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Research article

Immediate Effects of Calf Tissue Flossing on Ankle Joint Torque and Dorsiflexion Range of Motion in Healthy Individuals: A Randomized Controlled Crossover Trial

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Abstract
Tissue flossing involves wrapping a rubber band around a muscle group for a few minutes while performing joint motion, enhancing ankle joint torque and range of motion. As limited ankle dorsiflexion range of motion and plantar flexion muscle weakness are risk factors for sports injury, assessing the therapeutic effects of tissue flossing is important. This study aimed to evaluate the immediate effects of calf tissue flossing on enhancing ankle joint torque and dorsiflexion range of motion. We conducted a randomized controlled crossover trial involving 19 healthy adult males who received two interventions (low and high-pressure tissue flossing bands) and a control condition (underwrap). Each intervention was applied for 2 minutes on the non-dominant calf, with 5–10 days between sessions. A pressure sensor placed on the posterior calf monitored the wrapping compression force. The intervention exercise comprised six voluntary isometric contractions of the ankle at three angles (20° plantar flexion, neutral 0°, and 10° dorsiflexion) for 3 seconds each using a dynamometer. The maximal isometric ankle plantar flexion torque and dorsiflexion range of motion were evaluated pre- and post-intervention. Significant interactions were observed in ankle plantar flexion torque at 10° dorsiflexion ($p < 0.01$) but not at 0° or 20° plantar flexion. The low- and high-pressure bands significantly enhanced ankle plantar flexion torque by 4.3 Nm (effect size [ES]: 0.14, $p = 0.02$) and 4.9 Nm (ES: 0.15, $p < 0.05$), respectively, and also enhanced the ankle dorsiflexion range of motion by 1.7° (ES: 0.43, $p < 0.01$) and 1.3° (ES: 0.35, $p = 0.02$), respectively, compared to the control. The low- and high-pressure band conditions had comparable effects on torque and range of motion. A few minutes of the calf tissue flossing intervention significantly enhanced ankle plantar flexion torque and dorsiflexion range of motion, although the effect sizes were trivial to small.

Key words: Ankle sprain, prevention, exercise therapy, ankle injuries, ultrasound imaging, fascia.

Introduction

Ankle sprains and related joint dysfunctions are significant problems in various sports. Approximately three million ankle sprains are identified annually in the United States (Waterman et al., 2010), representing about 15% of all high school and college sports injuries (Herzog et al., 2019). In 2010, basketball was the most common sport associated with ankle sprains (41.1%), followed by soccer (17.2%) (Waterman et al., 2010). Ankle sprains have a high re-injury rate (Herzog et al., 2019; Kucera et al., 2016) and induce chronic ankle instability in up to 70% of athletes (Anandacoomarasamy and Barnsley, 2005; Smith and Reischl, 1986; Waterman et al., 2010). Some risk factors for ankle sprains and re-injury include limited ankle dorsiflexion (DF) range of motion (ROM) and plantar flexion (PF) muscle weakness (de Noronha et al., 2006), which increase the incidence of ankle sprains due to fatigue in subsequent halves of games (Ekstrand et al., 2011). Therefore, immediate improvement in ankle DF-ROM and PF torque is crucial for preventing ankle sprains and improving performance.

Tissue flossing is a technique designed to reduce soft tissue tenderness and improve joint ROM and torque (Konrad et al., 2021b). Proposed by Starrett and Cordoza, this method involves wrapping an elastic latex band (floss band) temporarily around a joint or soft tissue while performing active and passive motion under pressure (Starrett and Cordoza, 2015). Studies have shown that a brief and easy tissue flossing intervention of only 1–3 minutes can improve joint ROM (Driller et al., 2017), joint torque (Konrad et al., 2021a), and efficacy against delayed-onset muscle soreness (Prill et al., 2019). Three of four studies showed increased ankle joint DF-ROM with calf tissue flossing (Kaneda et al., 2020a; Konrad et al., 2021b). However, this effect varied with the compression force magnitude (Galis and Cooper, 2022). While thigh tissue flossing has been shown to increase maximal isometric knee extension and eccentric knee flexion torque (Kaneda et al., 2020b; Konrad et al., 2021a), no studies have shown an increase in ankle joint torque following calf tissue flossing (Konrad et al., 2021b). One study noted a significant increase in the rate of force development during the 0–50 milliseconds (ms) phase of isometric PF contraction (Kaneda et al., 2020a). Thus, these issues remain unresolved owing to a lack of well-designed evidence for the participants' characteristics, controlled tissue flossing band compression force, and interventions emphasizing muscle contraction.

Although there are variations in its effect, tissue

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flossing is appealing because any individual can easily perform it quickly. This intervention can potentially benefit athletes and trainers in sports before games or at half-time intervals. However, it is necessary to establish an appropriate band pressure to obtain a highly reproducible effect on joint ROM and torque. Therefore, this study aimed to clarify the immediate effect of calf tissue flossing using several compression bands on ankle joint torque and DF-ROM.

Methods

Participants

Twenty healthy adult males from soccer or basketball teams in our university participated in the study (age: 19.6 ± 1.0 years; height: 171.3 ± 6.8 cm; weight: 64.7 ± 6.5 kg). The recruitment period was from September 8 to September 18, 2022, with 3 weeks of follow-up from September 27 to October 19, 2022. One participant withdrew after the first examination, leaving 19 males in the final analysis (Figure 1). This study followed the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of Kitasato University (study number: 2021-020-2).

The inclusion criteria included participants aged 18–30 years who regularly compete in events involving jumps and sprints for at least 30 minutes per session, at least twice a week. The exclusion criteria were those with severe lower extremity (hip, knee, and ankle joint) musculoskeletal disease (dislocation, fracture, muscle tear, tendon tear, and ligament tear); acute injuries (sprains, strains, and open wounds); latex allergy; hypertension (resting systolic pressure > 160 mmHg or diastolic pressure > 100 mmHg); venous thrombosis; heart disease; respiratory disease; and obvious nerve, skin, or neuromuscular problems in the lower extremities within 6 months. All participants were informed of the benefits and risks of the study and provided written informed consen t before participation. The relevant ethics committee approved this study.

Study design and procedure

This randomized controlled crossover trial included two interventions (two types of tissue flossing bands) and control conditions. Each participant underwent three examinations regarding the non-dominant leg (the one not used when kicking a ball) with 5–10 days washout periods between sessions (Kaneda et al., 2020b). The order of interventions was randomly assigned using Excel (Microsoft, Redmond, WA, USA; 2019). This study had no allocation concealment mechanism or blinding.

On each test day, participants followed the procedure outlined in Figure 2. First, the participants walked comfortably for 3 minutes as a warm-up. Baseline data measurements included ankle joint DF-ROM followed by maximal voluntary isometric PF and DF torque. Then, an intervention exercise using a floss band was performed on the calf for 2 minutes. Finally, the outcome data were measured in the same manner as the baseline data.

Intervention with the tissue flossing band

The intervention utilized two different tensile strengths of a natural rubber floss band (Sanctband COMPREFloss™; 5.1 cm × 3.5 m; Sanct Japan Co., Tokyo, Japan): a low-pressure band (Lime green) and a high-pressure band (Blueberry). Tissue flossing was performed by licensed instructors Y.U., Y.W., and Y.T. (Easy Tissue Flossing Instructor Course Level 1–2). The floss band was wrapped around the calf from just above the most prominent part of the medial ankle to the inferior border of the patella, extending 1.5 times the natural length and overlapping the bands by 50% (Figure 3). Likewise, underwrap (L-Underwrap®; Lindsports®, Osaka, Japan) was used for the control condition. All interventions were performed in less than 2 minutes.

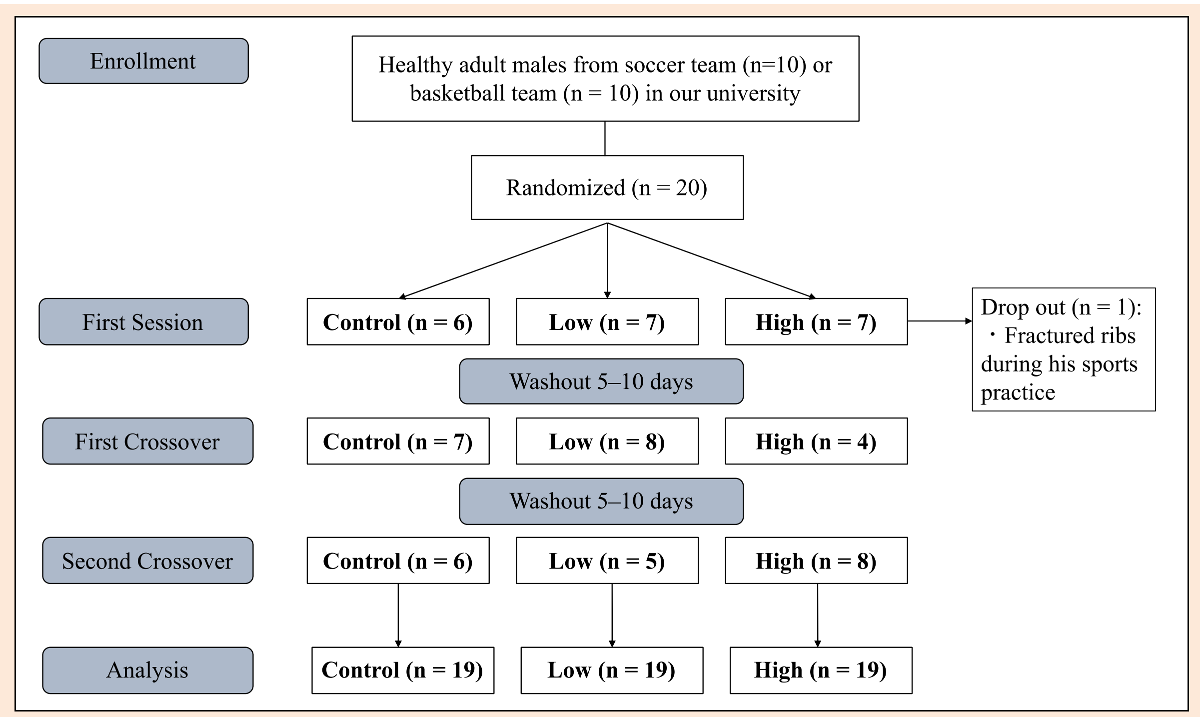

Figure 1. Flowchart of the participant selection process.

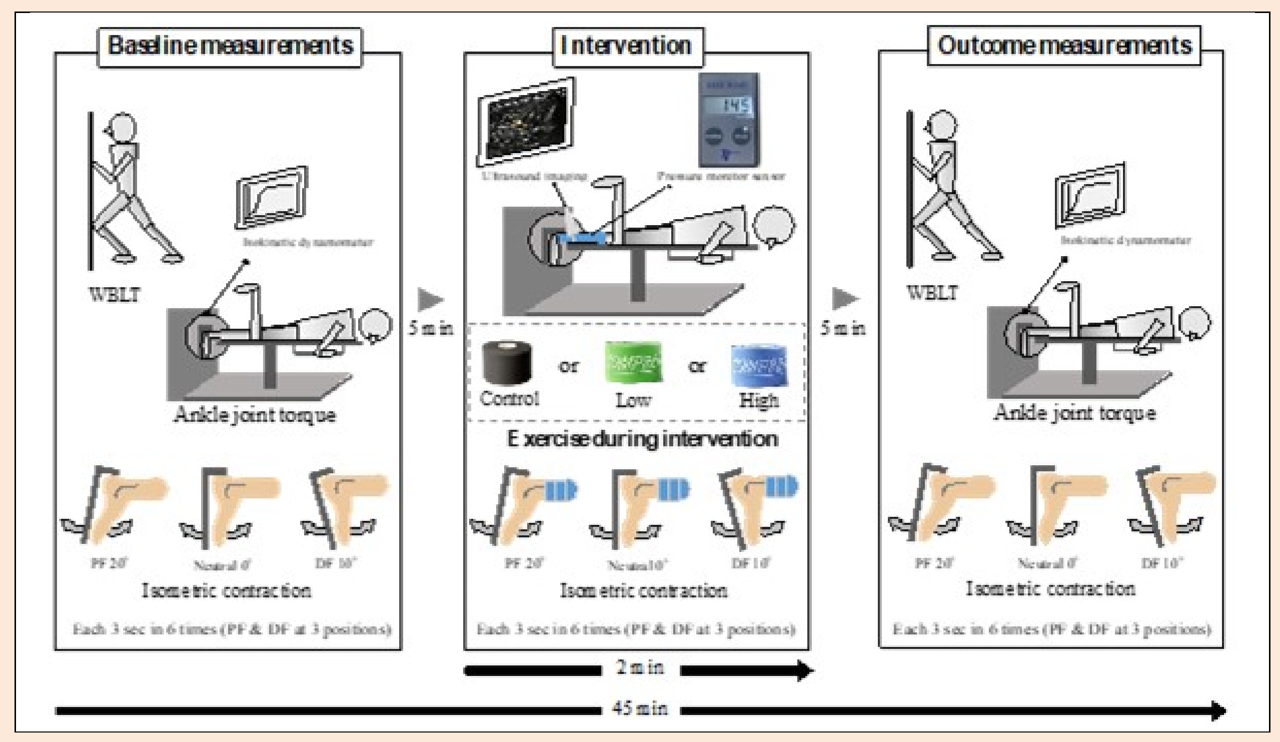

Figure 2. Measurement and intervention flow. WBLT and ankle joint torque measurements in the isokinetic dynamometer were performed in baseline measurements. One of the three bands was selected for the intervention. During the intervention, the pressure was monitored using the Kikuhime pressure monitor sensor, and the posterior tibial artery was monitored using ultrasound imaging. Outcome measurements were taken using the same methods as before the intervention. WBLT: weight-bearing lunge test; PF: plantar flexion; DF: dorsiflexion; sec: seconds; min: minutes.

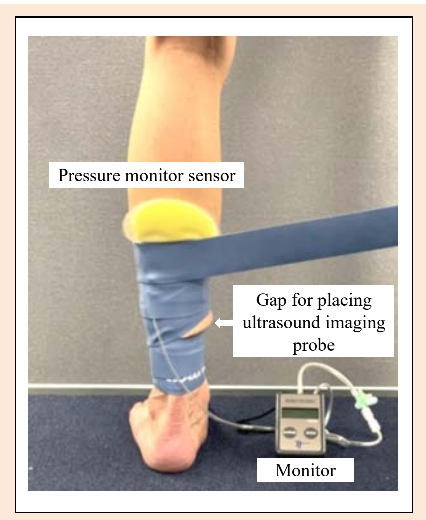

Figure 3. Illustration of wrapping tissue flossing and inserting pressure monitor sensor. The floss band was wrapped around the non-dominant calf from just above the most prominent part of the medial ankle to the inferior border of the patella, extending 1.5 times the natural length and overlapping the bands by 50%. The Kikuhime pressure monitor sensor was placed at the largest bulge at the center of the posterior calf.

The Kikuhime pressure monitor sensor (ZiboCare® Kikuhime, TT Meditrade; ZiboCare, Horsens, Denmark) was placed at the largest bulge at the center of the posterior calf to measure the pressure (Figure 3). The Kikuhime pressure monitor sensor has good validity (intraclass correlation coefficient = 0.99, coefficient of variation [CV] = 1.1%) and reliability (CV = 4.9%) for studies on sports compression wear (Brophy-Williams et al., 2015). In this study, all the data regarding the means and standard deviations of compression force for the three conditions were 7.9 ± 2.0, 137.9 ± 7.7, and 162.8 ± 11.3 mmHg in the control, low-pressure and high-pressure conditions, respectively.

We observed the short axis of the posterior tibial artery using musculoskeletal ultrasound imaging mounted on an 11-MHz linear probe (SONIMAGE MX1 SNiBLE yb; KONICA MINOLTA, INC., Tokyo, Japan) (Figure 4). A previous study suggested that a high compression band of approximately 200 mmHg may cause complete occlusion of the arteries (Galis and Cooper, 2022). To prevent arterial occlusion, the myotendinous transition area of the gastrocnemius muscle was marked in advance with the size of the ultrasound imaging probe (5 cm [length] × 2 cm [width]), ensuring that the tissue flossing band did not cover this area.

Baseline and Outcome Measurements

Maximal isometric torque on ankle PF and DF

The maximal isometric torque on the ankle PF and DF were measured using an isokinetic dynamometer (Cybex Norm Testing & Rehabilitation System; Cybex Norm Int. Inc., Rosemont, IL, USA). Each participant's ankle joint was fixed using a belt while in a prone position with the knee extended, and they gripped handles on both sides to stabilize their trunk and buttocks. Maximal isometric contractions were performed once for 3 seconds after sufficient practice. The order of PF and DF at three ankle joint angles (neutral 0°, PF 20°, and DF 10°) was performed with a rest time of 10 seconds each.

Ankle DF-ROM

The ankle DF-ROM was measured using the weight-bearing lunge test (WBLT) (Figure 5) (Bennell et al., 1998). The WBLT is a validated and reliable method for indirectly assessing ankle DF in the loading position (Bennell et al., 1998). The participants squatted maximally with their knees against a wall while keeping their heels on the floor. The examiner measured the distance from the floor to the knee (FK) and the distance from the wall to the heel (WH), and the ankle joint DF-ROM was calculated using the formula (Langarika-Rocafort et al., 2017): Leg inclination angle = arctan (WH / FK).

Statistical analysis

Sample size estimation was conducted using G*Power software (version 3.1.9.2; University of Kiel, Kiel, Germany). A two-tailed test with a significance level of 0.05 estimated that 17 participants were required to achieve 80% power.

Continuous variables are presented as means and standard errors of the mean, including 95% confidence intervals (CIs). Between-condition comparisons were performed using repeated-measures two-way analysis of variance with a mixed-effects model, considering two factors: intervention (three conditions) and time (before and after the intervention). Multiple comparisons were performed using Tukey's post-hoc test when significant differences were detected. Each test's effect size was calculated using Cohen's d statistic, with values of 0.2, 0.5, and 0.8 or greater were considered small, medium, and large, respectively. All statistical analyses were performed with EZR version 1.61 (Saitama Medical Center, Jichi Medical University, Saitama, Japan) (Kanda, 2013), a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at $p < 0.05$.

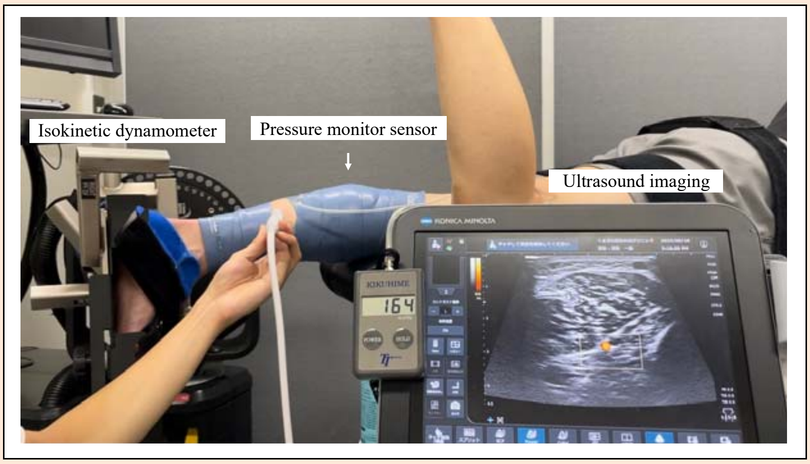

Figure 4. Interventions with tissue flossing bands under conditions of ultrasound imaging observation and pressure measurement. Observation of the short axis of the posterior tibial artery using musculoskeletal ultrasound imaging mounted the 11-MHz linear probe.

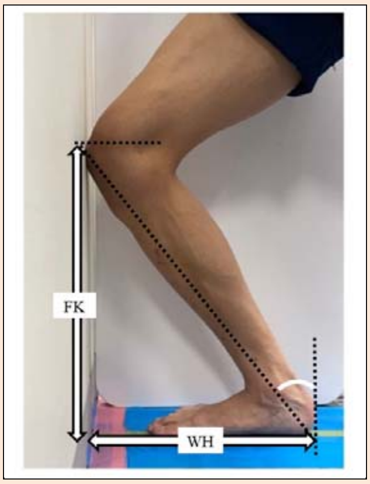

Figure 5. Illustration of the WBLT. FK: distance from the floor to the knee; WH: distance from the wall to the heel; WBLT: weight-bearing lunge test

Results

Table 1 presents the results of the two factors (three band conditions and time) on ankle joint PF and DF isometric torque, as well as ankle joint ROM.

Ankle joint PF torque showed a significant interaction at DF 10°; however, no interaction was observed at neutral 0° or PF 20°. Post-hoc tests revealed that, at DF 10°, both the low- and high-pressure band conditions significantly enhanced the ankle PF torque compared to the control condition ($p = 0.02$ and $p < 0.05$, respectively); however, the effect sizes were trivial (0.14–0.15). No significant difference in ankle PF torque was found between the low- and high-pressure band conditions ($p = 0.89$). In addition, there was no interaction regarding DF torque at any joint angle position (Table 1).

In the WBLT, a significant interaction was observed between the three band conditions and time (Table 1). In the post-hoc test, both the low- and high-pressure band conditions significantly enhanced the ankle DF-ROM compared to the control condition ($p < 0.01$ and $p = 0.02$, respectively); however, the effect sizes were small (0.35–0.43). No significant difference was found between the low- and high-pressure band conditions in the WBLT ($p = 0.53$). No short- or long-term adverse effects were reported after all interventions.

Table 1. Changes in maximal isometric ankle joint torque and DF-ROM before and after the intervention, depending on the band intervention conditions.

		(a) control					(b) Low					(c) High					Interaction		Tukey
	Position	Pre	Post	d	95% CI	ES	Pre	Post	d	95% CI	ES	Pre	Post	d	95% CI	ES	F-value	P-value	
PF (Nm)	at PF 20°	59.7 ± 3.8	56.2 ± 3.7	−3.5	−6.4 to −0.7	0.22	58.5 ± 3.9	58.1 ± 3.6	−0.5	−3.8 to 2.8	0.03	57.6 ± 3.6	58.7 ± 3.4	1.1	−6.4 to −0.7	0.07	2.40	0.10	
	at 0°	98.8 ± 6.4	94.9 ± 7.2	−3.8	−8.1 to −0.4	0.13	95.2 ± 6.4	97.3 ± 6.4	2.2	−2.1 to −6.4	0.08	94.6 ± 6.4	96.9 ± 6.4	2.4	−4.5 to 9.2	0.09	1.98	0.15	
	at DF 10°	105.3 ± 7.1	100.0 ± 7.9	−5.3	−11.2 to 0.6	0.16	99.7 ± 7.4	104.0 ± 7.1	4.3	0.6 to 8.0	0.14	98.3 ± 7.5	103.2 ± 7.9	4.9	−0.5 to 10.4	0.15	5.50	0.01*	a vs. b, c
DF (Nm)	at PF 20°	36.6 ± 1.5	35.7 ± 1.8	−0.9	−2.2 to 0.4	0.13	36.8 ± 1.6	36.4 ± 1.7	−0.4	−1.5 to 0.8	0.05	36.8 ± 1.8	35.5 ± 1.9	−1.3	−2.5 to 0.0	0.16	0.58	0.57	
	at 0°	33.8 ± 1.7	33.7 ± 1.8	−0.2	−1.0 to 0.6	0.02	35.2 ± 1.7	33.7 ± 1.6	−1.5	−3.1 to 0.0	0.22	33.1 ± 1.8	32.7 ± 1.7	−0.4	−1.9 to 1.1	0.06	1.31	0.28	
	at DF 10°	24.3 ± 1.7	23.7 ± 1.4	−0.5	−1.8 to 0.8	0.08	23.7 ± 1.5	23.2 ± 1.4	−0.5	−1.5 to 0.4	0.09	24.5 ± 1.5	25.6 ± 1.7	1.1	−1.2 to 3.3	0.16	1.46	0.24	
WBLT (°)		45.4 ± 0.9	45.6 ± 0.9	0.2	−0.5 to 0.8	0.04	44.3 ± 0.9	45.9 ± 0.9	1.7	0.8 to 2.5	0.43	44.9 ± 0.8	46.2 ± 0.9	1.3	0.7 to 1.9	0.35	5.59	0.01*	a vs. b, c

Continuous variables are presented as means and standard errors of the mean, CI: confidence interval; PF: Plantar flexion; DF: Dorsiflexion torque; WBLT: Weight-bearing lunge test; d: difference; ES: Effect Size; Tukey: Tukey's multiple comparison test. * Interaction between bands at p<0.05 (two-way ANOVA). Significant differences in the post hoc analysis (p <0.05) per the intervention condition (Tukey's multiple comparison test).

Discussion

From our findings, calf tissue flossing at two different pressures significantly increased PF torque in the DF 10° and DF-ROM compared to control conditions, although the effect sizes were trivial to small.

Maximal Isometric Torque on Ankle PF and DF

We observed an interaction effect for PF torque at DF 10°. The low- and high-pressure band conditions enhanced the PF torque by up to 4.3% and 5.0%, respectively, whereas the control condition decreased it by 5.0%. A previous study using a high-pressure band for the calf found that the rate of force development of the PF at 0–50 ms was increased, but not the peak torque value (Kaneda et al., 2020a). The study's intervention method consisted of mobilization, such as passively twisting the calf with a band around it and calf stretching and PF exercises in the standing position. However, our intervention methods comprised only maximal isometric contractions in PF and DF positions. This difference in intervention methods may explain the disparities in effectiveness observed. While calf tissue flossing significantly increased PF torque in our study, the effect sizes were trivial; therefore, it was difficult to reach a conclusion regarding its effectiveness in improving PF torque. However, despite the 5% decrease in PF torque observed in the control condition, the tissue flossing conditions maintained or slightly increased PF torque. This suggests that calf tissue flossing may help mitigate fatigue-induced decreases in PF torque.

Tissue flossing, which uses more compression than is commonly used in blood flow restriction therapy, is thought to increase fascia sliding in addition to its blood flow restriction effect (Starrett and Cordoza, 2015). Some individuals may find the compression force too strong and painful because of the high-pressure band. Although there were no adverse effects following our interventions, previous studies involving calf tissue flossing reported several adverse effects regarding ROM and torque results using the high-pressure band (200 mmHg) compared to the low-pressure band (150 mmHg) (Galis and Cooper, 2022). Some adverse events included severe pain, skin color changes, hematoma, and numbness in the shoulder (Wienke et al., 2020). Although limb muscle training with blood flow restriction is effective for increasing joint torque (Fahs et al., 2015; Scott et al., 2015; Takarada et al., 2002), strong compression forces can lead to adverse events (Loenneke et al., 2012; Yasuda et al., 2011). The low-pressure band used in this study (137.9 ± 7.7 mmHg) can moderately tighten the calf without painful sensations, making it suitable for a wide range of individuals.

In our study, no significant interactions were found between PF torque at PF 20° and neutral 0° or between DF torque in all ankle positions. Ankle joint torque is influenced by the muscle's length-force relationship (Gordon et al., 1966). The triceps surae muscles, which are shortened in the PF position, may have reduced contraction capacity compared to the DF position (Guimaraes et al., 1994). The greater PF torque observed in the DF position than in the other positions in our study supports this finding. Therefore, at PF 20° and neutral 0°, the lack of active contraction in the musculotendinous unit could explain the lack of significant effects. Another possible reason is fascial gliding related to changes in tissue viscosity. In the DF position, the triceps surae muscles are more stretched; this increases muscle stiffness and could lead to impaired fascial gliding (Murayama et al., 2012). Calf tissue flossing reduces muscle stiffness (Kaneda et al., 2020a), and the compression from the floss band applied to the calf muscles, where gliding was restricted in the DF position, may have influenced deeper tissue structures, promoted viscosity reduction, and improved fascial gliding (Behm et al., 2016). This could explain why the PF torque effect was more pronounced in the DF position. Regarding DF torque, we believe that because the dorsal muscles have less volume than the posterior calf muscles, they were not affected. These results showing no change in the calf band intervention would contribute to understanding the indications and benefits of calf banding.

Ankle DF-ROM

In this study, calf tissue flossing significantly increased ankle joint DF-ROM by 1.7° and 1.3° in the low- and high-pressure conditions, respectively, while the control condition showed almost no change (0.2°). However, considering that the minimum detectable change for the WBLT is 4.7° (Powden et al., 2015), we concluded that the clinical effect of calf tissue flossing on DF-ROM was negligible. According to a scoping review, the mean change in DF-ROM across four studies involving calf tissue flossing was 20.0% (95% CI, 11.6–28.8%) (Konrad et al., 2021b). These studies typically used interventions that focused on stretching the calf tissue through repeated maximal PF and DF motions and passive twisting of the calf tissue. In contrast, we focused on enhancing ankle joint torque by several maximal voluntary isometric contractions using a compression band for the calf tissue, which may explain the limited effect on DF-ROM.

The exact mechanism by which compression bands improve ROM remains unclear. It is hypothesized that the compression band may influence the viscoelasticity of soft tissue and fascia gliding (Starrett and Cordoza, 2015). The fascia, innervated by mechanoreceptors, responds to stimulation of the compression band, potentially decreasing sympathetic tone (Schleip, 2003). In addition, a relationship with stretch tolerance has also been suggested (Konrad et al., 2021b). Increased DF ROM observed after ankle tissue flossing has been linked to stretch tolerance, with no changes in muscle stiffness (Vogrin et al., 2020). In contrast, calf tissue flossing, compared with static stretching, resulted in decreased muscle stiffness without changes in stretch tolerance (Kaneda et al., 2020a). Given that our study involved calf intervention, it is likely that the effect on muscle stiffness played a more significant role. A previous study found that a low-pressure band (150 mmHg) improved the DF-ROM, whereas a high-pressure band (200 mmHg) did not, indicating that excessive compression is ineffective for joint ROM because the arterial occlusion reduced the inflow of blood containing oxygen and vital nutrients to the muscles (Galis and Cooper, 2022). In our study, we observed no arterial occlusion under either compression band condition (137.9 ± 7.7 to 162.8 ± 11.3 mmHg), which must have prevented any adverse effects. Still, further studies are needed to determine the optimal compression force and mechanisms underlying the effects of compression bands.

Clinical Significance and Limitations

The main clinical implication of this study is that a brief calf tissue flossing session can immediately enhance PF torque without reducing DF-ROM, both of which are critical factors for preventing ankle injuries (Backman and Danielson, 2011; de Noronha et al., 2006; Fong et al., 2011). While commonly used techniques such as dynamic stretching and foam rolling have been suggested to produce similar effects (Su et al., 2017), recent studies indicate that tissue flossing may offer superior benefits. For instance, thigh tissue flossing has reportedly demonstrated greater improvements in eccentric torque and hamstring flexibility than has dynamic stretching (Kaneda et al., 2020b). Although foam rolling has been reported to improve joint torque and flexibility (Su et al., 2017), a recent meta-analysis concluded that it does not significantly increase myofascial tissue compliance or isometric torque (Glänzel et al., 2023). The simple and quick tissue flossing intervention can be performed by any individual anywhere - as a warm-up before a game, during practice, or at half-time - making it accessible for individuals regardless of their sports setting or medical resources. This intervention technique can help prevent performance deterioration and lower limb disability.

This study had some limitations. First, the participants were all young adult males from a university sports club and did not include top-level competitive athletes or women. The effect of the compression band may vary based on different muscle masses and adipose tissues (Hirsch et al., 2016). Second, the intervention methods used in this study slightly modified the general recommendations to demonstrate only maximal voluntary isometric contractions. An additional focus on calf stretching, an effective intervention method for DF-ROM, would provide additional benefits (Starrett and Cordoza, 2015). Third, the influence of fatigue must also be considered. In muscle strength measurements, the sequence of measuring different angles was not randomized, and the rest period was limited to 10 seconds. Therefore, the possibility that fatigue influenced the measurement results cannot be excluded. Fourth, this study examined the immediate effect of tissue flossing on the calf; thus, the effect on durability or prevention of injury remains unknown. Therefore, further studies are required to address these aspects and confirm our findings.

Conclusion

This study showed that a simple intervention using calf tissue flossing for a few minutes significantly enhanced ankle PF torque in the DF position and DF-ROM, although the effect sizes were trivial to small. Future studies should explore the long-term effects and potential for injury prevention of tissue flossing across diverse populations and conditions, as well as evaluate optimal compression parameters and the integration of complementary rehabilitation techniques.

Acknowledgements

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Key points

- An acute bout of calf tissue flossing immediately inhibited the decrease in ankle plantar flexion torque and slightly enhanced it.
- The intervention had a minor effect on ankle dorsiflexion range of motion.
- The technique is quick and easy to perform, suitable for sports warm-ups and practice.
- No adverse effects or arterial occlusion were observed with either compression level.
- Further research is needed to explore long-term benefits, optimal compression levels, and effects on diverse populations.

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