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Comparison between foam rolling with and without vibration on passive and active plantar flexor muscle properties

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Abstract

Although foam rolling interventions with and without vibration have been used to increase flexibility in the field of sports, their effects on passive and active properties remain unclear. Hence, this study aimed to investigate the effects of foam rolling interventions on range of motion (ROM), shear elastic modulus, plantar flexor muscle strength, and jump performance. This randomized, controlled, crossover study included 16 healthy male participants who visited the laboratory three times (control condition, foam rolling condition, and vibration foam rolling condition), each with an interval of >72 h. In both foam rolling and vibration foam rolling conditions, participants were instructed to perform 60-s bouts of intervention for three sets, with 30-s rest between each set. In the vibration foam rolling condition, the intensity of vibration was set at a frequency of 48 Hz. Dorsiflexion (DF) ROM, shear elastic modulus, plantar flexor muscle strength, and drop jump height were determined before and after the rolling intervention. Our results showed a similar increase in DF ROM ($p < 0.01$, $d = 0.51$; $p < 0.01$, $d = 0.65$, respectively) and passive torque at DF ROM ($p = 0.02$, $d = 0.51$ and $p < 0.01$, $d = 0.65$, respectively) after foam rolling and vibration foam rolling. Medial gastrocnemius shear elastic modulus decreased only after vibration foam rolling ($p < 0.01$, $d = 0.44$). No significant main effects of time were observed in maximal voluntary isometric contraction torque ($F = 2.0$, $p = 0.15$, $\eta_p^2 = 0.119$) and drop jump height ($F = 1.5$, $p = 0.24$, $\eta_p^2 = 0.091$) after both interventions. Maximal voluntary concentric contraction torque showed a significant main effect of time ($F = 7.59$, $p = 0.02$, $\eta_p^2 = 0.336$). However, only after foam rolling, the maximal voluntary concentric contraction torque significantly decreased ($p = 0.01$, $d = 0.39$). Our results suggest that vibration foam rolling effectively alters passive muscle properties without decreasing muscle strength and performance.

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Keywords

shear elastic modulus; maximal voluntary isometric contraction; concentric strength; drop jump; roller massage

Introduction

Foam rolling (FR) interventions have been increasingly used as a warm-up routine to increase range of motion (ROM) in sports and rehabilitation settings. Studies have shown that FR interventions can acutely increase ROM (27, 31). A recent meta-analysis by Wilke et al. (2020) concluded that FR interventions promoted an increase in ROM similar to that observed after stretching interventions (38). Although no consensus exists on the effect of FR interventions on muscle strength and athletic performance (19, 30, 35), a recent meta-analysis by Wiewelhove et al. (37) revealed that changes in jump and strength performance after FR interventions were small and negligible. In sports and rehabilitation settings, stretching interventions have remained one of the most common interventions to increase flexibility. However, studies have shown that >60 s of static stretching could induce muscle strength loss, otherwise known as stretch-induced force deficit (4, 14). Hence, FR interventions can be considered to increase flexibility without inducing muscle strength loss.

Another approach that has gained popularity in recent years is vibration FR. Vibration foam rollers are commonly used in sports and rehabilitation. A few studies have investigated the effect of a single bout of vibration FR. Cheatham et al. (2018) showed that vibration FR promotes a greater increase in ROM than FR alone (6). Reiner et al. (2021) showed that vibration FR on the quadriceps muscle could increase hip extension ROM, but FR alone did not induce this change (31). Some studies have shown no significant difference in ROM increase between FR interventions with and without vibration (10, 19). However, the meta-analysis by Wilke et al. (2020) speculated, based on little evidence, that FR interventions with vibrations could induce greater ROM increases than FR interventions without vibrations (38). A possible superior effect of vibration FR over FR alone could be attributed to the greater changes in mechanoreceptors caused by vibration (5). Pacinian corpuscles are sensitive to high-frequency vibrations, and in combination with Ruffini receptors, there might be induced muscle relaxation due to an inhibition of sympathetic activation (5). However, only few studies have investigated vibration FR intervention, warranting future studies to compare the effects of FR interventions with and without vibration on flexibility.

Some studies have also investigated the effects of FR interventions on passive stiffness. Therefore, while some have shown that FR interventions did not affect passive stiffness (3, 18, 40), other studies have revealed that FR interventions could decrease passive stiffness (3, 22, 39), with conflicting views prevailing until now. Miyamoto et al. (20) showed that the shear elastic modulus of the vastus lateralis was negatively correlated with the 100-m race time in sprinters and positively correlated with the 5,000-m race time in long-distance runners. Ando et al. (2) showed that the shear elastic modulus of the medial gastrocnemius (MG) is significantly associated with drop jump height. Because there is a relationship

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between the shear elastic modulus and athletic performance, it is necessary to investigate the change in shear elastic modulus after FR and vibration FR interventions. To the best of our knowledge, there is only one study investigating the effects of vibration FR intervention on passive muscle stiffness. A study showed that the tendency of absolute changes in muscle stiffness to decrease after vibration FR was higher than that after FR (31). As described earlier, vibration FR can be assumed to produce larger changes in mechanoreceptors, e.g., Pacinian corpuscles, and might decrease muscle stiffness, unlike FR along. However, because there have not been enough studies investigating a possible superior effect in decreasing muscle stiffness after vibration FR intervention, more research is needed to establish their usefulness in decreasing muscle stiffness.

The present study aimed to compare the effects of FR interventions with and without vibration on dorsiflexion (DF) ROM, passive torque at DF ROM, MG shear elastic modulus, muscle strength (maximal voluntary isometric [MVC-ISO] and concentric contraction [MVC-CON]) torque, and jump performance. Previous studies (5, 30, 37) suggest that vibration FR produced larger changes in mechanoreceptors, e.g., Pacinian corpuscles, than FR without vibration. We hypothesized that vibration FR would exhibit superior effects than FR alone on changes in DF ROM and MG shear elastic modulus but not on changes in muscle strength and jump performance.

Methods

Experimental approach to the problem

A randomized repeated measures experimental design was used to compare the effects of FR interventions with and without vibration on DF ROM, passive torque at DF ROM, MG shear elastic modulus, muscle strength, and drop jump performance in the dominant leg (preferred kicking ball). Participants were instructed to visit the laboratory three times with a >72-h interval, during which they were exposed to the following three conditions: the control condition (CON) comprising only sitting for 300 s; the FR condition comprising 60-s bouts of FR for three sets; and the vibration FR condition comprising 60-s bouts of vibration FR for three sets (Figure 1). Outcome variables were measured before (PRE) and immediately after the interventions (POST). (1) DF ROM and passive torque, (2) MG shear elastic modulus, (3) plantar flexor muscle strength (MVC-ISO and MVC-CON torque), and (4) single-leg drop jump height were measured in this order both at PRE and POST.

Participants

Sixteen healthy untrained university male students participated in this study (age: 21.7 ± 1.3 years, height: 170.7 ± 4.2 cm, body weight: 62.1 ± 5.2 kg). The inclusion criteria were as follows: no regular resistance training within the past 6 months, no neuromuscular disease, and no history of lower-limb orthopedic disease. All participants provided written informed consent after being fully informed regarding the procedures and aims of this study. After calculating the sample size required for a two-way repeated measures analysis of variance (ANOVA) (effect size = 0.40 [large], α error = 0.05, and power = 0.80) using G* power 3.1 software (Heinrich Heine University, Düsseldorf, Germany) based on a previous study (38), we determined that >14 participants were required for the study. This study was conducted in accordance with the Declaration of Helsinki and approved by the Niigata University of Health and Welfare, Niigata, Japan.

Assessment of DF ROM and passive torque

Participants were secured in a seated position on the chair of an isokinetic dynamometer (Biodex System 3.0, Biodex Medical Systems Inc., Shirley, NY, USA) with a knee angle of 0° (i.e., anatomical position). The trunk and pelvis of the participant were fixed with a belt while the participant was reclined (hip angle at 70°) to prevent tension at the back of the knee (Figure 2). Thereafter, the footplate of the dynamometer was passively and isokinetically dorsiflexed at a speed of 5°/s from 30° plantar flexion position to DF; this was halted when they started to feel discomfort or pain. Before DF ROM and passive torque assessment, two cycles of passive DF were performed to familiarize the participants and prevent passive stretching from inducing conditioning effects on muscle–tendon stiffness (13, 17, 29). After familiarization trials, participants stopped the dynamometer by activating a safety trigger when they started to feel discomfort or pain; the angle just before this point was defined as DF ROM (1, 28, 29, 33). In addition, passive torque at DF ROM was defined as the stretch tolerance (9, 21, 29, 36).

Throughout the passive DF test, participants were requested to relax completely and not offer any voluntary contraction. We confirmed the absence of MG voluntary contraction by monitoring muscle activity via surface electromyography (FA-DL-720-140; 4Assist, Tokyo, Japan). Surface electrodes (Blue Sensor N, Ambu A/S, Ballerup, Denmark) were placed on the muscle belly of MG. All data were confirmed to have been collected in a relaxed state (i.e., muscle activity did not exceed 5% of MVC-ISO) (25). Muscle activity was filtered using a bandpass filter at 10–1,000 Hz before being digitally stored (10-kHz sampling rate) on a personal computer for offline analysis. Analysis was performed using PowerLab 8/30 (AD Instruments, Colorado Springs, CO, United States) and LabChart 7 (AD Instruments), after which the root–mean–square (RMS, 50-ms window) values were calculated.

MG shear elastic modulus assessment

MG shear elastic modulus was measured using ultrasonic shear wave elastography (Aplio 500, Toshiba Medical Systems, Tochigi, Japan) with a 5–14-MHz linear probe at a 10° DF position, similar to that during DF ROM measurement. The measurement was performed at 30% of the lower leg length from the popliteal crease to the lateral malleolus near the point where the maximal cross-sectional area in the lower leg is located (1, 24). Ultrasound image measurements were performed twice using the long-axis image of MG. Shear wave speed analysis on ultrasound images was performed using image analysis software (MSI Analyzer version 5.0; Rehabilitation Science Research Institute, Japan). The largest possible area in MG was set as the region of interest for shear wave speed (Vs) measurement, with the average Vs value inside the region of interest being obtained. The shear elastic modulus was calculated as μ (kPa) = ρVs^2, where ρ is muscle mass density (1,000 kg/m^3). For analysis, the mean value of the shear elastic modulus obtained from two ultrasound images was used. A previous study confirmed that MG shear elastic modulus at a 10° DF position provided good reliability (intraclass correlation coefficient = 0.80, coefficient of variation = 5.7%) (32).

MVC-ISO, MVC-CON, and torque measurements

MVC-ISO torque was measured using the dynamometer, with the measurement position similar to that of DF ROM and shear elastic modulus assessments. The measurement of the plantar flexors was performed at the ankle joint in the neutral position (0°). MVC-ISOs were performed for a 5-s bout over two sets with a 60-s rest between each set. The average MVC-ISO value over both sets was used for analysis. Likewise, plantar flexor MVC-CON torque was measured with participants positioned similar to that during MVC-ISO measurements. ROM was measured from 10° of DF to 20° of plantar flexion, with an angular velocity of 30°/s. Moreover, concentric contraction protocols were applied three times in each sequence. Throughout the measurements, participants were verbally encouraged during muscle contraction to promote maximal efforts. Maximum torque was measured over three concentric contractions.

Single-leg drop jump height

Single-leg drop jumps were performed from a 20-cm box onto a set of mat switches (Jump mat system; 4Assist, Tokyo, Japan). After three familiarization repetitions, three sets of single-leg drop jumps were performed and measured. Participants were instructed to step off the box for single-leg drop jump measurements and upon landing with the same leg, immediately perform a maximal vertical jump using only the dominant side of the ankle plantar flexors without trying to minimize the use of the knee and hip muscles. We also ensured that the knee and hip joints did not move as much as possible during the jump measurement. Both hands were crossed in front of the chest. The maximal vertical jump height over three jump measurements was then calculated using the flight time method.

FR intervention with and without vibration

FR was applied over the gastrocnemius muscle using a foam roller (Vyper 2.0, Hyperice, Irvine, CA, USA, dimensions: 15 × 30 cm; weight 1.2 kg) with a vibration booster surrounded by a high-intensity expanded polypropylene foam outer shell. If the vibration booster is switched on, the entire foam roller vibrates. During vibration FR, the vibrator booster was set to a frequency of 48 Hz and an amplitude of 1.95 mm. During FR only, the vibration mode was switched off. In both FR conditions, participants were instructed by a physical therapist to use the foam roller. They were allowed to practice using the foam roller for three to five rollings on the nondominant leg (nonintervention leg) for familiarization. In both FR conditions, participants were instructed to perform 60-s bouts of FR intervention for three sets, with a 30-s rest between each set. Here, one cycle of FR intervention was defined as that from the Achilles tendon to the popliteal fossa, particularly on the medial portion of plantar flexors, with a frequency of 15 cycles/min using a metronome (Smart Metronome; Tomohiro Ihara, Japan). FR only intervention was performed unilaterally in a seated position with the knees extended but relaxed (Figure 3). With the dominant lower leg lying on the foam roller, the nondominant lower leg was put on the dominant lower leg and the participants placed both hands on the floor to support their weight (16, 27). Participants were asked to place as much body mass on the roller as tolerable. The therapist confirmed that all participants could follow the study protocol.

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Test–retest reliability of measurements

The test–retest reliability of all measurement variables was determined by coefficient variation (CV) and intraclass correlation coefficient (ICC) using eight healthy male volunteers (age: 21.6 ± 1.1 y, height: 171.3 ± 5.3 cm, body weight: 65.3 ± 5.1 kg). We measured all variables twice in the same order as in the current study with a 5-min interval. CV for DF ROM, passive torque at DF ROM, shear elastic modulus, MVC-ISO, MVC-CON, and drop jump were 3.7% ± 3.8%, 6.6% ± 7.1%, 6.2% ± 5.9%, 1.1% ± 0.7%, 4.0% ± 2.2%, and 3.4% ± 1.4%, respectively. ICC (1,2) was 0.99, 0.90, 0.88, 0.99, 0.76, and 0.95, respectively. We also calculated the minimal detectable change (MDC) for the measurement variables and MDC for DF ROM, passive torque at DF ROM, shear elastic modulus, MVC-ISO, MVC-CON, and drop jump; the results were 0.86, 2.72, 8.78, 2.84, 7.49, and 0.95, respectively.

Statistical analyses

Statistical analyses were performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA). The normality of data distribution was confirmed using the Shapiro–Wilk test. Differences in all variables at PRE measurement between the three conditions were determined using a one-way repeated measures ANOVA. For all variables, a two-way repeated measures ANOVA (PRE vs. POST and CON vs. FR vs. vibration FR) was performed to analyze the interaction and main effects. Upon confirming a significant interaction or main effect, a paired t-test with Bonferroni correction was performed to compare PRE and POST values in each condition as a post-hoc test. Upon confirming a significant interaction effect, changes between the PRE and POST values were calculated and a paired t-test was performed to compare changes between the FR and vibration FR conditions. Effect size (ES) was calculated as a difference in the mean value between PRE and POST divided by the pooled standard deviation (SD) (7), with an ES of 0.00–0.19, 0.20–0.49, 0.50–0.79, and ≥0.80 being considered trivial, small, moderate, and large, respectively. A p-value of <0.05 indicated statistical significance. Descriptive data were reported as means ± SD.

Results

Comparison between PRE values among the three conditions

A one-way repeated measure ANOVA showed no significant differences in all PRE variables among the three conditions.

Changes in DF ROM, passive torque at DF ROM, and MG shear elastic modulus

Table 1 shows changes in DF ROM, passive torque at DF ROM, and MG shear elastic modulus before and after intervention in the three conditions. A two-way repeated measures ANOVA showed a significant interaction effect for DF ROM ($F = 11.6$, $p < 0.01$, $\eta_p^2 = 0.436$). A post-hoc test showed that DF ROM increased significantly after both FR and vibration FR interventions ($p = 0.02$, $d = 0.54$ and $p < 0.01$, $d = 0.54$, respectively), but no significant change was observed in CON ($p = 0.73$, $d = 0.03$). No significant difference in changes from the PRE to POST values was noted between the FR (4.3 ± 5.0) and vibration

FR (4.6 ± 3.0) conditions ($p = 0.77$, $d = 0.09$). Likewise, two-way repeated measures ANOVA showed a significant interaction effect for passive torque at DF ROM ($F = 5.38$, $p < 0.01$, $\eta_p^2 = 0.264$). The post-hoc test showed that DF ROM increased significantly after both FR and vibration FR interventions ($p < 0.01$, $d = 0.51$ and $p < 0.01$, $d = 0.65$, respectively), but no significant change was noted in CON ($p = 0.56$, $d = 0.11$). No significant difference in changes from the PRE to POST values was observed between the FR (3.9 ± 3.4) and vibration FR (5.6 ± 4.4) conditions ($p = 0.10$, $d = 0.45$).

Two-way repeated measures ANOVA showed a significant interaction effect for MG shear elastic modulus ($F = 3.9$, $p = 0.03$, $\eta_p^2 = 0.205$). The post-hoc test showed that MG shear elastic modulus decreased significantly after vibration FR intervention ($p < 0.01$, $d = 0.44$), but no significant changes were noted in the CON and FR condition ($p = 0.70$, $d = 0.05$ and $p = 0.82$, $d = 0.03$, respectively).

Changes in MVC-ISO, MVC-CON, and drop jump height

Results for MVC-ISO, MVC-CON, and drop jump height are presented in detail in Table 2. Two-way repeated measures ANOVA showed no significant interaction effects for all variables (MVC-ISO: $F = 2.0$, $p = 0.15$, $\eta_p^2 = 0.119$; MVC-CON: $F = 1.5$, $p = 0.24$, $\eta_p^2 = 0.091$; drop jump height: $F = 1.16$, $p = 0.326$, $\eta_p^2 = 0.072$). Although no main effects were noted for MVC-ISO and drop jump height ($F = 3.9$, $p = 0.067$, $\eta_p^2 = 0.207$ and $F = 2.38$, $p = 0.14$, $\eta_p^2 = 0.137$, respectively), a main effect was observed for MVC-CON ($F = 7.59$, $p = 0.02$, $\eta_p^2 = 0.336$). The post-hoc test showed that MVC-CON decreased after the FR condition ($p = 0.01$, $d = 0.39$), but no significant changes were observed in MVC-CON following the vibration FR and CON condition ($p = 0.12$, $d = 0.28$ and $p = 0.70$, $d = 0.06$, respectively).

Discussion

We investigated the effects of FR interventions with and without vibration on the passive and active properties of the plantar flexors. Our results showed that although FR interventions with and without vibration promoted similar increases in DF ROM, MG shear elastic modulus decreased significantly only after vibration FR intervention, with no reduction in muscle strength and performance. To the best of our knowledge, this is the first study to thoroughly investigate the effects of vibration FR intervention.

Concerning changes in DF ROM, our results showed that DF ROM increased significantly after both FR interventions, with no significant difference in the increase in DF ROM. The results of this study are inconsistent with those in the previous study showing that vibration FR intervention produced a greater increase in ROM than FR intervention (6); however, our findings are consistent with other previous studies that found no significant difference in the increase in ROM between both FR interventions (10, 19). As mentioned earlier, vibration FR intervention could induce changes in mechanoreceptors (5). This fact may lead one to hypothesize that vibration FR intervention promotes a greater increase in ROM than FR only intervention. Contrary to this hypothesis, the present study found a similar increase in DF ROM after both FR interventions. Although passive torque at DF ROM increased significantly after both FR interventions, no significant difference therein was noted. Previous studies showed that the passive torque at DF ROM could reflect stretch tolerance (15, 26). In addition, it has been shown that an increase in ROM after FR interventions could involve changes in passive torque at ROM (i.e., modification in stretch tolerance) (16). In line with this, the current study results showed significant associations between changes in DF ROM and changes in passive torque at DF ROM in both FR interventions (data not shown). These results suggested that vibration FR does not significantly alter stretch tolerance, which would explain the lack of a significant difference in the increase in DF ROM between FR interventions with and without vibration.

Our results revealed that MG shear elastic modulus decreased only after vibration FR intervention. Previous studies have shown no significant change in MG muscle hardness (40) and shear elastic modulus (23). The results of previous studies were consistent with our results, which showed no significant change in shear elastic modulus after FR intervention without vibration. By contrast, our findings showed that vibration FR intervention, which is assumed to induce greater changes in mechanoreceptors (5), promoted a decrease in MG shear elastic modulus.

Although no significant changes in MVC-ISO and drop jump height were noted, our results, surprisingly, showed that MVC-CON torque decreased significantly after FR intervention without vibration. Our findings are partly consistent with those presented in previous studies, which showed no significant muscle strength and jump performance changes after FR intervention (12, 37). Lee et al. (2018), who investigated the effects of vibration FR intervention, showed a significant increase in quadriceps strength but no significant change in hamstring strength after vibration FR intervention (19). Moreover, García-Gutiérrez et al. (2018) showed no significant change in plantar flexor strength after vibration FR intervention (10). Although the effects of vibration FR intervention on muscle strength and performance might vary depending on the target muscle, a decrease in muscle strength or performance is not expected. Miyamoto et al. (20) showed a significant association between shear elastic modulus and running performance. Ando et al. (2) showed a positive association between MG shear elastic modulus and drop jump height. A decrease in shear elastic modulus after vibration FR intervention could possibly lead to a decrease in muscle strength and jump performance. There is also a possibility that a decrease in shear elastic modulus after vibration FR intervention could lead to a decrease in muscle strength and jump performance. By contrast, it has been suggested that vibration stimulation stimulates more muscle receptors, leading to increased motor unit recruitment (8, 11). Considering the decrease in MG shear elastic modulus and the possible increase in motor unit recruitment following vibration FR, no significant changes in muscle strength and jump performance might be a consequence of vibration FR. Although there were no significant changes in MVC-ISO and drop jump height, a significant decrease in MVC-CON torque after FR intervention without vibration was observed in the current study. This discrepancy between our results and those from previous studies remains unclear; however, the decrement effects of muscle strength in sports may be minute and negligible given the small effect sizes (FR intervention: $d = -0.39$). FR intervention with vibration, in particular, may be recommended to be included as part of the warm-up routine because it has been shown to increase ROM without reducing muscle strength or performance.

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Some limitations of the current study should be noted. Only the acute effects of vibration FR intervention on ROM and muscle stiffness were investigated in this study. To the best of our knowledge, while previous studies have investigated the chronic effects of FR intervention (16, 34), no study has yet determined the chronic effects of vibration FR intervention on ROM and muscle stiffness, which needs to be addressed in future studies. Furthermore, our participants were not athletes but sedentary male individuals. Thus, the effect of vibration FR intervention in athletes needs to be studied. Finally, we investigated the acute effect of FR intervention with and without vibration for 180 s (60 s × 3 sets) in this study, which might be a longer duration than a typical sports application. It is, therefore, necessary to study the effect of FR intervention (with and without vibration) with shorter durations as in sport settings.

Practical applications

Our results showed that FR intervention with and without vibration could increase ROM similarly; however, vibration FR intervention could increase ROM and decrease muscle stiffness, regardless of muscle strength and performance changes. Thus, FR interventions with and without vibration are satisfactory approaches if the athlete and coach's goal is to increase ROM. If the goal is to decrease muscle stiffness without muscle strength and jump performance reductions, vibration FR could be a more efficient approach than FR intervention without vibration.

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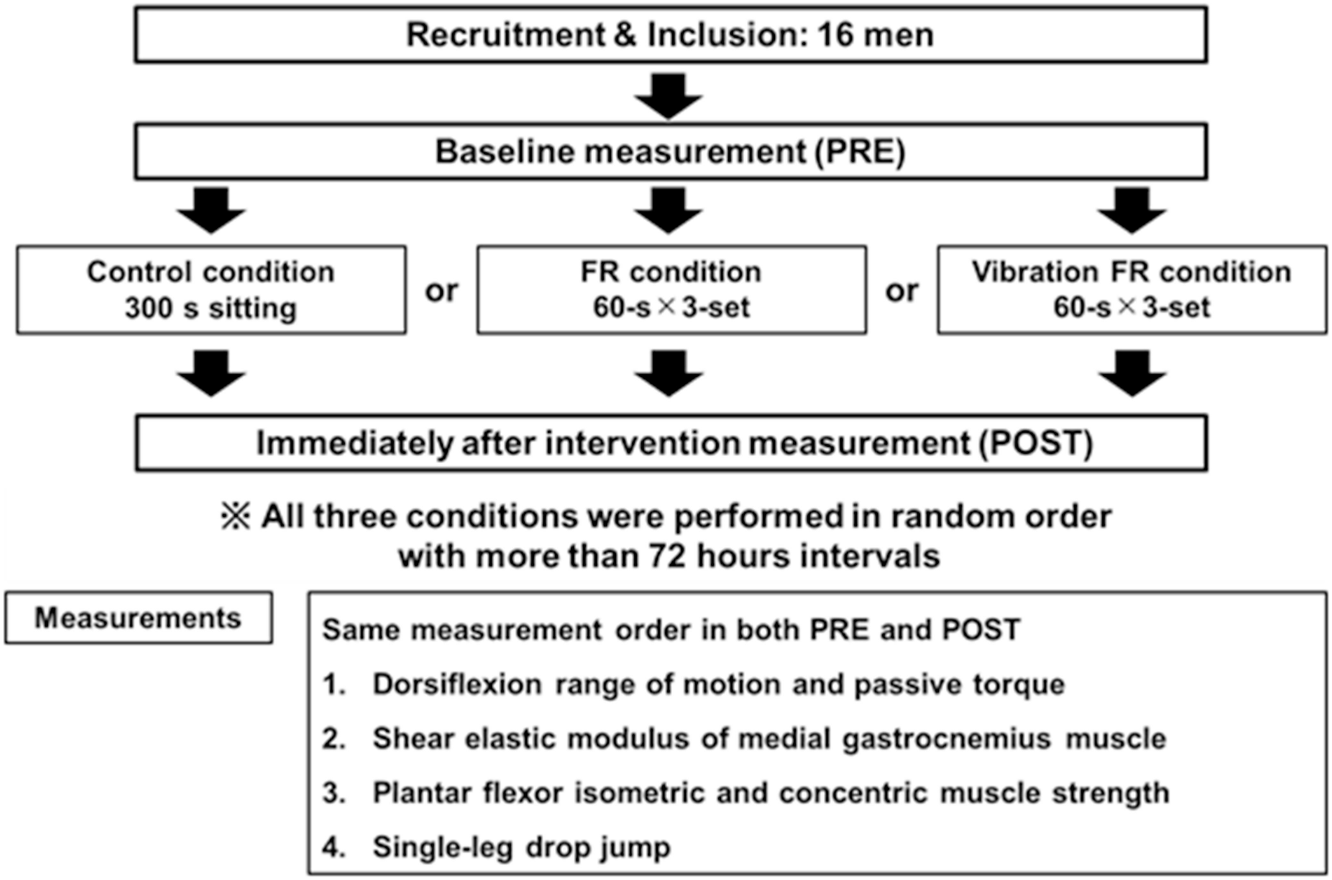

Fig. 1. Flow chart of the study

Three measurements (foam rolling [FR] interventions without vibration. Vibration FR intervention, and control conditions) were conducted in random order with more than 72hours intervals.

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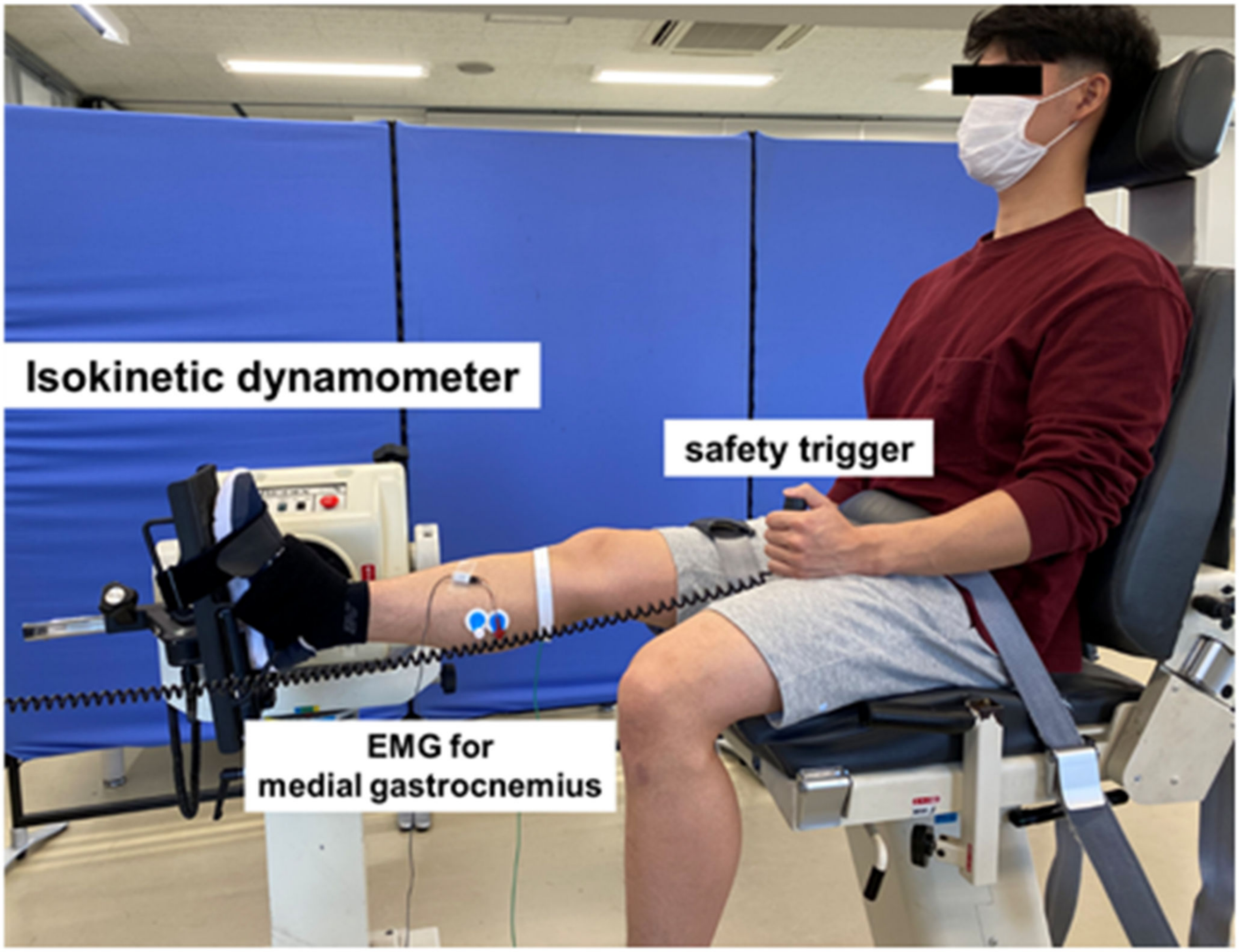

Fig. 2. Experimental set-up for passive stretching test

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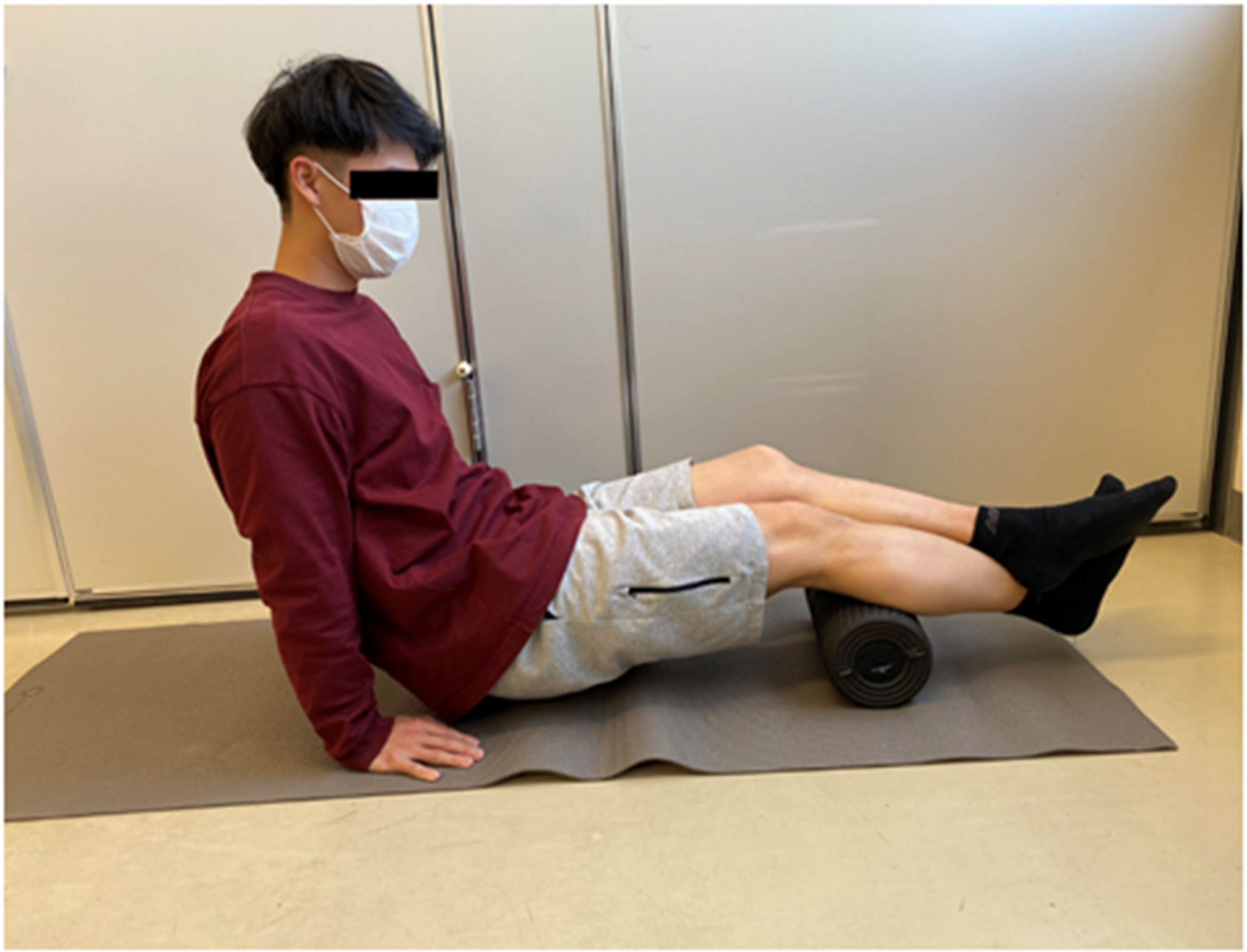

Fig. 3. Foam rolling with and without vibration technique

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Table 1

The changes in the dorsiflexion range of motion (DF ROM), passive torque at DF ROM, and shear elastic modulus before (PRE) and immediately after foam rolling (FR) intervention (POST)

	CON		FR		Vibration-FR		Interaction effect	
	PRE	**POST**	**PRE**	**POST**	**PRE**	**POST**	**P value**	**n_p^2**
DF ROM (°)	21.8±9.9	21.5±8.7	21.8±6.8	26.0±8.9 *	21.7±8.6	26.3±8.7 **	p < 0.01	0.44
Effect size	d=	0.03	d=	0.54	d=	0.54		
Passive torque at DF ROM (Nm)	21.0±8.9	22.1±10.6	20.7±6.7	24.6±8.5 **	20.4±8.0	26.0±9.3 **	p =0.01	0.26
Effect size	d=	0.11	d=	0.51	d=	0.65		
Shear elastic modulus (kPa)	25.3±9.0	25.7±8.8	25.5±12.6	25.9±9.5	25.3±10.2	21.0±8.9 **	p = 0.03	0.205
Effect size	d=	0.05	d=	0.03	d=	0.44		

Data are presented as mean ± standard deviation. * $p < 0.05$, ** $p < 0.01$, significant difference between PRE and POST

Table 2

Changes in maximal voluntary isometric contraction torque (MVC-ISO), concentric torque at 30°/s (MVC-CON), and drop jump height before (PRE) and immediately after foam rolling (FR) intervention (POST).

	CON		FR		Vibration-FR		Interaction effect		
	PRE	POST	PRE	POST	PRE	POST	P value	n_p^2	
MVC-ISO (Nm)	160.8±27.8	161.6±27.1	162.4±24.8	157.9±24.9	160.4±28.0	158.3±24.8	0.15	0.12	
Effect size	d=	0.03	d=	0.18	d=	0.08			
MVC-CON (Nm)	127.0±18.9	125.9±16.4	130.6±17.6	124.0±15.8 *	124.0±15.8 *	129.1±19.5	124.1±15.7	0.24	0.091
Effect size	d=	-0.06	d=	-0.39	d=	-0.28			
Drop Jump (cm)	19.2±2.9	19.3±2.7	20.0±3.2	19.2±3.2	19.9±3.3	19.7±2.7	0.326	0.072	
Effect size	d=	0.00	d=	0.23	d=	0.09			

Data are presented as mean ± standard deviation. * p <0.05, significant difference between PRE and POST