or balance disorders, foot deformities, or generalized hypermobility; ④ Participants with any condition that could affect the test performance.

Methods

The participants wore the testing shoes and tight clothing. After the warm-up, reflective markers were pasted in their bodies according to the Helen Hayes model [16]. Elastic ankle protection was defined as using a figure-eight bandage or other elastic material to protect the ankle joints from stretch injuries. The elastic ankle brace used in this study was purchased from McDavid company, USA, as shown in **Figure 2**. The characteristics of elastic ankle brace included cross straps, anti-slip pressurization, adjustable straps and lightweight breathability. The participants completed the walking test at 1.5±0.2 m/s and the running tests at 3.0±0.4 m/s, both with and without ankle brace. A 12-lens infrared light point 3D motion capture system (200 Hz, Nokov Mars 2H, Beijing Nokov Science & Technology Co., Ltd.) and a 3D force measurement platform (1 kHz, Betec Company, USA) were used to synchronously collect the kinematic and dynamic data. Valid data for each motion were collected for three times for each subject.

Data collection

General information of eligible participants was collected, including sex, age, body mass index (BMI), duration of regular exercise, number of feet, CAIT score, and rate of perceive exertion (RPE) score.

The examination results, which consisted of kinematic and dynamic data, were obtained from the records. These data included vertical ground reaction force (vGRF) peak, time to peak of vGRF, range of sagittal motion, peak of ankle varus angle, speed of ankle varus angle, peak of ankle valgus torque, knee flexion angle at the landing moment, knee varus-valgus angle at the landing moment, knee internal rotation angle at the landing moment, knee range of sagittal motion, knee range of frontal motion, knee range of horizontal motion, knee flexion moment peak, knee extension moment peak, knee varus moment peak, knee valgus moment peak, knee internal rotation moment peak, knee external rotation moment peak, and energy absorption of knee and ankle joints.

Observation indicators

The kinematic and dynamic data were analyzed using Cortex-64 software version 2.6.2 (Motion Analysis Company, USA). A Butterworth with a truncation frequency of 13 Hz was used to smooth the three-dimensional coordinates of

Table 1. Comparison of general information between two groups

Group	Control group (n=12)	Ankle brace group (n=18)	t/χ^2	P
Male/Female (n)	6/6	7/11	0.157	0.694
Age (years)	23.25±2.39	23.84±2.56	0.317	0.762
BMI (kg/m^2)	20.45±0.94	20.57±0.97	0.418	0.684
Duration of regular exercise (Hours/Weeks)	9.21±5.15	8.17±4.96	0.461	0.640
Number of feet (Left/Right)	5/7	6/12	0.328	0.571
CAIT scores (n)	16.50±6.12	16.50±6.12	0.086	0.774
RPE score (n)	17.41±0.72	18.22±0.95	0.284	0.592

Note: BMI: Body mass index; CAIT: Cumberland ankle instability tool; RPE score: Rate of perceive exertion score.

Table 2. The influences of ankle braces on ankle biomechanics under the condition of walking

Parameters	Control group	Ankle brace group	t/χ^2	P
vGRF peak (BW)	2.31±0.21	2.38±0.22	0.891	0.380
Time to peak of vGRF (ms)	290.14±70.67	303.25±86.67	0.454	0.653
Range of sagittal motion (°)	27.95±4.21	25.28±3.83	1.817	0.080
Peak of ankle varus angle (°)	13.06±4.78	7.02±3.64	3.894	<0.001
Speed of ankle varus angle (°/s)	64.39±14.54	49.12±10.67	3.279	0.003
Peak of ankle valgus torque (BH × BW)	-0.025±0.018	-0.046±0.015	3.471	0.002

Note: vGRF: Vertical ground reaction force; BW: body weight; BH: body height.

all landmark points. A multi rigid body model of the human body segment was established based on the reflective landmark points. The three-dimensional angle of the lower limbs was calculated using the Euler angle method [17]. The dynamic data was firstly subjected to a 50 Hz low-pass filter on the original data, and then the three-dimensional torque of the lower limbs was calculated using the inverse dynamics method. Speed was defined as the velocity of the center of mass of the human body. The support period was defined as from landing (vGRF ≥ 20N) to off ground (vGRF ≤ 20N) [18]. The joint angle and torque peak were defined as the maximum joint angle and torque, respectively. The varus angle velocity was defined as the maximum vagus angle speed of ankle. The activity degrees in the frontal, sagittal, and horizontal planes were defined as the different value between maximum and minimum angle. The time to reach the peak of vGRF was defined as the time from landing to the peak of vGRF. The joint power was calculated based on the following formula: Joint power = joint torque × joint angular velocity. Subsequently, the negative values of the knee and ankle joints power were integrated to obtain the work done by each joint, which was defined as the energy absorption [19]. The joint torque was standardized relative to body height (BH) and body weight (BW) (BH × BW), and the ground reaction force was standard relative to BW [20].

Statistical methods

SPSS 22.0 software was applied for analyzing the collected data. The measured data were expressed as mean ± standard deviation (SD). The parameters were compared between two groups by independent sample t test. The enumeration data were expressed as [n (%)], and χ^2 partition test was used for the comparison. $P<0.05$ was considered statistically significant.

Results

General information

Table 1 shows that there were no significant differences regarding sex, age, BMI, duration of regular exercise, Number of feet, CAIT score and RPE score between control group and ankle brace group (all $P>0.05$), indicating that the two groups were comparable.

Effects of ankle braces on ankle biomechanics in the walking pattern

As shown in **Table 2**, there was no significant difference in the term of vGRF peak, time to peak of vGRF, and range of sagittal motion between ankle brace group and control group

Table 3. The effects of ankle braces on ankle biomechanics under the condition of running

Parameters	Control group	Ankle brace group	t/χ^2	P
vGRF peak (BW)	4.81±0.49	4.78±0.46	0.173	0.864
Time to peak of vGRF (ms)	149.14±12.58	142.86±11.79	1.411	0.169
Range of sagittal motion (°)	39.47±4.42	36.18±5.88	1.732	0.094
Peak of ankle varus angle (°)	12.55±4.63	6.94±1.84	4.361	<0.001
Speed of ankle varus angle (°/s)	47.75±10.58	39.02±9.27	2.404	0.023
Peak of ankle valgus torque (BH × BW)	-0.030±0.016	-0.065±0.025	4.567	<0.001

Note: vGRF: Vertical ground reaction force; BW: body weight; BH: body height.

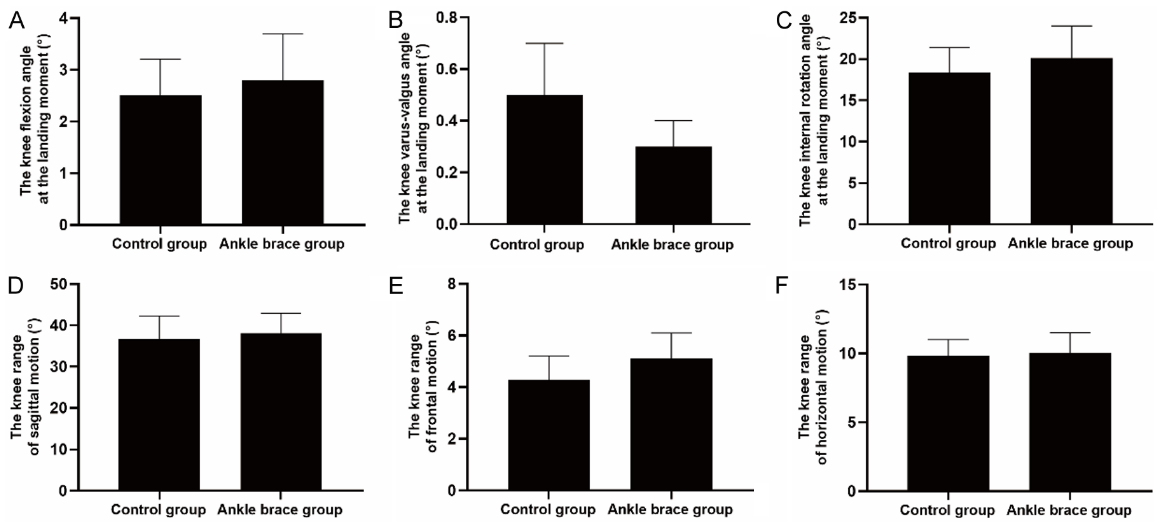

Figure 3. Effects of ankle braces on kinematics of knee joint in the walking pattern. A: The knee flexion angle at the landing moment; B: The knee varus-valgus angle at the landing moment; C: The knee internal rotation angle at the landing moment; D: The knee range of sagittal motion; E: The knee range of frontal motion; F: The knee range of horizontal motion.

in the walking pattern. Peak of ankle varus angle (P<0.001) and speed of ankle varus angle (P=0.003) in ankle brace group were obviously lower than those in control group, while peak of ankle valgus torque in ankle brace group was remarkably higher than that in control group (P=0.002).

Effects of ankle braces on ankle biomechanics in the running pattern

As shown in **Table 3**, there were no significant differences for vGRF peak, time to peak of vGRF and range of sagittal motion between ankle brace group and control group in the running pattern. Peak of ankle varus angle (P<0.001) and speed of ankle varus angle (P=0.023) in ankle brace group were significantly lower than those in control group. In addition, peak of ankle valgus torque in ankle group was significantly higher than that in control group (P<0.001).

Effects of ankle braces on kinematics of knee joint in the walking pattern

As shown in **Figure 3**, knee flexion angle at the landing moment, knee varus-valgus angle at the landing moment, knee internal rotation angle at the landing moment, knee range of sagittal motion, knee range of frontal motion and knee range of horizontal motion in ankle brace group in the walking pattern were 2.8±0.9°, 0.3±0.1°, 20.1±3.9°, 38.2±4.8°, 5.0±1.0° and 10.1±1.5°, which were all comparable to those in control group (all P>0.05).

Effects of ankle braces on kinematics of knee joint in the running pattern

As shown in **Figure 4**, knee flexion angle at the landing moment, knee varus-valgus angle at the landing moment, knee internal rotation angle at the landing moment, knee range of sagittal motion, knee range of frontal motion

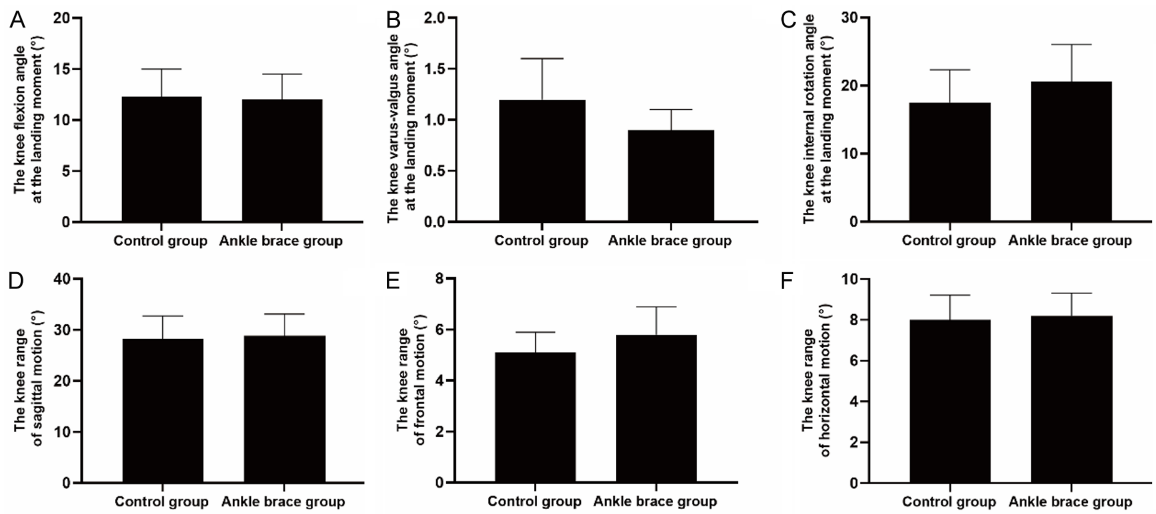

Figure 4. Effects of ankle braces on kinematics of knee joint in the running pattern. A: The knee flexion angle at the landing moment; B: The knee varus-valgus angle at the landing moment; C: The knee internal rotation angle at the landing moment; D: The knee range of sagittal motion; E: The knee range of frontal motion; F: The knee range of horizontal motion.

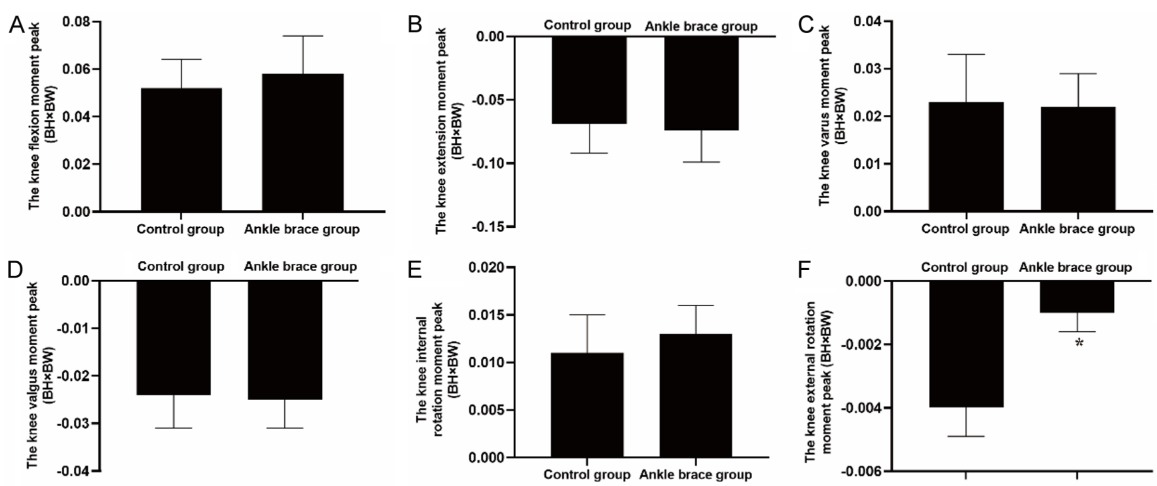

Figure 5. Effects of ankle braces on kinetics of knee joint in the walking pattern. A: The knee flexion moment peak; B: The knee extension moment peak; C: The knee varus moment peak; D: The knee valgus moment peak; E: The knee internal rotation moment peak; F: The knee external rotation moment peak.

and knee range of horizontal motion in ankle brace group in the running pattern were 12.0±2.5°, 0.9±0.2°, 20.6±5.4°, 28.8±4.3°, 5.8±1.1° and 8.2±1.1°, which were also comparable to those in the control group (all P>0.05).

Effects of ankle braces on kinetics of knee joint in the walking pattern

As shown in **Figure 5**, in the walking pattern, there were no significant differences in knee flexion moment peak, knee extension moment peak, knee varus moment peak, knee valgus moment peak and knee internal rotation moment peak between control group and ankle brace group; However, the knee external rotation moment peak in ankle brace group was obviously lower than that in control group (P=0.026).

Effects of ankle braces on kinetics of knee joint in the running pattern

As shown in **Figure 6**, in the running pattern, no significant differences were found in knee flex-

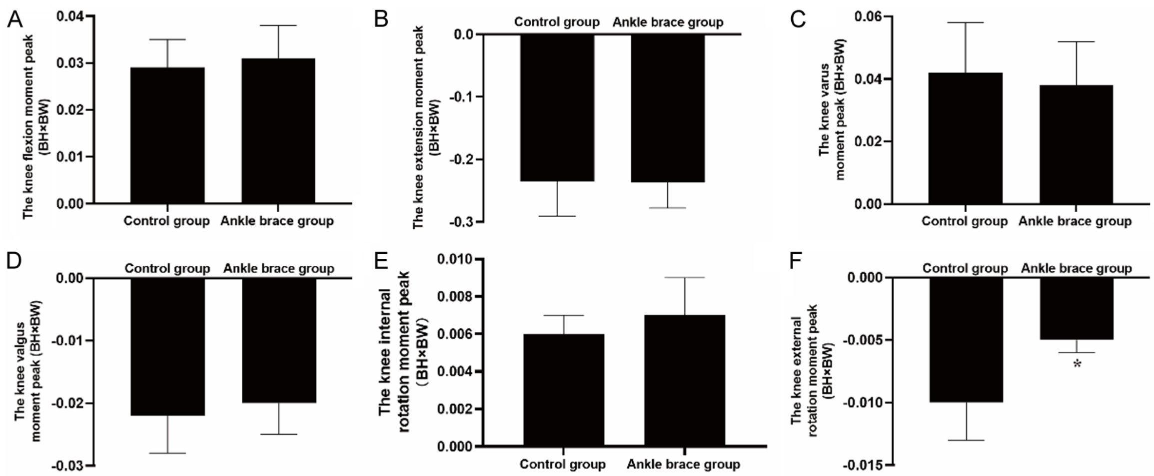

Figure 6. Effects of ankle braces on kinetics of knee joint in the running pattern. A: The knee flexion moment peak; B: The knee extension moment peak; C: The knee varus moment peak; D: The knee valgus moment peak; E: The knee internal rotation moment peak; F: The knee external rotation moment peak.

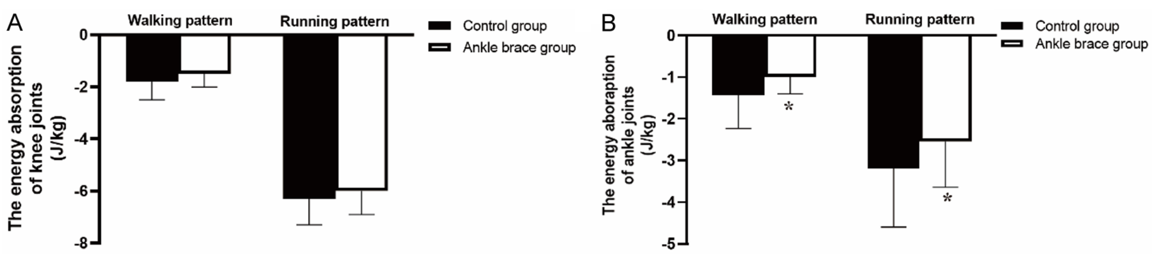

Figure 7. Effects of ankle braces on energy absorption of knee and ankle joints in the movement pattern. A: The knee joints; B: The ankle joints.

ion moment peak, knee extension moment peak, knee varus moment peak, knee valgus moment peak and the knee internal rotation moment peak between the control group and the ankle brace group; However, the knee external rotation moment peak in ankle brace group was significantly lower than that in the control group (P=0.031).

Effects of ankle braces on energy absorption of knee and ankle joints in the movement pattern

As shown in **Figure 7**, in the walking or running patterns, there was no significant difference in energy absorption of knee joint between control group and ankle brace group. In the term of ankle joints under the conditions of movement, the energy absorption in ankle brace group was significantly less than that in control group (Walking pattern: P=0.034, Running pattern: P=0.029).

Discussion

Functional ankle instability is a condition in which patients frequently experience ankle sprains or a recurrent feeling of "giving way". Much effort has been devoted to developing various prevention strategies. A recent study showed that an ankle brace might help to reduce the recurrence of ankle sprains and other symptoms [17]. Another previous study has shown that ankle braces could reduce ankle injuries by 50-70%, indicating that this is an effective protective method [18]. It has been suggested that the primary mechanism for reducing ankle injuries is that the ankle brace provides additional mechanical stiffness to the ankle joint [19]. However, the effects of the ankle brace on ankle joint kinematics in different movement patterns are scarcely reported [20]. Whether the ankle brace could obviously stabilize the ankle joints against the enormous forces that occur during daily activities still needs to be explored.

In this study, participants with functional ankle instability who wore an elastic ankle brace experienced a decrease in ankle varus angle and velocity compared to participants without wearing ankle brace. Fuerst et al. [21] reported similar results that elastic ankle brace could effectively limit the ankle varus angle. Previous studies reported that ankle varus angle of 30°-45° at the moment of landing could cause the sprains of the lateral collateral ligament in the ankle joints [22]. As the movement time grew, the increase in ankle varus angle and varus angle velocity may lead to the increase of the ankle joint load, further resulting in the development of osteoarthritis. Interestingly, Scheuffelen et al. [23] found that when running at a uniform speed of 3.3 m/s, elastic ankle brace did not limit the angle of ankle inversion, which was different from our study. This is possibly due to different speed settings. It has been confirmed that as the speed increased, the ankle joint inversion angle grew [24]. As speed may alter the biomechanics of the ankle, which in turn may affect the protective effects of ankle supports.

This study showed that the peak ankle valgus torque in the ankle brace group was greater than that in the control group, which was similar to previous study [25]. It was indicated that ankle braces provided an eversion torque for the ankle joint, thereby increasing joint stiffness to limit excessive ankle inversion angle [26]. The increase in ankle eversion torque is a positive effect of the ankle brace, which is beneficial in preventing ankle sprains. This study also showed that no differences in sagittal range of motion, time to peak vGRF, and vGRF were observed between the ankle brace and control groups in participants with functional ankle instability. Mann et al. [27] found that elastic ankle protection could limit the range of sagittal motion in the ankle joint, which differed from our study due to different movement patterns. Other studies indicated that ankle brace may potentially protect the ankle joints through avoiding the ankle joint bearing a large vGRF [28].

Joint torque is typically used to reflect the local load on the joint, and the greater the internal and external rotation torque of the knee joint, the greater the risk of knee joint injuries such as the anterior cruciate ligament (ACL). This study showed that the peak knee external rotation moment was lower in the ankle brace group than in the control group, suggesting that elastic ankle braces may reduce ACL stress and provide positive knee joint protection. This study also demonstrated that compared with no ankle protection, elastic ankle protection reduced the energy absorption in the ankle joint, which was consistent with the finding of Jiang et al. [29]. The reason for this may be that wearing an elastic ankle brace may increase the nerve suppression of the plantar flexor muscle in the ankle joint, affecting its eccentric contraction, thereby reducing energy absorption in the ankle joint and protecting the damaged ankle joints.

There were some limitations in this study. First, the number of participants was relatively small and all of them were from one single center regardless of the similar ratio between groups. Second, this study focused on the kinematics of the lower extremities and did not include electromyography (EMG) data. Third, the test movements in this study were limited to walking and running patterns. Although these are common daily movements, the range of movements in this study were relatively few. Fourth, participants were evaluated after wearing the ankle braces for only several hours, and it is unclear whether better effects could be obtained with long-term use of ankle braces in patients with functional ankle instability.

In conclusion, ankle braces can actively protect patients with functional ankle instability from re-injury during walking and running patterns, by significantly reducing the peak of ankle varus angle, the velocity of ankle varus angle, the peak of knee external rotation moment, and the energy absorption of knee joints compared with no ankle brace, while increasing the peak of ankle valgus torque. The results of this study provided evidence to prevent ankle injuries and reduce the risk of re-injury in patients with functional ankle instability during waking and running.

Disclosure of conflict of interest

None.

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