©Journal of Sports Science and Medicine (2023) **22,** 681-687
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.681

Research article

Acute Effects of Different Foam Roller Intervention Techniques on Knee Extensors

Kazuki Kasahara [1], Andreas Konrad [2], Yuta Murakami [1], Riku Yoshida [3], Ewan Thomas [4] and Masatoshi Nakamura [5]✉
[1] Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Japan; [2] Institute of Human Movement Science, Sport and Health, University of Graz, Graz, Austria; [3] Maniwa Orthopedic Clinic, Yamakido, Higashi-Ku, Niigata, Japan; [4] Sport and Exercise Sciences Research Unit, Department of Psychology, Educational Science and Human Movement, University of Palermo, Palermo, Italy; [5] Faculty of Rehabilitation Sciences, Nishi Kyushu University Kanzaki, Saga, Japan

Abstract

The usefulness of Foam Roller (FR) even without a rolling stimulus (e.g., static compression with or without dynamic joint movements) has been recently demonstrated; however, the different effects of these methods remain unclear. Thus, this study aimed to compare and investigate the effects of such FR intervention methods on knee extensors. The dominant knee extensors of 20 male university students were investigated using the following four conditions: control (CON), FR with rolling (FR_rolling), FR with static compression (FR_SC), and FR with static compression + dynamic movement of the knee joint (FR_DM). FR_SC was intervened to compress the muscle belly of the knee extensors. FR_DM involved knee flexion and extension while maintaining the FR_SC condition. Knee flexion ROM, pain pressure threshold (PPT), tissue hardness, and countermovement jump (CMJ) height were outcome variables; they were compared before and immediately after the intervention. The results of this study showed that knee flexion ROM was significantly ($p < 0.01$) increased in FR_rolling ($d = 0.38$), FR_SC ($d = 0.28$), and FR_DM ($d = 0.64$). Tissue hardness was significantly ($p < 0.01$) decreased in FR_rolling ($d = -0.55$), FR_SC ($d = -0.28$), and FR_DM ($d = -0.42$). A main effect of time ($p < 0.01$) was observed in knee flexion ROM, PPT, and tissue hardness, but no change in CMJ was observed. The results of this study suggested that clinicians and athletes could choose any method they like as a warm-up routine.

Key words: Range of motion, flexibility, tissue hardness, countermovement jump, foam rolling.

Introduction

It has been reported that rolling with a foam roller (FR_rolling) is effective in increasing the range of motion (ROM) (Behm et al., 2020; Konrad et al., 2022b; Konrad et al., 2022c; Wilke et al., 2020). Furthermore, some studies showed that the FR_rolling intervention decreases tissue hardness (Glänzel et al., 2023; Kasahara et al., 2022) and significantly increases pain pressure threshold (PPT) (Cavanaugh et al., 2017; Cheatham and Baker, 2017; Kasahara et al., 2022). In addition to these effects, FR_rolling did not decrease muscle strength and athletic performance, such as jump height and sprint speed (Wiewelhove et al., 2019). It has also been reported in a systematic review and meta-analysis by Konrad et al. (Konrad et al., 2022a). Conversely, Glänzel et al. (2023) reported an increase in maximum voluntary concentric contraction torque of knee extensors. Thus, the FR_rolling intervention is expected to be applied as an alternative warm-up method to static stretching that could impair muscle strength and athletic performance in the sports field.

Interestingly, previous studies have explored methods for maximizing the FR_rolling intervention effect. FR_rolling is commonly used to roll the target muscle, but the effects of an intervention method that compresses the target muscle without rolling have been investigated. Wilke et al. (2018) compared the effects of FR_rolling, static compression, and placebo on PPT for trigger points in ankle plantar flexors. The results indicated no significant change in the FR_rolling intervention and placebo groups. However, the static compression group had significantly increased PPT. Furthermore, Cheatham and Stull (2018) examined the difference in the effect on the left knee extensors with and without joint (dynamic) movement during FR_rolling. The intervention group with dynamic movement is a cycle in which the rolling motion is temporarily stopped during the FR_rolling intervention, the dynamic movement is performed, and then the FR_rolling is performed again. The results indicated a significant increase in ROM in both groups. More interestingly, the authors reported that the effect of increased ROM was significantly higher in the dynamic movement group than in the group without dynamic movement. Interestingly, Warneke et al. (2023) also reported that a similar increase in ROM as in rolling movements was observed by simulating rolling movements. Taken together, rolling is not always necessary when performing FR_rolling interventions. However, based on previous studies (Cheatham and Stull, 2018; Wilke et al., 2018), static compression of target muscles may be sufficient to increase ROM and PPT without rolling or movements that simulate rolling. Moreover, dynamic movement during static compression may be more effective than static compression without dynamic movement. However, the acute effect of dynamic movement during static compression on ROM and PPT without adversely affecting muscle strength is unknown. In addition, it is unclear whether this method is more effective than FR_rolling with conventional rolling. The superiority of dynamic movement during static compression is important information in the field of sports and rehabilitation. Therefore, this study aimed to compare the acute effect of the FR intervention and static compression with or without dynamic movement on the passive and active properties of knee extensors. As aforementioned, FR_rolling intervene-

Received: 13 September 2023 / Accepted: 03 October 2023 / Published (online): 01 December 2023

tions have a small beneficial effect on muscle strength and performance (Wiewelhove et al., 2019). It has also been reported that FR_rolling interventions accompanied by dynamic movement exert a significant effect on the increase in ROM (Cheatham and Stull, 2018). Therefore, we hypothesized that the effect of ROM increase would be greater in the dynamic movement group than in the FR_rolling and static compression groups.

Methods

Experimental approach to the problem

A randomized repeated-measures experimental design was adopted to compare four conditions: control (CON), FR with rolling (FR_rolling), FR with static compression (i.e., without rolling) (FR_SC), and FR with dynamic movement (FR_DM) (Figure 1). The participants were instructed to visit the laboratory four times with a break ≥48 h. The measurement periods were before (PRE) and after (POST) the intervention. The measured parameters were tissue hardness, PPT, knee flexion ROM, and unilateral countermovement jump (CMJ) height, which was evaluated in this order. Because knee flexion ROM measurements may influence PPT and tissue hardness measurements, measurements were performed in this order.

Blinded design

The present study followed a blinded design. Two physical therapists conducted the measurements in the study. One therapist only performed the measurements and was not informed of the intervention conditions for the participants. The other explained the intervention conditions to the participants. The measurement and intervention were performed in the same room; however, the room was divided with a curtain, so the intervention was not visible to the measurer. During the intervention, the measurer wore noise-canceling earphones to block out external sound. A metronome was also used in all intervention conditions. After the intervention, the participants immediately returned to the measurement area for the POST measurement.

Participants

A total of 20 healthy, recreationally active men were enrolled (mean ± SD: age, 23.3 ± 0.6 years; height, 171.8 ± 4.6 cm; weight, 68.8 ± 6.8 kg). They randomly completed the aforementioned conditions. Those with a history of neuromuscular disease and musculoskeletal injury involving the lower extremities were excluded. Based on the ROM results of our previous study (Nakamura et al., 2023) using G* power 3.1 (Heinrich Heine University, Dusseldorf, Germany), the required sample size for a repeated-measures two-way analysis of variance (ANOVA) (effect size = 0.25 [large when considering interaction effects for two-way ANOVAs], αerror = 0.05, power = 0.80) was greater than 17 participants.

The participants were fully informed about the procedures and aims of the study, after which they provided written informed consent. The study complied with the requirements of the Declaration of Helsinki and was approved by the Ethics Committee of the Niigata University of Health and Welfare, Niigata, Japan (Procedure#18615)

Outcome assessment

Tissue hardness

A portable tissue hardness meter (NEUTONE TDM-N1; TRY-ALL Corp., Chiba, Japan) was used to measure tissue hardness. The participant's measurement position and posture were similar to those in the PPT measurements. The tissue hardness meter measured the penetration distance until a pressure of 14.71 N (1.5 kgf) was reached (Sawada et al., 2020). The participants were instructed to relax during the measurement, and the mean value at each measurement period was used for further analysis.

Pain pressure threshold

PPT measurements were performed in the supine position using an algometer (NEUTONE TAM-22(BT10); TRY-ALL, Chiba, Japan). The measurement location was set at the midway of the distance between the anterior superior iliac spine and the dominant side's superior border of the patella for the rectus femoris muscle. With continuous

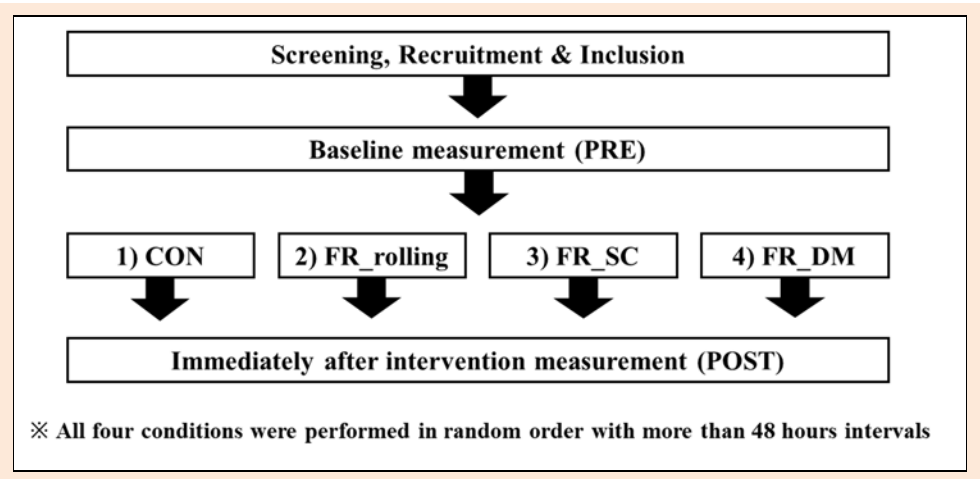


Figure 1. The experimental set-up for the four interventions: control (CON), foam roller with rolling (FR_rolling), foam roller with static compression (FR_SC), and foam roller with dynamic movement (FR_DM). The intervention was set at 30 seconds. The CON condition was rest in the sitting position for 60 seconds. The FR_rolling condition were performed from proximal to distal and back to proximal of the dominant (preferred to kick a ball) knee extensors in 2 seconds. The FR_SC condition compressed the muscle belly of knee extensors. The FR_DM condition was knee flexion with the muscle belly of the knee extensors compressed. The measured parameters were knee flexion range of motion, pain pressure threshold, tissue hardness, and countermovement jump height.

increase in pressure, the soft tissue in the measurement area was compressed using the metal rod of the algometer. The participants were instructed to immediately press a trigger when pain, rather than just pressure, was experienced. At this time point, the value read from the device (kilograms per square centimeter) corresponded to the PPT. In each condition, PPT was measured three times at each measurement period, and the mean value at each period was used for further analysis.

Knee flexion ROM

Each participant was placed in a side-lying position on a massage bed with the hips and the knee of the nondominant leg flexed at 90° to prevent pelvic movements (Kasahara et al., 2022; Nakamura et al., 2020). The investigator, a licensed physical therapist, brought the dominant leg to full knee flexion with the hip joint in a neutral position. A goniometer (MMI universal goniometer Todai 300 mm, Muranaka Medical Instruments, Co., Ltd., Osaka, Japan) was used to measure knee flexion ROM three times at each measurement period; the average values at each measurement period were used for analysis. In this study, no participant was able to perform full knee joint flexion in the PRE and POST measurements.

Unilateral countermovement jump height

Unilateral CMJ height was calculated from flight time using a contact mat (jump mat system; 4Assist, Tokyo, Japan). The participants started with the foot of the dominant leg on the mat with their arms crossed in front of their chest. They were instructed to quickly dip (eccentric phase) from this position, reaching a self-selected depth to jump as high as possible in the next concentric phase. Landings were performed on both feet. The knee of the noninvolved leg was held at approximately 90° flexion. After three familiarization trials, three maximum unilateral CMJ were conducted at both PRE and POST in each condition, and the average of the three trials was used for further analysis (Kasahara et al., 2023).

Intervention conditions

The four intervention conditions were CON, FR_rolling, FR_SC, and FR_DM, the target muscles were knee extensors of the dominant leg. The intervention time was 30 seconds, based on a previous study of Behm et al. (2020). A foam roller (Stretch Roll SR-002, Dream Factory, Umeda, Japan) was used. One physical therapist provided instructions to the participants before the intervention. The control condition required resting in the sitting position for 30 s. For the FR_rolling conditions, one cycle of FR was defined as one distal rolling movement followed by one proximal rolling movement performed in 2 s. In FR_SC and FR_DM, the participants were instructed to remain in the plank position and place the foam roller at the midpoint of the knee extensors of the dominant leg (Figure 2, A) as in the previous study (Nakamura et al., 2022). For FR_SC, they were instructed to press their trunk against the roller as far as they could tolerate. For FR_DM, they were instructed to keep compression and press their trunk against the roller as far as they could tolerate while performing knee flexion (Figure 2, B) and knee extension (Figure 2, A) both in 1 s. The ROM was instructed to be as much maximum flexion and extension as possible. A metronome (Smart Metronome; Tomohiro Ihara, Japan) set up at 60 bpm was used for control in all interventions.

Statistical analysis

SPSS (version 29.0; IBM Corp., Armonk, NY, USA) was used for the statistical analysis. We calculated the coefficient of variation (CV) and intraclass correlation coefficient (ICC) from these data from PRE data in the four conditions to check the test–retest reliability (Weir, 2005). To verify the consistency of the PRE values, they were tested among all conditions *via* one-way ANOVA. For all the variables, a two-way repeated-measures ANOVA using two factors (test time [PRE vs. POST] and conditions [CON vs. FR_rolling vs. FR_SC vs. FR_DM]) was employed to analyze the interaction and main effects. Classification of the effect size was set where $\eta_p^2 < 0.01$ was considered small; 0.02 - 0.1, medium; and more than 0.1, large (Cohen, 1988). If the interaction effect was significant, a *post hoc* analysis was conducted using paired *t*-tests with Bonferroni correction on each condition to determine the difference between the PRE and POST values.

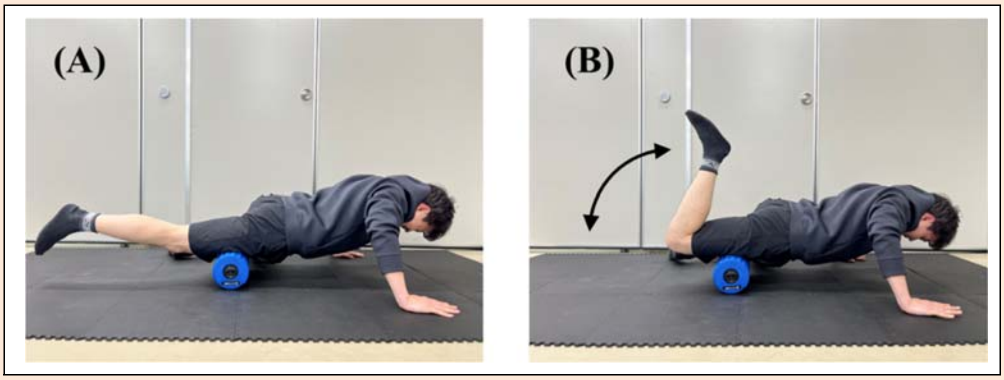


Figure 2. For the foam roller with static compression (FR_SC) and foam roller with dynamic movement (FR_DM) conditions, participants were instructed to remain in the plank position and place the foam roller only at the midpoint of the knee extensors of the dominant leg (A). The FR_SC condition was instructed to remain in that position (A) for 30 seconds, pressing the trunk against the foam roller as far as it could tolerate. The FR_DM condition was instructed to hold compression and mobilize the knee to maximum flexion in 1 second (B) and again in 1 second to maximum extension (A). A metronome (60bpm) was used for control.

The POST values and amount of change were tested among the FR_rolling, FR_SC, and FR_DM conditions using paired *t*-tests with Bonferroni correction. In addition, the effect size (Cohen's d) was calculated as differences in the mean value divided by the pooled SD between PRE and POST in each group; an effect size of 0.00 - 0.19 was considered as trivial; 0.20 - 0.49, small; 0.50 - 0.79, moderate; and ≥0.80, large (Cohen, 1988). The significance level was set to 5%, and all the results are expressed as mean ± SD.

Results

Comparison between the PRE values among the four conditions

No significant differences were observed in all PRE variables between the four conditions. The CVs of the measurements for knee flexion ROM, PPT, tissue hardness, and CMJ height were 1.3% ± 0.6%, 14.8% ± 5.6%, 7.6% ± 4.8%, and 4.4% ± 2.3%, respectively, and the ICCs (1,1) for measurements were 0.788, 0.676, 0.733, and 0.835, respectively.

Changes in knee flexion ROM, PPT, tissue hardness, and CMJ height after interventions

Figure 3 presents the changes in knee flexion ROM, PPT, tissue hardness, and CMJ height before and after the intervention. Significant interaction effects in knee flexion ROM (F = 5.4, $p < 0.01$, $\eta_p^2 = 0.18$) and tissue hardness (F = 5.1, $p < 0.01$, $\eta_p^2 = 0.17$) were observed. *Post hoc* test results indicated that knee flexion ROM significantly increased in FR_rolling (1.3% ± 0.0%), FR_SC (1.0% ± 0.0%), and FR_DM (1.9% ± 0.0%). However, no significant differences were observed in the POST values in the knee flexion ROM among FR_rolling, FR_SC, and FR_DM. Similarly, tissue hardness significantly decreased in FR_rolling (-10.0% ± 0.1%), FR_SC (-5.7% ± 0.1%), and FR_DM (-6.9% ± 0.1%).

In addition, there were no significant interaction effects for PPT (F = 2.2, $p = 0.09$, $\eta_p^2 = 0.08$) and CMJ height (F = 0.9, $p = 0.44$, $\eta_p^2 = 0.03$). However, PPT showed a main effect for time and increased after the intervention (F = 45.6, p < 0.01, ηp2 = 0.38), but not on CMJ (F = 2.2, p = 014, ηp2 = 0.03).

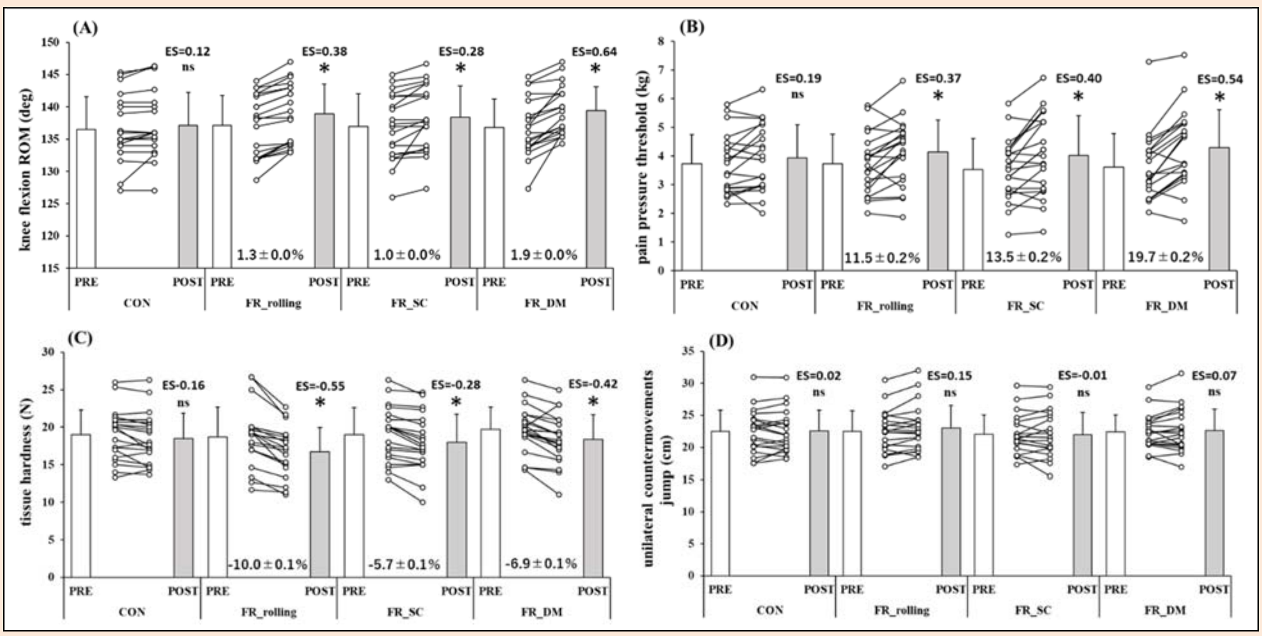


Figure 3. The changes (mean±SD) in knee flexion range of motion (ROM) (A), pain pressure threshold (B), tissue hardness (C), and unilateral countermovement jump height (D) before (PRE) and immediately after (POST) the intervention in four conditions: control (CON), foam roller with rolling (FR_rolling), foam roller with static compression (FR_SC), and foam roller with dynamic movement (FR_DM). *: significantly (p<0.05) different from the PRE-value. ns: no significant difference from the PRE-value. The average (±SD) magnitude of change (%) is included for the significant (p< 0.05) change and Cohen's d effect size (ES) is also provided for all conditions.

Discussion

This study investigated effective FR intervention methods such as FR_rolling, FR_SC, and FR_DM. The results indicated that 30 s of FR_rolling, FR_SC, and FR_DM significantly increased knee flexion ROM and decreased tissue hardness. A significant main effect for time revealed PPT increases, whereas no significant change was observed in CMJ. The results of this study suggest that FR_SC and FR_DM can be as effective as FR_rolling in increasing ROM and decreasing tissue hardness.

Many previous studies have demonstrated that FR_rolling increases ROM (Behm et al., 2020; Konrad et al., 2022c; Wilke et al., 2020). In this study, a significant increase in ROM was observed in all intervention conditions, but there was no difference among them. These results support the findings of Warneke et al. (2023) who found an increase in ROM-like form rolling in a sham condition in which movements like FR but without form rolling were performed. In addition, Cheatham and Stull (2018) compared the effects of FR_rolling alone and FR_rolling with dynamic movement on knee flexion ROM. The results indicated that ROM significantly increased in both intervention methods and that the effect was significantly greater in FR_rolling with dynamic movement than in FR_rolling alone. In this study, the effect size on ROM was larger for FR_DM (d = 0.64) than for FR_rolling (d = 0.38), although no significant difference was found. Thus, our results partially support the findings of a study by Cheatham and Stull (2018). This discrepancy between the previous study (Cheatham and Stull, 2018) and our results may be due to differences in the intervention method and time. As regards the intervention methods, dynamic movement was performed during the FR_rolling intervention in the study by Cheatham and Stull (2018), whereas in the present study, the FR_DM condition was applied, and dynamic movements were performed while maintaining static compression without rolling movements. As for the intervention time, it was 30 s in this study and 120 s in the study by Cheatham and Stull (2018). Thus, FR_rolling interventions suggest a dose–response relationship (Sullivan et al., 2013). Therefore, the rolling motion or brief intervention could be the reason why no differences occurred between the conditions in this study. Furthermore, Cheatham and Stull (2018) observed a greater increase in ROM in dynamic movement compared to rolling because of antagonist muscle contraction inhibition. This suggests that the contraction of antagonist muscles is important for the increase in ROM.

In this study, a main effect of time was observed in PPT. Previous studies have demonstrated that FR_rolling interventions increase PPT (Cheatham and Kolber, 2018; Kasahara et al., 2022). Wilke et al. (2018) reported that static compression on fascial trigger points significantly increased PPT, whereas FR_rolling exerted no significant effect on PPT. On the other hand, Cheatham and Stull (2018) observed a significant increase in PPT in both the FR_rolling-alone intervention and FR_rolling intervention with dynamic movement. They also reported that the effect of increased PPT was significantly greater in the FR_rolling intervention with dynamic movement. However, no interaction effect was observed in the present study, suggesting PPT changes in all conditions. The lack of interaction effect in this study may be due to the effect of the short intervention time and order of measurements. In this study, the intervention time was 30 s, and the time from PRE to POST measurement was approximately 60 s. FR_rolling suggests a dose–response relationship (Sullivan et al., 2013), which may explain the smaller change in PPT in the intervention than in the control condition. Moreover, the short interval between PRE and POST measurements in this study may have influenced the POST measurement by the PRE measurement itself. In addition, pain occurred during the intervention condition might also affect the increase in PPT values. Previous studies have demonstrated that FR_rolling interventions have a significant influence on pain reduction (Behm and Wilke, 2019; Konrad et al., 2022b). In addition, FR may reduce pain by activating either neural-gating mechanisms (Melzack and Wall, 1965; Moayedi and Davis, 2013) or releasing endorphins and enkephalins as theorized with the diffuse noxious inhibitory control mechanism (Le Bars et al., 1992). However, the detailed mechanism of the increase in PPT is unknown. The differences observed in previous studies (Cheatham and Stull, 2018; Kasahara et al., 2022; Wilke et al., 2018) also occurred in the present study. Future studies are warranted to examine the detailed mechanism of PPT by FR_rolling intervention.

The results of this study showed a significant decrease in tissue hardness in FR_rolling, FR_SC, and FR_DM. A previous study by Behm and Wilke (Behm and Wilke, 2019) has suggested that thixotropic changes are among the mechanisms by which FR_rolling reduces tissue hardness (Behm and Wilke, 2019; Konrad et al., 2022b). In addition, Hotfiel et al. (Hotfiel et al., 2017) reported that FR_rolling increased tissue perfusion and consequently decreased tissue hardness. The significant decrease in tissue hardness in this study could also have been caused by the same mechanism as in the previous study.

The results of this study showed no effect on CMJ in all conditions. Wiewelhove et al. (2019) have reported that FR_rolling has no negative effects on muscle strength and performance. In addition, the effect of FR_rolling on CMJ is reportedly negligible. Moreover, Konrad et al. (Konrad et al., 2022a) also shows no significant performance improvement after to FR intervention program. The results of the previous and present studies have indicated that FR_SC and FR_DM can increase knee flexion ROM without decreasing performance.

A previous study by Nakamura et al. (2021a) has suggested that the mechanism of ROM increase by FR_rolling intervention is a change in stretch tolerance. In this study, PPT and tissue hardness also changed. These changes as well as changes in stretch tolerance may be responsible for the increase in ROM. More interestingly, Warneke et al. (2023) compared the effects in three intervention conditions: FR_rolling, intervention condition which mimics the movement without the application of pressure on the soft tissue (sham group), and control condition. The results indicated a significant increase in ROM in the FR_rolling intervention condition and the sham group. Such results suggest that the increase in flexibility with the FR_rolling intervention is not due to changes in stretch tolerance but rather to the warm-up effect of the whole-body exercise. In this study, changes in PPT were observed, but an increase in ROM was only seen in the intervention condition. This suggests that the increase in ROM in the present study was also influenced by the warm-up effect of the whole-body exercise, as supported by the findings of Warneke et al. (2023).

This study has several limitations. First, the differences by intervention time are unknown. Because a dose–response relationship has been suggested for the FR_rolling intervention, there may be differences between conditions during longer interventions. Second, this study only included healthy male university students. Therefore, it is unknown whether the same effects can be obtained in athletes, older, and sex populations. Third, the effect of FR equipped with vibratory stimuli is unknown. However, a previous study by Nakamura et al. (2021b) showed that FR equipped with vibratory stimuli to the muscle belly of the ankle plantar flexors produced changes similar to the present study. Therefore, it is conceivable that the effect is sufficient for static compression and dynamic movements in FR equipped with vibratory stimuli. Fourth, the mechanism for the changes in the measured items in this study is unclear. It is necessary to examine the mechanism for the effects obtained by FR in the future.

Conclusion

In conclusion, the FR_rolling, FR_SC, and FR_DM conditions with an intervention time of 30 s are effective in increasing ROM and PPT and decreasing tissue hardness while maintaining performance. Static compression and dynamic movements exhibit the same effect as FR_rolling; furthermore, the physical load is reduced. Therefore, FR_SC and FR_DM, which can intervene more easily than conventional FR_rolling, have potential applications in clinical and sports fields.

Acknowledgements
This work was supported by JSPS KAKENHI with grant number 19K19890 (Masatoshi Nakamura), and the Austrian Science Fund (FWF) project J4484 (Andreas Konrad). The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article. The present study complies with the current laws of the country in which it was performed. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

References

Behm, D.G., Alizadeh, S., Hadjizadeh Anvar, S., Mahmoud, M.M.I., Ramsay, E., Hanlon, C. and Cheatham, S. (2020) Foam Rolling Prescription: A Clinical Commentary. *Journal of Strength & Conditioning Research* **34**, 3301-3308. https://doi.org/10.1519/JSC.0000000000003765

Behm, D.G. and Wilke, J. (2019) Do Self-Myofascial Release Devices Release Myofascia? Rolling Mechanisms: A Narrative Review. *Sports Medicine* **49**, 1173-1181. https://doi.org/10.1007/s40279-019-01149-y

Cavanaugh, M.T., Döweling, A., Young, J.D., Quigley, P.J., Hodgson, D.D., Whitten, J.H., Reid, J.C., Aboodarda, S.J. and Behm, D.G. (2017) An acute session of roller massage prolongs voluntary torque development and diminishes evoked pain. *European Journal of Applied Physiology* **117**, 109-117. https://doi.org/10.1007/s00421-016-3503-y

Cheatham, S.W. and Baker, R. (2017) Differences in pressure pain threshold among men and women after foam rolling. *Journal of Bodywork and Movement Therapies* **21,** 978-982. https://doi.org/10.1016/j.jbmt.2017.06.006

Cheatham, S.W. and Kolber, M.J. (2018) Does Roller Massage With a Foam Roll Change Pressure Pain Threshold of the Ipsilateral Lower Extremity Antagonist and Contralateral Muscle Groups? An Exploratory Study. *Journal of Sport Rehabilitation* **27,** 165-169. https://doi.org/10.1123/jsr.2016-0196.

Cheatham, S.W. and Stull, K.R. (2018) Comparison of a foam rolling session with active joint motion and without joint motion: A randomized controlled trial. *Journal of Bodywork and Movement Therapies* **22**, 707-712. https://doi.org/10.1016/j.jbmt.2018.01.011

Cohen, J. (1988) Statistical power analysis for the behavioral sciences., Hillsdale, Routledge.

Glänzel, M.H., Rodrigues, D.R., Petter, G.N., Pozzobon, D., Vaz, M.A. and Geremia, J.M. (2023) Foam Rolling Acute Effects on Myofascial Tissue Stiffness and Muscle Strength: A Systematic Review and Meta-Analysis. *Journal of Strength & Conditioning Research* **37**, 951-968. https://doi.org/10.1519/JSC.0000000000004385

Hotfiel, T., Swoboda, B., Krinner, S., Grim, C., Engelhardt, M., Uder, M. and Heiss, R.U. (2017) Acute Effects of Lateral Thigh Foam Rolling on Arterial Tissue Perfusion Determined by Spectral Doppler and Power Doppler Ultrasound. *Journal of Strength & Conditioning Research* **31**, 893-900. https://doi.org/10.1519/JSC.0000000000001641

Kasahara, K., Konrad, A., Yoshida, R., Murakami, Y., Koizumi, R., Sato, S., Ye, X., Thomas, E. and Nakamura, M. (2022) Comparison of the Prolonged Effects of Foam Rolling and Vibration Foam Rolling Interventions on Passive Properties of Knee Extensors. *Journal of Sports Science and Medicine* **21(4)**, 580-585. https://doi.org/10.52082/jssm.2022.580

Kasahara, K., Konrad, A., Yoshida, R., Murakami, Y., Sato, S., Koizumi, R., G Behm, D. and Nakamura, M. (2023) The comparison between foam rolling either combined with static or dynamic stretching on knee extensors' function and structure. *Biology of Sport* **40(3)**, 753-760. https://doi.org/10.5114/biolsport.2023.119987

Konrad, A., Nakamura, M. and Behm, D.G. (2022a) The Effects of Foam Rolling Training on Performance Parameters: A Systematic Review and Meta-Analysis including Controlled and Randomized Controlled Trials. *International Journal of Environmental Research and Public Health* **19(18)**, 11638. https://doi.org/10.3390/ijerph191811638

Konrad, A., Nakamura, M., Paternoster, F.K., Tilp, M. and Behm, D.G. (2022b) A comparison of a single bout of stretching or foam rolling on range of motion in healthy adults. *European Journal of Applied Physiology* **122(7)**, 1545-1557. https://doi.org/10.1007/s00421-022-04927-1

Konrad, A., Nakamura, M., Tilp, M., Donti, O. and Behm, D.G. (2022c) Foam Rolling Training Effects on Range of Motion: A Systematic Review and Meta-Analysis. *Sports Medicine* **52(10)**, 2523-2535. https://doi.org/10.1007/s40279-022-01699-8

Le Bars, D., Villanueva, L., Bouhassira, D. and Willer, J.C. (1992) Diffuse noxious inhibitory controls (DNIC) in animals and in man. *Pathological Physiology and Experimental Therapy* **4**, 55-65.

Melzack, R. and Wall, P.D. (1965) Pain mechanisms: a new theory. *Science* **150**, 971-979. https://doi.org/10.1126/science.150.3699.971

Moayedi, M. and Davis, K.D. (2013) Theories of pain: from specificity to gate control. *Journal of Neurophysiology* **109,** 5-12. https://doi.org/10.1152/jn.00457.2012

Nakamura, M., Kasahara, K., Yoshida, R., Yahata, K., Sato, S., Murakami, Y., Aizawa, K. and Konrad, A. (2022) The Effect of Static Compression via Vibration Foam Rolling on Eccentrically Damaged Muscle. *International Journal of Environmental Research and Public Health* **19(3)**, 1823. https://doi.org/10.3390/ijerph19031823

Nakamura, M., Konrad, A., Kasahara, K., Yoshida, R., Murakami, Y., Sato, S., Aizawa, K., Koizumi, R. and Wilke, J. (2023) The Combined Effect of Static Stretching and Foam Rolling With or Without Vibration on the Range of Motion, Muscle Performance, and Tissue Hardness of the Knee Extensor. *Journal of Strength & Conditioning Research* **37(2)**, 322-327. https://doi.org/10.1519/JSC.0000000000004263

Nakamura, M., Yasaka, K., Kiyono, R., Onuma, R., Yahata, K., Sato, S. and Konrad, A. (2020) The Acute Effect of Foam Rolling on Eccentrically-Induced Muscle Damage. *International Journal of Environmental Research and Public Health* **18(1)**, 75. https://doi.org/10.3390/ijerph18010075

Sawada, T., Okawara, H., Nakashima, D., Iwabuchi, S., Matsumoto, M., Nakamura, M. and Nagura, T. (2020) Reliability of Trapezius Muscle Hardness Measurement: A Comparison between Portable Muscle Hardness Meter and Ultrasound Strain Elastography. *Sensors (Basel)* 20(24), 7200. https://doi.org/10.3390/s20247200 10.3390/s20247200

Sullivan, K.M., Silvey, D.B., Button, D.C. and Behm, D.G. (2013) Roller-massager application to the hamstrings increases sit-and-reach range of motion within five to ten seconds without performance impairments. *International Journal of Sports Physical Therapy* **8(3)**, 228-236.

Warneke, K., Aragão-Santos, J.C., Alizadeh, S., Bahrami, M., Anvar, S.H., Konrad, A. and Behm, D.G. (2023) Are Acute Effects of Foam-Rolling Attributed to Dynamic Warm Up Effects? A Comparative Study. *Journal of Sports Science and Medicine* 22, 180-188.

Weir, J.P. (2005) Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength & Conditioning Research* **19(1)**, 231-40. https://doi.org/10.1519/15184.1

Wiewelhove, T., Döweling, A., Schneider, C., Hottenrott, L., Meyer, T., Kellmann, M., Pfeiffer, M. and Ferrauti, A. (2019) A Meta-Analysis of the Effects of Foam Rolling on Performance and Recovery. *Frontiers Physiology* **10**, 376.

https://doi.org/10.3389/fphys.2019.00376

Wilke, J., Müller, A.L., Giesche, F., Power, G., Ahmedi, H. and Behm, D.G. (2020) Acute Effects of Foam Rolling on Range of Motion in Healthy Adults: A Systematic Review with Multilevel Meta-analysis. *Sports Medicine* **50(2)**, 387-402. https://doi.org/10.1007/s40279-019-01205-7

Wilke, J., Vogt, L. and Banzer, W. (2018) Immediate effects of self-myofascial release on latent trigger point sensitivity: a randomized, placebo-controlled trial. *Biology of Sport* **35,** 349-354. https://doi.org/10.5114/biolsport.2018.78055

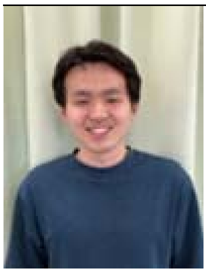
Key points

- We investigated the acute effect of foam rolling even without a rolling stimulus (e.g., static compression with or without dynamic joint movements) on knee extensors.
- Static compression and dynamic movements exhibit the same effect as rolling using foam roller.
- Static compression and dynamic movements via FR can intervene more easily than conventional foam roller.

AUTHOR BIOGRAPHY

Kazuki KASAHARA
Employment
Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Niigata, Japan
Degree
BSc, MSc student
Research interests
Physical therapy, foam rolling, stretching, performance, muscle strength
E-mail: hpm22005@nuhw.ac.jp

Andreas KONRAD
Employment
Institute of Human Movement Science, Sport and Health, Graz University
Degree
PhD, MSc
Research interests
Biomechanics, muscle performance, training science, muscle-tendon-unit, soccer science
E-mail: andreas.konrad@uni-graz.at



Yuta MURAKAMI
Employment
Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Niigata, Japan
Degree
BSc, MSc student
Research interests
Physical therapy, stretching, muscle stiffness, stretch tolerance
E-mail: hpm22003@nuhw.ac.jp

Riku YOSHIDA
Employment
Maniwa orthopedic clinic, Niigata City, Niigata, Japan
Degree
BSc, MSc
Research interests
Physical therapy, resistance training, eccentric contraction
E-mail: hpm21017@nuhw.ac.jp

Ewan THOMAS
Employment
Assistant Professor, Department of Psychology, Educational Science and Human Movement, University of Palermo, Italy
Degree
PhD, DO
Research interests
Strength and conditioning research, stretching, exercise physiology, adapted physical activity
E-mail: ewan.thomas@unipa.it

Masatoshi NAKAMURA
Employment
Associate professor, Faculty of Rehabilitation Sciences, Nishi Kyushu University, Saga, Japan
Degree
PhD
Research interests
Physical therapy, stretching, exercise physiology, flexibility
E-mail: nakamuramas@nisikyu-u.ac.jp

✉ **Masatoshi Nakamura**
Faculty of Rehabilitation Sciences, Nishi Kyushu University, 4490-9 Ozaki, Kanzaki, Saga, 842-8585, Japan