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Research article

Elucidation of The Effect of Flossing on Improving Joint Range of Motion

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Abstract

Flossing has been hypothesized to improve joint range of motion (flexibility), potentially through enhanced fascial gliding, although this mechanism remains speculative. This study aimed to clarify the effect of flossing, a new type of myofascial release, on joint range of motion by focusing on tissue gliding properties. This study involved 14 healthy participants (aged 18 - 25 years) who performed two types of active exercises with floss bands wrapped around their lower legs. As a control, the participants performed the same active exercises on different days without floss bands. Measurements taken before and after the intervention included ankle dorsiflexion range of motion, ankle plantar flexion maximum voluntary contraction, medial head of the gastrocnemius muscle thickness using ultrasound, and fascial hardness at five locations according to depth. Lower leg flossing significantly increased ankle dorsiflexion range of motion by 28.3 ± 19.9% (control: 14.6 ± 12.4%, P = 0.04, d = 0.83). No significant changes were observed in maximum voluntary plantar flexion contraction or overall muscle and fascial hardness. However, the rate of change in hardness showed a trend toward reduction in the superficial fascia and the upper and middle gastrocnemius muscles, with the upper gastrocnemius muscle exhibiting a statistically significant decrease in hardness (P = 0.05). Flossing showed trends toward reducing superficial muscle and fascial hardness, particularly in the superficial fascia and the upper gastrocnemius muscle, although not all changes were statistically significant. This suggests that potential improvements in intertissue gliding around the fascia could contribute to an increased range of motion.

Key words: Muscle contraction, muscles, tissues.

Introduction

The effects of myofascial release (MR) include increased range of motion (ROM) (Wilke et al., 2020; Skinner et al., 2020; Murray and Clarkson, 2019; Rhyu et al., 2018) and reduced pain (Skinner et al., 2020; Wilke et al., 2020; Murray and Clarkson, 2019; Rhyu et al., 2018; Hughes and Ramer, 2019; Aboodarda et al., 2015; Seju and Rajput, 2021; Teut et al., 2018; Chi et al., 2016; Mohamed et al., 2023). Representative MR methods, such as foam rollers, massage guns, and instrument-assisted soft tissue mobilization tools, are widely used as self-conditioning techniques among athletes (Wilke et al., 2020; Skinner et al., 2020; Ikeda et al., 2019; Cheatham et al., 2020; and Kalichman and David, 2017). However, the classification of foam rolling as a self-myofascial release (SMR) technique remains debated. Behm and Wilke (2019) argue that the primary mechanisms behind foam rolling effects may involve thixotropic changes and increased pain tolerance, rather than direct myofascial release.

Recently, flossing has gained attention as a type of MR. Flossing involves wrapping a natural rubber band, called a floss band, around muscles and joints to apply pressure and perform active and passive movements, such as manual twisting. Flossing positively affects performance-related factors, such as increased ROM (Cheatham et al., 2020; Kaneda et al., 2020a; Driller et al., 2017; Mills et al., 2020; Galis and Cooper, 2022; Konrad et al., 2021a; Vogrin et al., 2020; Wu et al., 2022; Kielur and Powden, 2020; Konrad et al., 2021b), increased maximum voluntary muscle strength (Kaneda et al., 2020b; Galis and Cooper, 2022; Konrad et al., 2021a; Vogrin et al., 2020), and improved jumping ability (Driller et al., 2017; Mills et al., 2020; Wu et al., 2022; García-Luna et al., 2020). It is also an effective tool for ameliorating pain in delayed-onset muscle soreness (Prill et al., 2018), Osgood-Schlatter disease (Weber, 2018), and Kienböck disease (Cage et al., 2018). It is widely used in hospitals and sports facilities by physical therapists and athletic trainers as a treatment method and by athletes as a self-conditioning tool. Unlike other MR techniques, flossing targets specific areas, allowing for a wide range of approaches. Exercises such as stretching and manual twisting can be combined during flossing.

Kruse suggested that fascial gliding might play a significant role in physiological function, although this hypothesis was based on the limited research available at that time (Kruse, 2017). Performing active and passive movements under compression changes tissue structure and properties, improves tissue adhesion, resolves fascial gliding dysfunction, and restores restricted ROM (Gao et al., 2024). However, studies on the effect of flossing on joint ROM improvement are limited; the specific tissues affected by flossing, including muscles and fascia, remain unclear. In clinical and sports settings, significant improvements in joint ROM have been observed in cases with restricted ROM due to wound adhesions after flossing. When observing tissue movement during joint movement, flossing was performed using an ultrasound imaging diagnostic device, and improvements were observed in wound adhesions and tissue gliding. Tissue gliding affects joint ROM, and decreased gliding reduces joint ROM (McCombe et al., 2001; Pavan et al., 2014). Therefore, tissue gliding may influence whether flossing can increase joint ROM.

This study focused on the stiffness-related characteristics of tissues, which may indirectly influence intertis-

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sue movement, and aimed to determine the effect of flossing on joint ROM using shear wave elastography integrated into an ultrasound imaging diagnostic device to evaluate tissue hardness. We hypothesized that flossing would not change muscle stiffness but would reduce fascial stiffness, thereby enhancing tissue gliding and improving the ROM.

Methods

Participants

This study involved 14 healthy young men (age: 22.9 ± 2.5 years, height: 170.0 ± 5.0 cm, weight: 67.7 ± 7.8 kg) with no impairment in motor function and no history of orthopedic injury in the lower limbs (muscle, tendon, joint capsule, ligament injury, and peripheral neuropathy). In our initial study on floss band usage, we focused solely on male participants due to physiological differences in muscle and fascia structure and responses between sexes. By limiting our study to one sex, we were able to control variables and ensure data consistency, thereby enhancing the reliability of our results. This approach allows for a more accurate evaluation of the effects of floss bands. In this study, the same participants underwent two distinct experimental conditions: one involving floss band application (FLOSS) and one serving as a control (CON). Participants with blood diseases, neurological disorders, diabetes, or latex allergies were excluded due to the physical constraints associated with wrapping floss bands around the lower leg. Additionally, preliminary examinations ensured no bone impingement issues occurred in the anterior talocrural joint during dorsiflexion, as determined using the talus-posterior sliding test. This eliminated restrictions on talus posterior sliding or bony limitations in ankle dorsiflexion ROM. Consequently, no restrictions on talus posterior sliding during dorsiflexion or bony restrictions on ankle dorsiflexion ROM in the anterior talocrural joint were observed.

The purpose of the study, measurement methods, and ethical considerations were explained to the participants in advance, and their consent was obtained before conducting the research. This study was approved by the Waseda University Human Research Ethics Committee (approval number: 2023-172).

Study design

This study used a randomized crossover design. Participants were categorized into two groups: a flossing group (FLOSS) and a control group (CON). A washout period of at least 48 h was set for each condition. Ankle dorsiflexion range, ankle plantar flexion maximum voluntary contraction, and the muscle and fascial hardness of the medial head of the gastrocnemius (from the lateral epicondyle of the tibia to the most convex part of the lateral malleolus) were measured before and after the intervention. The study was conducted at Waseda University's Medical Sciences Clinic from July to October 2023.

Flossing method

The floss band used was the Sanctband COMPRE Floss Blueberry 5 cm × 3.5 m (Sanct Japan Co., Ltd.). The floss band application and technique were performed according to the manufacturer's instructions. The right lower leg was selected as the flossing site. After wrapping the floss band once around the distal 20% of the leg, it was pulled, half-covered, and wrapped proximally up to the tibial tuberosity (Figure 1). Active exercises were performed after the floss band was wrapped. The exercises included 10 calf raises and 10 ankle dorsiflexion stretches, each performed in two sets. Subjective pain assessment (numerical rating scale: NRS) was performed during floss band wrapping and scored below 3 on a visual analog scale of 1 to 5 (1: no pain at all, 5: unbearable discomfort, in 0.5 increments). In the control group, flossing was not performed; the same active exercises were performed without wrapping the floss band. An expert with 2 years of experience wrapped all floss bands.

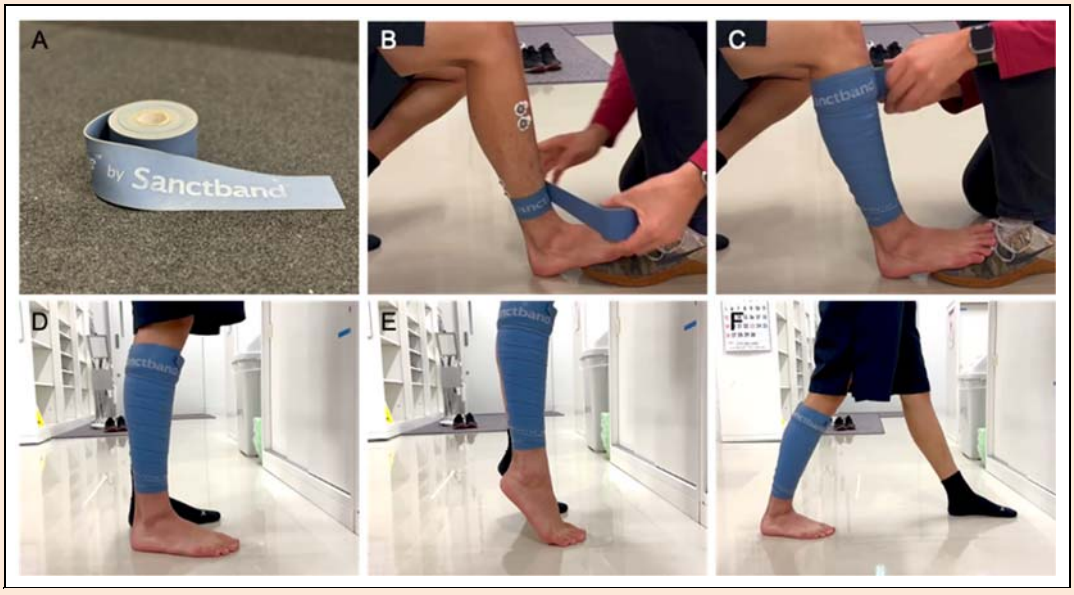

Figure 1. Flossing intervention methods. (A) Floss band manufactured by Sankt Japan. (B, C) After wrapping the floss band once around the distal 20% of the lower leg, the floss band is wrapped proximally up to the tibial tuberosity while pulling the floss band halfway over the second and subsequent wraps. (D, E, F) Automatic movement performed after wrapping the floss band. The participants performed two sets, each including (1) 10 calf raises and (2) 10 ankle dorsiflexion stretches.

Ankle dorsiflexion ROM

Ankle dorsiflexion ROM was measured using an isokinetic dynamometer (Biodex System 4; Biodex Medical Systems, Shirley, NY, USA). Participants sat with 70° hip flexion and full knee extension, and their thighs and feet secured to the dynamometer with a belt. The ankle was dorsiflexed from 30° plantar flexion to the peak dorsiflexion angle at an angular velocity of 2°/s. Participants were instructed not to resist passive dorsiflexion or relax during the measurement. The discomfort angle was determined by a subjective pain rating of 4 on the NRS. Notably, if a difference of 10% or more was observed between measurements, a third measurement was performed. The average of the two valid ROM measurements was used as the representative value. During the ROM measurement, muscle activity was simultaneously recorded using surface electromyography (EMG) at a sampling frequency of 1000 Hz, targeting the medial head of the gastrocnemius, soleus, and tibialis anterior muscles.

Notably, the ROM measurement was performed at a controlled angular velocity of 2°/s. The EMG data collection was recorded simultaneously; however, the muscle activity measurement was based on passive movement at this velocity, without involving active muscle contraction, as in an MVC measurement. Therefore, the muscle activity measured here reflects the muscle response during passive dorsiflexion rather than during active isometric or isokinetic contraction.

EMG data collection

Muscle activity at peak dorsiflexion was recorded concurrently with the ROM measurement using a surface electromyograph (BioSignal Splux, Lisbon, Portugal) at a sampling frequency of 1000 Hz. EMG data were recorded for 5 s at the peak dorsiflexion angle. The target muscles were the medial heads of the gastrocnemius, soleus, and tibialis anterior. Electrode placements followed standard anatomical guidelines, with electrodes attached as follows: Tibialis anterior: proximal one-third of the line between the head of the fibula and the medial malleolus. Gastrocnemius: proximal one-third of the line between the lateral epicondyle of the tibia and the most convex part of the lateral malleolus. Soleus: distal one-third of the line between the lateral epicondyle of the femur and the lateral malleolus. Prior to electrode placement, the skin was shaved, cleaned, and disinfected to minimize impedance and ensure optimal signal quality.

Maximal voluntary contraction (MVC)

The MVC of plantar flexion was measured using an isometric dynamometer (Biodex System 4; Biodex Medical Systems, Shirley, NY). Participants were instructed to gradually increase force over 3 s until they reached maximal contraction. Once maximum force was achieved, they were instructed to hold it for 3 s at peak force. Subsequently, participants gradually decreased the force over another 3-s period. The maximum force achieved during the 3-s hold was recorded as the MVC value. Prior to the MVC measurement, participants practiced at 80% of their maximal strength for two trials. Participants were given a 1-min rest before the MVC measurements were taken. The MVC was performed twice, and the highest recorded value was used. A rest period was provided between the MVC and ROM measurements to minimize fatigue.

Muscle and fascia stiffness

The measurement site was the belly of the medial head of the gastrocnemius (from the lateral epicondyle of the tibia to the most convex part of the lateral malleolus, proximal to the lateral malleolus). Muscle and fascia stiffness were measured using shear wave elastography (Applio α) (Figure 2). Based on a previous study (14), participants maintained the same position during the measurement of the ankle dorsiflexion ROM, with the ankle dorsiflexed at 0°.

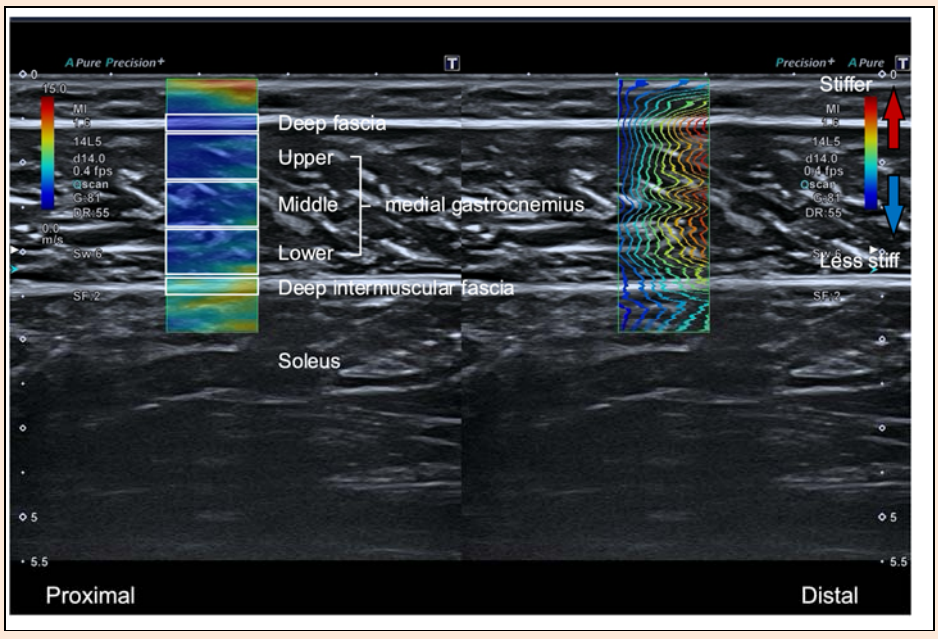

Figure 2. Ultrasound elastography imaging screen. The region of interest has a vertical width of deep fascia; the deep intermuscular fascia measurement covers only the target area; the upper, middle, and lower medial gastrocnemius are demarcated by dividing the muscle thickness into three equal regions after measurement. The width is standardized to 1 cm.

Ultrasound images were captured three times each before and after the intervention. The medial gastrocnemius belly was divided into five regions of interest according to depth: deep fascia (DF), upper medial gastrocnemius (UMG), middle medial gastrocnemius (MMG), lower medial gastrocnemius (LMG), and deep intermuscular fascia (DIF). Muscle and fascial hardness were also measured. The width of the regions of interest was standardized to 1 cm. The vertical width covered only the target area for the DF and DIF, and the gastrocnemius thickness was divided equally into thirds for the UMG, MMG, and LMG. The measurement sites were marked before the intervention, and a linear ultrasound probe was placed at each site after the intervention. Hardness was measured three times at each site, and the average of the three measurements was used as the representative value. Intra-examiner reliability at the five measurement sites was evaluated using an ICC one-way random effects model (model 1) with single measurement and agreement. The following values were obtained: DF, 0.93 (95% confidence interval [CI]: 0.84 - 0.98); UMG, 0.94 (95% CI: 0.86 - 0.98); MMG, 0.96 (95% CI: 0.91 - 0.99); LMG, 0.91 (95% CI: 0.79 - 0.97); and DIF, 0.88 (95% CI: 0.73 - 0.96).

Statistical analysis

All data are expressed as mean ± standard deviation. The normality of the data was assessed using the Shapiro-Wilk test, confirming that all datasets followed a normal distribution ($P > 0.05$). Homogeneity of variances was tested using Levene's test, and sphericity for repeated measures analysis of variance (ANOVA)was confirmed with Mauchly's test. If the sphericity assumption was violated, a Greenhouse-Geisser correction was applied.

A two-way repeated measures ANOVA was conducted to examine interactions between intervention condition (FLOSS and CON) and time (pre- and post-intervention). Effect sizes for interactions were calculated as partial eta-squared (ηp^2), with the following thresholds applied: small ($\eta p^2 = 0.01$), medium ($\eta p^2 = 0.06$), and large ($\eta p^2 = 0.14$) (Cohen, 1988).

Post-hoc analyses were conducted using paired t-tests to compare pre- and post-intervention values within each group. Changes between groups were compared using independent t-tests for rate of change data. The rate of change in ROM was calculated as:

$$Rate\ of\ change(\%) = \frac{Post\ intervention\ ROM - Pre\ intervention\ ROM}{Pre\ intervention\ ROM} \times 100$$

For all t-tests, effect sizes were calculated as Cohen's d, with thresholds defined as small (d = 0.2), medium (d = 0.5), and large (d = 0.8) (Cohen, 1988).

As a result of an a priori statistical power analysis, which calculated Cohen's *d* as the effect size (for post hoc comparisons), 14 participants were estimated to be required for each of the two conditions (within-factor repeated measures ANOVA; effect size, 0.4; power, 0.8; α level, 0.05; G*power 3 was used). The analysis was based on expected changes in ankle dorsiflexion range of motion following myofascial interventions, as suggested in prior studies, including that by Gao et al. (2024). Statistical analyses were performed using IBM SPSS Statistics version 28 (SPSS, NY, USA). Statistical significance was set at $P < 0.05$.

Results

During ankle dorsiflexion ROM, an interaction was observed between the intervention groups and time ($P = 0.01$, $\eta p^2 = 0.09$). In the FLOSS group, a significant change was observed after the intervention (before: 23.9° ± 7.2°, after: 29.6° ± 6.9°, $P < 0.04$, $d = 0.81$, large effect). However, in the CON group, no significant change was observed after the intervention (before: 26.3° ± 7.3°, after: 29.5° ± 7.0°, $P = 0.28$, $d = 0.45$). A significant difference was observed between the groups in the rate of change in ankle dorsiflexion ROM after the intervention, with a greater change in the FLOSS group (28.3% ± 19.9%) compared with the CON group (14.6% ± 12.4%, $P = 0.04$, $d = 0.83$) (Table 1) (Figure 3).

During the MVC of the ankle joint plantar flexor, an interaction was observed between the intervention groups and time ($P = 0.01$, $\eta p^2 = 0.12$, medium effect). No significant change was observed after the intervention in either the FLOSS group (before: 195.6 ± 41.6 Nm/kg, after: 190.0 ± 40.0 Nm/kg, $P \leq 0.73$) or the CON group (before: 198.9 ± 44.9 Nm/kg, after: 196.5 ± 47.0 Nm/kg, $P = 0.87$). No significant difference was observed between the groups in the rate of change before and after the intervention during MVC of the ankle joint plantar flexor (FLOSS group: −2.2% ± 9.4%, CON group: −1.3% ± 7.9%; $P = 0.81$) (Figure 4).

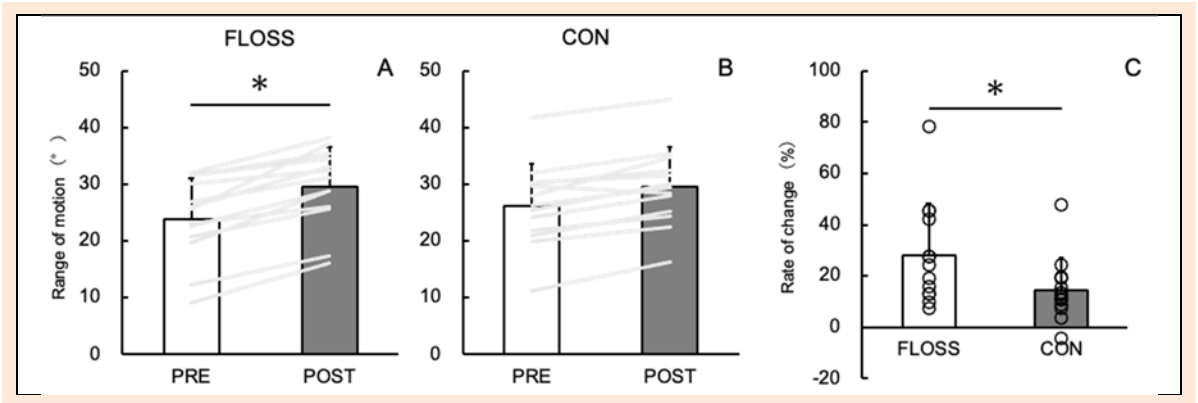

Figure 3. Ankle joint dorsiflexion range of motion results. (A) Changes after intervention in the FLOSS and (B) control (CON) groups. (C) Rate of change due to intervention in each group.

Table 1. Stiffness measurement results.

	FLOSS		*P*	CON		*P*
	PRE	POST		PRE	POST	
Deep fascia	5.8 (1.4)	4.9 (1.5)	0.14	6.0 (1.5)	5.8 (1.1)	0.79
Upper medial gastrocnemius	4.8 (0.9)	4.2 (1.1)	0.18	3.9 (0.9)	4.2 (1.1)	0.48
Middle medial gastrocnemius	5.2 (1.8)	4.7 (1.4)	0.37	3.9 (1.2)	4.4 (1.4)	0.36
Lower medial gastrocnemius	5.4 (1.5)	6.0 (1.4)	0.18	5.3 (1.5)	6.0 (1.8)	0.48
Deep intermuscular fascia	8.7 (1.5)	9.0 (2.2)	0.75	8.9 (1.6)	8.4 (2.4)	0.49

Values are expressed as the mean (standard deviation). FLOSS, flossing group; CON, control group; PRE, before intervention; POST, after intervention.

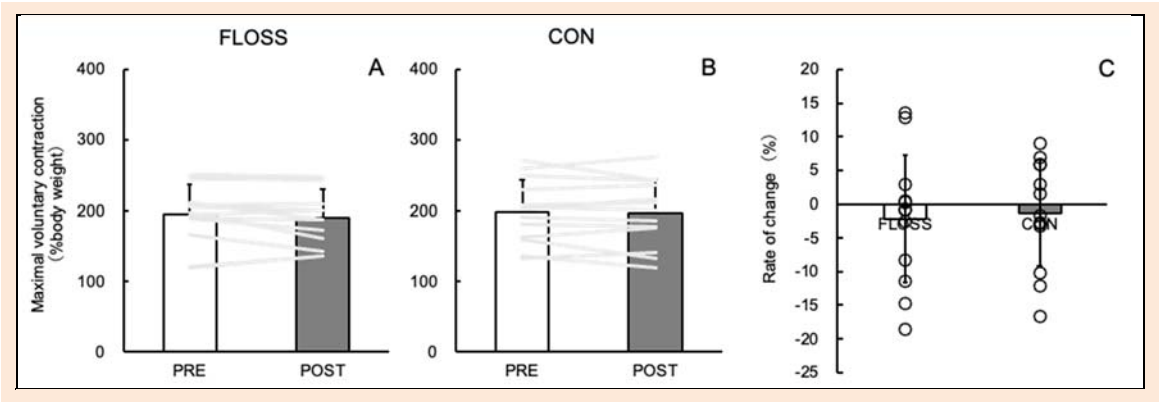

Figure 4. Maximum voluntary contraction results of ankle plantar flexors. (A) Changes after intervention in the FLOSS and (B) control (CON) groups. (C) Rate of change due to intervention in each group.

No interaction was observed between the intervention group and time for the DF ($P = 0.39$, $\eta p^2 = 0.01$), and no significant changes were observed in the FLOSS (before: 5.8 ± 1.4 m/s, after: 4.9 ± 1.5 m/s, $P = 0.14$) or CON (before: 6.0 ± 1.5 m/s, after: 5.8 ± 1.1 m/s, $P = 0.79$) group. No interaction was observed between the intervention group and time for the UMG (P = 0.15, $\eta p^2 = 0.41$), and no significant changes were observed in the FLOSS (before: 4.8 ± 0.9 m/s, after: 4.2 ± 1.1 m/s, $P = 0.18$) or CON (before: 3.9 ± 0.9 m/s, after: 4.2 ± 1.1 m/s, $P = 0.48$) group. For the MMG, no interaction was observed between the intervention group and time ($P = 0.20$, $\eta p^2 = 0.33$). No significant changes were observed in the FLOSS (before: 5.2 ± 1.8 m/s, after: 4.7 ± 1.4 m/s, $P = 0.37$) or CON (before: 3.9 ± 1.2 m/s, after: 4.4 ± 1.4 m/s, $P = 0.36$) group. For the LMG, no interaction was observed between the intervention group and time ($P = 0.15$, $\eta p^2 = 0.41$). No significant changes were observed in the FLOSS (before: 5.4 ± 1.5 m/s, after: 6.0 ± 1.4 m/s, $P = 0.18$) or CON (before: 5.3 ± 1.5 m/s, after: 6.0 ± 1.8 m/s, $P = 0.48$) group. No interaction was observed between the intervention group and time for the DIF (P = 0.48, $\eta p^2 = 0.10$), and no significant changes were observed in the FLOSS (before: 8.7 ± 1.5 m/s, after: 9.0 ± 2.2 m/s, $P = 0.75$) or CON (before: 8.9 ± 1.6 m/s, after: 8.4 ± 2.4 m/s, $P = 0.49$) (Table 2) group.

A slight difference was observed between the groups in the rate of change in muscle and fascial hardness before and after the intervention in the UMG (FLOSS group: −10.5 ± 20.3%, CON group: 9.0 ± 25.8%, $P = 0.05$, d = 0.84) but not in the DF (FLOSS group: −12.7 ± 24.2%, CON group: 0.8 ± 17.4%, $P = 0.13$), MMG (FLOSS group: −4.1 ± 29.6%, CON group: 20.3 ± 39.5%, $P = 0.10$), LMG (FLOSS group: 15.5 ± 26.9%, CON group: 16.4 ± 30.3%, $P = 0.94$), or DIF (FLOSS group: 5.3 ± 28.3%, CON group: −3.5% ± 32.8%, $P = 0.49$) (Table 3).

Table 2. Stiffness change rate.

	FLOSS	CON	*P*
Deep fascia	-12.7 (24.2)	0.8 (17.4)	0.13
Upper medial gastrocnemius	-10.5 (20.3)	9.0 (25.8)	0.05
Middle medial gastrocnemius	-4.1 (29.6)	20.3 (39.5)	0.10
Lower medial gastrocnemius	15.5 (26.9)	16.4 (30.3)	0.94
Deep intermuscular fascia	5.3 (28.3)	-3.5 (32.8)	0.49

Values are expressed as the mean (standard deviation). FLOSS, flossing group; CON, control group.

Table 3. Muscle activities of triceps surae and tibialis anterior during maximum ankle dorsiflexion.

	FLOSS		CON	
	PRE	POST	PRE	POST
Tibialis anterior muscle	8.45 (8.52)	8.63 (6.14)	7.91 (4.08)	7.62 (1.1)
Gastrocnemius muscle	17.9 (25.95)	22.49 (37.86)	9.52 (3.96)	9.74 (4.55)
Soleus muscle	14.73 (7.91)	16.53 (10.16)	11.16 (5.53)	10.98 (4.78)

These parameters did not differ significantly from the pre-intervention values under any condition ($P > 0.05$). Values are expressed as the mean (standard deviation). FLOSS, flossing group; CON, control group; PRE, before intervention; POST, after intervention.

Discussion

This study aimed to investigate the effect of flossing, a novel MR technique, on joint ROM. It examined changes in tissue stiffness as an indicator of potential alterations in gliding properties between tissues.

Flossing the lower leg increased ankle dorsiflexion ROM. MR techniques using foam rollers and massage guns

are thought to exert a thixotropic effect, which reduces fascia viscosity by applying pressure (Bohlen et al., 2014; Konrad et al., 2020). As flossing also applies pressure over a wide area, it might have reduced fascia viscosity in the lower leg, leading to an increase in ankle dorsiflexion ROM. Plocker et al. (2015) reported that although the ROM of the shoulder joint increased after flossing, the increase was not statistically significant. They attributed the lack of significance to the difficulty of effectively covering the entire shoulder (rotator cuff complex) with a floss band and highlighted the importance of flossing the joint to enhance ROM. Therefore, their study suggests that flossing may not be effective for increasing shoulder ROM under these conditions (Plocker et al., 2015). In this study, flossing was performed only on the lower legs and not the ankle or knee joints. However, a more significant increase in ankle dorsiflexion ROM might have been observed by flossing the joints. Flossing increases joint ROM (Cheatham et al., 2020; Kaneda et al., 2020a; Kaneda et al., 2020b; Driller et al., 2017; Mills et al., 2020; Galis and Cooper, 2022; Konrad et al., 2021a; Vogrin et al., 2020; Wu et al., 2022; Kielur and Powden, 2020; Konrad et al., 2021b) and may serve as an effective tool for preventing injuries in various body parts. Conversely, Hodeaux et al. investigated the effect of flossing on the elbow joint of tennis players and reported no increase in joint ROM for elbow flexion, extension, forearm pronation, or supination. Therefore, enhanced effects cannot be obtained in all body parts.

No change was observed in the MVC of ankle plantar flexion owing to flossing of the lower legs. Previous studies have reported that flossing positively affects performance-related factors, such as increased MVC strength (Kaneda et al., 2020b; Galis and Cooper, 2022; Konrad et al., 2021a; Vogrin et al., 2020) and jumping power (Driller et al., 2017; Mills et al., 2020; Wu et al., 2022; García-Luna et al., 2020). However, other studies report no change in performance (Plocker et al., 2015), and no consensus has yet been reached. Ankle flossing significantly improves the height and speed of single-leg jumps as well as the ROM of the ankle joint during plantar flexion and dorsiflexion (Driller et al., 2017). The vascular occlusion effect of partial body compression significantly increases growth hormone and norepinephrine levels when the compression is removed. Moreover, an acute increase in norepinephrine is associated with improved vertical jumping ability. Although the exact cause is unknown, a physiological effect may be involved (Reeves et al., 2006; Takarada et al., 2000; Morales et al., 2014; Driller and Overmayer, 2017). Performance factors, such as ROM and MVC, may differ depending on the part of the body (upper or lower limbs) and location (muscles or joints) where flossing is applied. Therefore, future research should clarify the effects of flossing on each part and location.

No significant changes were observed in muscle or fascial hardness measurements, including those for DF and MMG. However, a trend toward statistical significance ($P = 0.05$) was observed in the UMG, located under the fascia. Although this trend is suggestive, the lack of statistical significance indicates that these findings should be interpreted with caution and may not represent consistent effects. Cross-bridges are formed when myosin heads bind to actin filaments during muscle contraction, affecting muscle stiffness (Hill, 1968; Proske and Morgan, 1999; Morales-Artacho et al., 2017). Massage may reduce hardness by shearing these cross-bridges (Proske and Morgan, 1999). In this study, the trend observed in the UMG might have resulted from flossing, which compresses the muscle through massage, shears cross-bridges, and potentially reduces stiffness.

Previous studies have shown that muscle stretching, contraction, and exercise affect muscle hardness (Fukunaga et al., 1997). However, in this study, we monitored the muscle activity of the medial head of the gastrocnemius, soleus, and tibialis anterior muscles while measuring the maximum ankle dorsiflexion angle and confirmed that there was no muscle contraction during the measurement. We also confirmed no significant difference in muscle activity during maximum ankle dorsiflexion (Table 3). Therefore, muscle hardness may not change significantly with muscle stretching. The relationship between muscle hardness and stretching is commonly regarded as follows: muscle hardness increases with muscle stretching, and hardness decreases when the stretch load decreases. In this study, the decrease in the hardness of the UMG might have been caused by a reduction in the stretch load on the muscle.

No significant change in hardness was observed in the MMG, located at the center of the muscle belly; however, a non-significant decrease was observed. One limitation of this study is that, although an experienced individual performed the intervention, the pressure used to wrap the floss band might not have been standardized. Because the depth of the effect may vary with wrapping strength, further research is needed to determine the range of flossing effects based on this variable.

Although flossing reportedly affects the fascia, as mentioned in theoretical discussions (Kruse, 2017), experimental evidence confirming such effects remains limited. In this study, the effect on the DIF, corresponding to the deep layer of the fascia, was small. However, the hardness of the DF, representing the superficial fascia, showed a decrease, though this result was not statistically significant.

The main determinant of the fascia's viscoelasticity is hyaluronic acid, whose properties can be influenced by factors such as heat, pH, and pressure (Cage et al., 2018). Physical stimulation of the fascia's periphery through flossing may reduce its viscoelasticity because of these effects, potentially enhancing tissue gliding and contributing to improved joint ROM. This hypothesis aligns with theoretical perspectives on fascia dynamics (McCombe et al., 2001) and provides a potential explanation for the observed increase in ROM in this study. Therefore, the increase in joint ROM observed in this study might have been influenced by improved tissue gliding ability owing to decreased fascia viscoelasticity from flossing. MR of the lower leg reduces DF hardness in patients with subacute pain (Luomala et al., 2014). This suggests that flossing can significantly reduce fascial hardness in patients with fascial abnormalities such as fatigue, contracture, and myofascial pain syndrome. In addition, passive exercise intervention was not performed in this study because it was difficult to quantify. However, as passive exercise intervention is also

recommended, significant changes might be observed.

Limitation

This study examined only the immediate effects of flossing; future research should investigate its long-term effects and underlying physiological mechanisms. Kiefer et al. (2017) suggested that flossing might have psychological benefits and could potentially be used to achieve soft tissue flexibility goals in patients and athletes. Although we did not directly assess fascial gliding in this study, flossing is hypothesized to affect tissue dynamics, potentially involving mechanisms such as proprioception, neural responses, and vascular changes (Kruse, 2017). These mechanisms may contribute to the observed changes in joint ROM and should be the focus of future physiological investigations to clarify the conditioning potential of flossing.

Conclusion

This study was conducted on healthy participants to clarify the effect of flossing on joint ROM, focusing on intertissue gliding. A significant decrease in hardness was observed in the UMG located under the fascia. A decrease in muscle hardness in the subfascial area may indicate improved intertissue gliding around the fascia. In other words, enhanced intertissue gliding around the fascia through flossing is a factor that may positively increase joint ROM.

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Key points

- Flossing is a myofascial intervention widely used by physical therapists and athletes.
- We investigated its effects on joint range of motion and found that it reduced superficial muscle and fascial hardness.
- The increase in joint range of motion might have resulted from improved tissue gliding owing to decreased fascia viscoelasticity.

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