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Section: Original Research Report

Article Title: Acute Effects of Foam Rolling, Static Stretching, and Dynamic Stretching During Warm-Ups on Muscular Flexibility and Strength in Young Adults

Authors: Hsuan Su, Nai-Jen Chang, Wen-Lan Wu, Lan-Yuen Guo, and I-Hua Chu

Affiliations: Department of Sports Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan.

Running Head: Acute effect of foam rolling on muscle performance

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Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults

Hsuan Su[a], Nai-Jen Chang[a], Wen-Lan Wu[a], Lan-Yuen Guo[a], I-Hua Chu[a]

[a]Department of Sports Medicine, Kaohsiung Medical University, 100 Shih-Chuan 1st Rd., Kaohsiung, 807, Taiwan.

Running head: Acute effect of foam rolling on muscle performance

Correspondence concerning this article should be addressed to I-Hua Chu, Department of Sports Medicine, Kaohsiung Medical University, 100 Shih-Chuan 1st Rd., Kaohsiung, 807, Taiwan.
Email: ihchu@kmu.edu.tw
Telephone: +886-7-3121101*2646#618
Fax: +886-7-3138359

Other contacts:
Hsuan Su: elmo0715@hotmail.com
Nai-Jen Chang: njchang@kmu.edu.tw
Wen-Lan Wu: wenlanwu@kmu.edu.tw
Lan-Yuen Guo: yuen@kmu.edu.tw

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Abstract

Context: Foam rolling has been proposed to improve muscle function, performance, and joint range of motion (ROM). However, whether a foam rolling protocol can be adopted as a warm-up to improve flexibility and muscle strength is unclear. ***Objectives:*** To examine and compare the acute effects of foam rolling, static stretching, and dynamic stretching used as part of warm-up on flexibility and muscle strength of knee flexion and extension. ***Design:*** Crossover study. ***Setting:*** University research laboratory. ***Participants:*** 15 male and 15 female college students (age 21.43 ± 1.48 y, weight 65.13 ± 12.29 kg, height 166.90 ± 6.99 cm). ***Main Outcome Measures:*** Isokinetic peak torque was measured during knee extension and flexion at an angular velocity of 60°/second. Flexibility of the quadriceps was assessed by the modified Thomas test, while flexibility of hamstrings was assessed using the sit-and-reach test. The 3 interventions were performed by all participants in random order on 3 days separated by 48-72 hours. ***Results:*** The flexibility test scores improved significantly more after foam rolling as compared to static and dynamic stretching. With regard to muscle strength, only knee extension peak torque (pre vs. post intervention) improved significantly after the dynamic stretching and foam rolling, but not after static stretching. Knee flexion peak torque remained unchanged. ***Conclusions:*** Foam rolling is more effective than static and dynamic stretching in acutely increasing flexibility of the quadriceps and hamstrings without hampering muscle strength, and may be recommended as part of a warm-up in healthy young adults.

Keywords: myofascial release, foam rolling, stretching exercise, flexibility, strength

Introduction

A single exercise session usually comprises four phases, warm-up, stretching, conditioning or sports-related exercise, and cool-down [1]. The warm-up phase consists of 5 to 10 minutes of low- to moderate-intensity physical activity, and is a generally accepted and recommended method of preparing the body for strenuous activity [1, 2]. The stretching exercise may be performed as part of a warm-up prior to the main exercise, with a goal to increase range of motion and decrease resistance to stretch, allowing freer movements and enhanced performance [3-5]. The effects of stretching have been related to both mechanical (e.g., viscoelastic deformation, plastic deformation of connective tissue) and neural (e.g., neuromuscular relaxation, modification of sensation) factors. A number of studies have provided detailed reviews about these mechanisms [5-7].

There are different types of stretching exercise, static stretching, dynamic stretching, ballistic stretching, and proprioceptive neuromuscular facilitation. Static and dynamic stretching exercises can be self-administered and are recommended as part of an exercise program [1, 8]. Static stretching usually involves actively or passively moving a limb to the end of its range of motion (ROM) and holding the stretched position for 15-60 seconds, and then repeating 2-4 times [8]. Fifteen to thirty seconds of static stretching has been shown to effectively increase flexibility and ROM in a myriad of studies [5, 8, 9]. However, recent studies have indicated that repetitive and sustained bouts of static stretching may attenuate muscle strength and sprint performance, and increase the risk of sports injuries during practices or competitions due to joint instability [5, 8, 10]. Alternatively, it is recommended that dynamic stretching exercise is performed at the warm-up phase [8]. Dynamic stretching incorporates whole body movements and involves actively moving a joint through its ROM without holding the movement at its endpoint [2, 11]. Research has shown that dynamic stretching is effective in increasing flexibility, maximal muscle strength, sprint performance, and vertical jump performance [2, 12, 13]. However, there are also studies suggested that dynamic stretching has no effect on muscle strength and performance [8, 14].

Recently, foam rolling exercise has been adopted as a tool for self-myofascial release (SMR) [15]. SMR is a therapeutic technique for treating soft-tissue restrictions and is commonly used by therapists and fitness professionals as a recovery and maintenance tool to promote the process of soft-tissue healing [16]. When using foam rolling for SMR, individuals use their body weight on a foam roller to exert pressure on the opposing soft tissues [15]. Similar to static and dynamic stretching, foam rolling has been shown to improve both active and passive ROM [16, 17]. Studies also consistently demonstrated the effects of foam rolling in reducing soft tissue adhesions and in alleviating muscle soreness [15-18]. However, the effect of foam rolling on muscle strength and performance remains controversial.

Healey and colleagues [15] examined the acute effect of foam rolling exercise on vertical jump height and power, isometric force, and agility. The results showed no significant differences between foam rolling and planking for all of the athletic tests. MacDonald et al. [16] examined the acute effect of foam rolling on quadriceps maximum voluntary contraction force and found no changes in muscle strength 2 and 10 minutes after foam rolling on the quadriceps. On the other hand, a study examined the effect of foam rolling after an intense bout of back squats. The results revealed that foam rolling substantially improved muscle activation and vertical jump height as compared to the no-treatment control group [17].

With so few studies, currently data on the acute effect of pre-performance foam rolling exercise on muscle strength is inconclusive. Additionally, no study has compared the effect of foam rolling to static and dynamic stretching on flexibility and muscle strength. Accordingly, this study aimed to examine and compare the acute effects of foam rolling, static stretching, and dynamic stretching used as part of warm-up on flexibility and muscle strength of knee flexion and extension.

Methods

Participants

A total of thirty volunteers (mean age 21.43 ± 1.5 y, 15 men) were recruited from a university and the surrounding community in southern Taiwan. Participants' characteristics are detailed in Table 1. Those with a history of cardiovascular or respiratory disease, having contraindications to exercise (e.g., musculoskeletal injury, low back pain), with any history of third-degree sprains (e.g., anterior cruciate ligament ruptures), grade II or III muscle strain, or surgery or fractures in the lower extremity in the past year, taking prescribed medication other than oral contraceptive pill, or being pregnant or breastfeeding were excluded from participation. Seventeen participants (10 men) reported engaging in regular exercise, that is, participating in at least 30 minutes of moderate intensity exercise on at least 3 days of the week for at least 3 months [1]. The majority of these participants reported engaging in walking, running, or cycling. About half of these participants also reported playing ball sports (e.g., basketball, volleyball) or practicing martial arts (e.g., tai chi) during their leisure time.

Sample size required was estimated at 24 with an alpha level of 0.05, a power of 0.80, and an effect size of 0.60 derived from a previous study [19] to detect a difference between conditions in changes in sit and reach test (cm). The G*Power was used for these calculations [20].The study protocol was approved by the Kaohsiung Medical University Chung-Ho Memorial Hospital Institutional Review Board. All participants were informed of the benefits and risks of the investigation, and written informed consent was received from all participants.

Procedures

This study used a within-subject design to examine and compare the acute effects of foam rolling, static stretching, and dynamic stretching of the quadriceps and hamstrings muscles on flexibility and isokinetic muscle strength. Prior to the test sessions, all eligible participants attended a familiarization session in which they were taught how to perform static stretching, dynamic stretching, and foam rolling exercises. They were also familiarized with the procedures and equipment used for the testing. Next, all participants completed three test sessions in randomized order, with 48-72 hours of rest between each session. For all test sessions, participants were requested to come to the laboratory between 2 pm and 4 pm and were instructed to avoid strength training or strenuous activities 24 hours before their lab visit. During each test session, a 5 minutes light aerobic cycling (Aerobike 75XLII; 70 rpm and 80W for men, 70 rpm and 50W for women) was followed by pre-test measures in the order of isokinetic strength for quadriceps and hamstrings, modified Thomas test, and sit and reach test. Next, participants performed another 5 minutes of light aerobic cycling followed by 6 minutes of foam rolling, static stretching, or dynamic stretching randomized for that session. The protocols for the foam rolling and stretching exercises are detailed below. Post-test measures were performed in the same order as the pre-test measures at 5 minutes after the intervention. The flowchart of the study is presented in Figure 1. All testing sessions took place in the same location and were supervised by the same experimenters. The room temperature was controlled at 25°C by an air conditioner. Care was taken to ensure that all participants received the same instructions and verbal encouragement for all exercises and tests.

Measures

Isokinetic knee extensor and flexor muscle strength were assessed using the Biodex isokinetic dynamometer (Biodex System 3 Pro, New York, USA). Participants sat in an upright position on the Biodex dynamometer chair with their trunk and right thigh stabilized by straps to minimize extraneous body movements (Figure 2). The right leg was placed on the dynamometer. The lateral femoral condyle was used as the bony landmark to align the axis of rotation of the knee with the axis of rotation of the dynamometer. Participants were asked to perform knee extension and immediate knee flexion as fast as they could three times at an angular velocity of 60°/second. The peak torque in N•m was recorded [21]. The isokinetic quadriceps and hamstrings muscle strength measured at 60°/second using the Biodex System has high intraclass correlation coefficient (ICC) values ranging from r = 0.88 to r = 0.97 [22].

The flexibility of the quadriceps muscle was assessed by modified Thomas test [23]. The participants were instructed to sit at the edge of a therapeutic bed and roll onto their back while pulling both knees to their chest. While maintaining the left limb in the fully flexed position, the right limb was lowered toward the floor. The right knee was then flexed passively by the experimenter until a there was a feeling of discomfort but no pain. Knee flexion angle was measured by a goniometer to determine passive quadriceps length. This modified Thomas test has a test retest reliability of 0.91–0.94 [24].

The standard sit-and-reach test was used to assess low back and hamstring flexibility. Participants were instructed to sit with their knees extended and the soles of their feet against the testing box. Participants were then instructed to slowly reach forward as far as possible along the top of the box and hold the position for 2 seconds, while keeping their knees fully extended. The participant's score was the most distant point the fingertips contact. Two trials were administered with the maximum score recorded to the nearest 0.5 cm [21]. The sit-and-reach test has a test retest reliability of above 0.90 [25].

Exercise Protocols

In the present study, foam rolling, static stretching, and dynamic stretching exercises were performed on quadriceps and hamstrings. The protocols for all exercises are detailed in Figure 3. The entire intervention for each exercise program lasted approximately 6 minutes.

Foam rolling exercise

Participants performed foam rolling on a foam roller that was constructed of hollow core (10 cm outer diameter and 0.3 cm thickness) surrounded by EVA foam (1.5 cm thickness). Participants first positioned their right lower limb into the designated position and then placed as much of their body weight as possible onto the foam roller and moved back and forth 2 times during 30 seconds of foam rolling. Next, the same exercise was performed on the left lower limb. The foam rolling exercise was performed on quadriceps and hamstrings three times in rotational order.

Static stretching exercise

Participants first positioned their right lower limb into each of the stretch positions then slowly stretched the target muscle to a position of mild discomfort and held this position for 30 seconds. Next, the same stretching exercise was performed on the left lower limb. Each stretching exercise was performed three times for quadriceps and hamstrings in rotational order.

Dynamic stretching exercise

Dynamic stretching consisted of 2 controlled movements (i.e., forward lunge and front kick) through the active ROM of the hip joint. Each movement was performed continuously for 1 minute, in which participants completed 15 repetitions on each leg reciprocally (about 2 seconds per repetition). Both movements were performed three times alternately for a total of 6 minutes.

Statistical Analyses

This was a randomized crossover study. Data were inspected visually and statistically for normality (Shapiro-Wilk's test, $P > 0.05$) and all variables were normally distributed. Descriptive statistics were performed for characteristics of the participants. A 3 (condition: foam rolling vs. static stretching vs. dynamic stretching) x 2 (time: pre-test vs. post-test) analysis of variance with repeated measures was performed to examine the effects of different conditions on the dependent variables. Significant F tests were followed by post-hoc comparisons using the Bonferroni correction method. Estimates of effect size using the partial eta squared (η^2) and Cohen *d* were reported to present the magnitude of the effect. The significance level (α level) was set at 0.05. All data analyses were performed with the Statistical Package for the Social Sciences Version 19 (SPSS, Chicago, IL, USA).

Results

The results for all outcome measures are presented in Table 2 and Figure 4. At pretest, there were no statistical differences among the three conditions for any of the dependent variables. For the modified Thomas test, there was a significant condition by time interaction effect ($F_{2,58}$ = 12.683, $P < 0.001$, partial $\eta^2 = 0.304$). In addition, there was a significant main effect of time ($F_{1,29}$ = 90.878, $P < 0.001$, partial $\eta^2 = 0.758$). Post hoc analyses revealed that participants improved significantly in the modified Thomas test after all three conditions ($P < 0.017$). Participants also improved significantly more after foam rolling in comparison with static stretching and dynamic stretching.

For the sit and reach test, there was a significant condition by time interaction effect ($F_{2,58}$ = 7.612, P = 0.002, partial η^2 = 0.208). The main effect of time was also significant ($F_{1,29}$ = 44.382, P < 0.001, partial η^2 = 0.605). Post hoc analyses revealed that participants improved significantly in the sit and reach test after all three conditions (P < 0.001). Additionally, participants improved significantly more after foam rolling in comparison with static stretching and dynamic stretching.

There was no significant interaction effect of time and conditions for the changes in knee extension peak torque ($F_{2,58}$ = 3.379, P = 0.057 partial η^2 = 0.104) and knee flexion peak torque ($F_{2,58}$ = 0.448, P = 0.641 partial η^2 = 0.015). The main effect of time was significant for knee extension peak torque ($F_{1,29}$ = 17.850, P < 0.001, partial η^2 = 0.381), but not for knee flexion peak torque ($F_{1,29}$ = 1.585, P = 0.218, partial η^2 = 0.052). Post hoc analyses revealed that participants improved significantly in knee extension peak torque after foam rolling (P = 0.003) and dynamic stretching (P = 0.020), but not after static stretching (P = 0.903).

Discussion

The purpose of this study was to evaluate and compare the acute effects of foam rolling, static stretching, and dynamic stretching used as part of warm-up on flexibility and muscle strength of knee flexion and extension. The results revealed that all three conditions were effective in acutely increasing flexibility of the quadriceps and hamstrings, and that foam rolling was significantly more effective than static and dynamic stretching in increasing flexibility. There were no significant differences between conditions in isokinetic muscle strength. Significant results of time (pre vs. post intervention) were seen in knee extension peak torque, which improved significantly after foam rolling and dynamic stretching, but not after static stretching. Knee flexion peak torque, on the other hand, remained unchanged.

The mean pretest value of the sit and reach test indicates good flexibility when the result is compared to norms for Northern American and Taiwanese adults [21, 26]. The mean pretest values of the isokinetic knee extension and flexion are also comparable to norms for non-athletes of similar age [27, 28]. Such comparison, however, cannot be made for the modified Thomas test, as the norms are not widely available.

Foam rolling has been shown to increase flexibility in previous studies [16, 17]. MacDonald et al.'s study [16] and the present study are, to the best of our knowledge, the only research articles to examine the acute effects of foam rolling as a pre-performance exercise on quadriceps flexibility. Similar to our findings, MacDonald et al. reported that an acute bout of foam rolling was effective in increasing quadriceps flexibility as compared with the control. While static stretching and dynamic stretching have also been shown to effectively increase flexibility in previous research [2, 5, 9], the present study is the first to compare the effects of foam rolling with static and dynamic stretching on flexibility. The results suggested that foam rolling is more effective than static and dynamic stretching in increasing flexibility of the quadriceps and hamstrings and may be recommended as part of a warm-up, especially for sports that necessitate a high degree of flexibility (e.g., gymnastics, ballet, diving).

The increase in flexibility after foam rolling may be explained by a change in the thixo-tropic property of the fascia encasing the muscle [29, 30]. The foam rolling technique involves small undulations back and forth over a dense foam roller which place direct and sweeping pressure on the soft tissue to stretch the tissue and generate friction between the soft-tissue of the body and the foam roller [16]. This friction was reported to cause warming of the fascia, promote the fascia to take on a more fluid-like form, break up fibrous adhesions between the layers of fascia, and result in the restoration of soft-tissue extensibility and greater flexibility [16, 31, 32]. The increased flexibility may also be attributed to the vigorous pressure placed on the soft-tissue during foam rolling. This vigorous pressure may overload the cutaneous receptors which possibly dulls the sensation of the stretch endpoint and results in increased stretch tolerance and subsequently improved flexibility [16, 33].

While a number of studies have demonstrated detrimental effects of static stretching on muscle strength and performance [3, 5, 10], other studies have suggested that short durations (<90 seconds total) of static stretching does not result in performance impairments [2, 8, 14]. Results of the present study revealed that 90 seconds of static stretching did not attenuate muscle strength of knee flexion and extension.

Two studies have investigated the acute effects of foam rolling as a pre-performance exercise on muscle strength and performance and reported no change in muscle strength after foam rolling [15, 16]. The present study showed a significant increase in knee extension peak torque after foam rolling with a medium effect size. Furthermore, the percentage of increase in peak torque (8%) is similar to those reported after strength training in healthy young adults (6%-10%) [34, 35]. However, this increase was not significantly different from the static stretching condition, which showed essentially no change in knee extension peak torque. Knee flexion peak torque was also not affected by foam rolling. Accordingly, similar to previous findings, the effect of foam rolling in enhancing muscle strength was not evidenced in the present study. The significant finding in knee extension peak torque may likely be due to measurement error. Nonetheless, the present study showed that an acute bout of foam rolling did not have harmful effects on muscle strength.

Dynamic stretching was also found to result in a significant increase in knee extension peak torque, and this increase was significantly different from the static stretching condition ($P = 0.044$). This finding is similar to a number of previous studies demonstrating improvements in muscle strength and performance after dynamic stretching [2, 12, 13]. An elevation in muscle temperature and postactivation potentiation (PAP) are two of the proposed theories to explain this improvement in muscle strength [36, 37]. In the present study, the movement used for dynamic stretching of the quadriceps (forward lunge) may also cause repeated contractions of the quadriceps muscle of the front leg. This may in turn result in elevated muscle temperature and PAP and subsequently improved quadriceps muscle strength. In other words, the increase in knee extension peak torque seen in the present was likely due to the "contraction part" rather than the "stretching part" of the dynamic stretching movement. This may also explain the non-significant finding in knee flexion peak torque as the movements used for dynamic stretching in the present study did not provide opportunities for repeated contractions of the hamstrings muscle.

This study had several limitations. The majority of the participants were healthy college students, which constrains the generalizability of the findings to other age groups. Another concern is that the amount of pressure placed on the foam roller varied depending on the individual's body weight and his/her discomfort tolerance, which may influence the effect of foam rolling each individual received. Also, it is important to note that the sit-and-reach test used in the present study assesses the flexibility of both low back and hamstring. As foam rolling is mainly applied on hamstring muscle, future study should also include a straight leg raise test to more specifically examine the effect of foam rolling on hamstring muscle length. Furthermore, this study only assessed flexibility and strength of a single muscle group. For practical application, a task-oriented approach such as jumping, sprinting, and other athletic performance may be evaluated in future research.

Conclusion

Foam rolling is more effective than static and dynamic stretching in acutely increasing flexibility of the quadriceps and hamstrings, and may be recommended as part of a warm-up to enhance performance. For sports that require a high degree of flexibility (e.g., gymnastics, ballet, diving), it is suggested that foam rolling be performed before the main exercise as it appears to be more effective in increasing flexibility without attenuating muscle strength.

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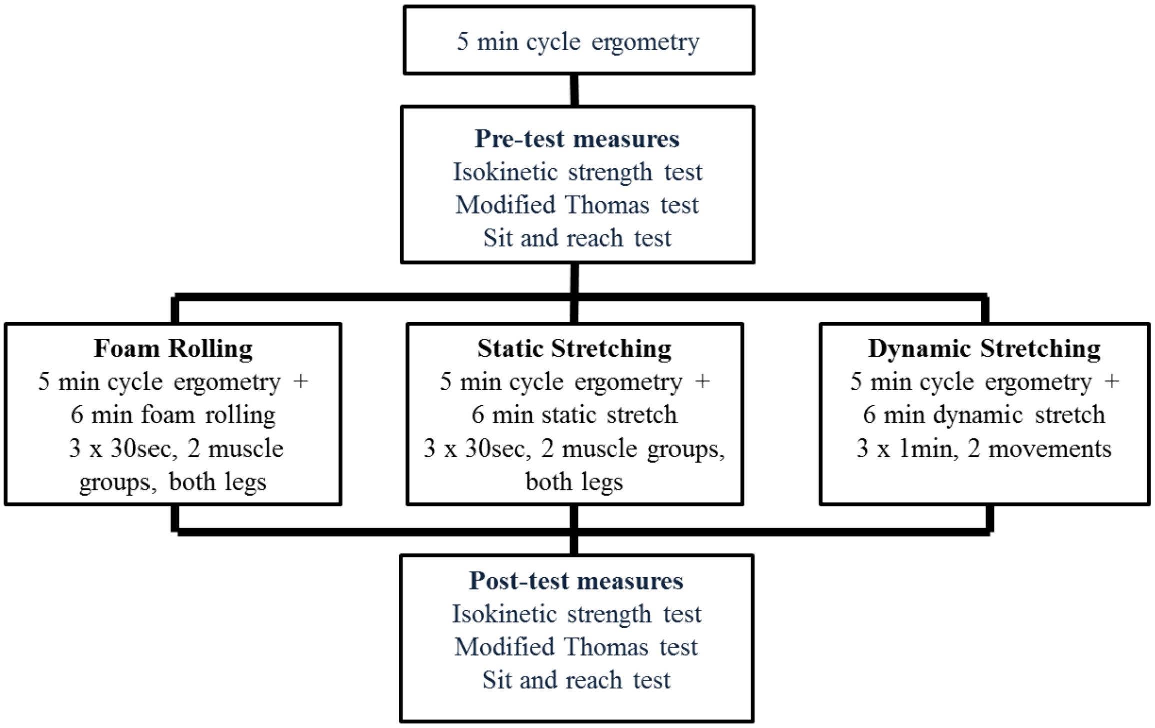

Figure 1. Summary of study design

Figure 2. The position for isokinetic strength test

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Foam rolling	
Quadriceps. Body is positioned prone with quadriceps of the right leg placed on the foam roller. Foam rolling from the proximal portion of the quadriceps down to just above the patella and back and forth for 30 seconds, then change to the left leg.	
Hamstrings. Place hamstrings of the right leg on the foam roller. Foam rolling from the proximal portion of the hamstrings down to knee and back and forth for 30 seconds, then change to the left leg.	
Static stretching	
Quadriceps. From a high kneeling squat position, bend and lower right knee toward the floor and lean backward. Hold the position for 30 seconds, then change to the left leg.	
Hamstrings. From a supine position, keep left leg on the floor and right knee extended, slowly raise right leg toward the chest using hands or a towel. Hold the position for 30 seconds, then change to the left leg.	
Dynamic stretching	
Quadriceps. From a standing position, step out with one leg, flex both knees until forward thigh reaches horizontal, then move back leg forward. Repeat this movement continuously for 1 minute.	
Hamstrings. From a standing position, kick one leg forward with knee extended. Step forward and kick the other leg forward with knee extended. Repeat this movement continuously for 1 minute.	

Figure 3. Exercise Protocols

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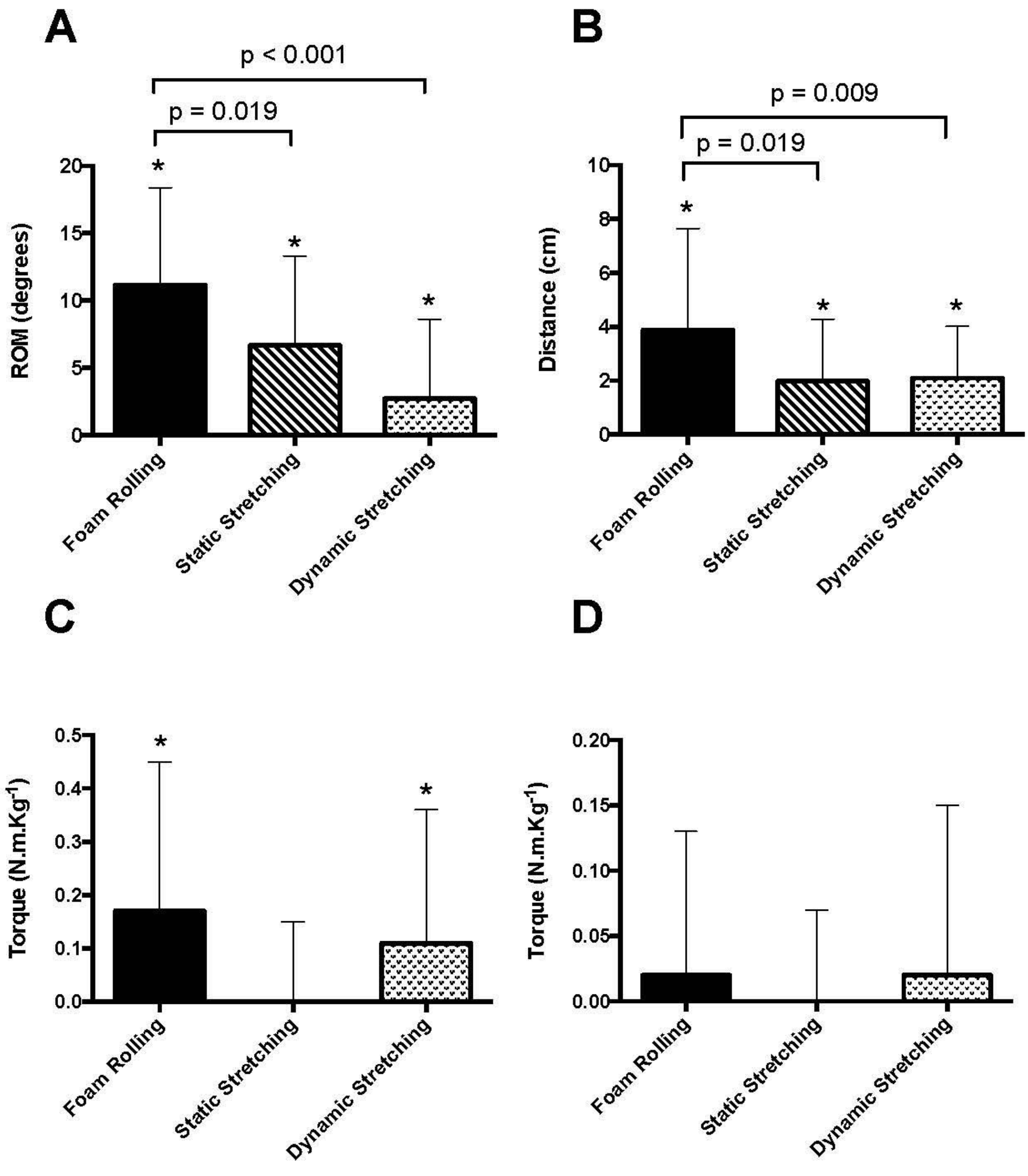

Figure 4. Changes in flexibility and strength after the foam rolling, static stretching, and dynamic stretching conditions. A) Modified Thomas test B) Sit and reach test C) Isokinetic knee extension D) Isokinetic knee flexion. * Indicates the change was statistically significant at $p < 0.05$. All data are presented as mean ± standard deviation.

Table 1. Participants characteristics

	Total (n=30)	Men (n=15)	Women (n=15)
Age (years)	21.43±1.48	21.47±1.77	21.40±1.18
Height (cm)	166.90±6.99	172.40±4.64	161.40±3.85
Weight (kg)	65.13±12.29	72.07±11.75	58.20±8.48
BMI (kg/m^2)	23.27±3.41	24.19±3.40	22.35±3.26

Values are mean ± standard deviation; BMI = body mass index.

“Acute Effects of Foam Rolling, Static Stretching, and Dynamic Stretching During Warm-Ups on Muscular Flexibility and Strength in Young Adults” by Su H et al.
Journal of Sport Rehabilitation

Table 2. Measurements for the foam rolling, static stretching, and dynamic stretching conditions

	Modified Thomas test (degrees)	Sit and reach test (cm)	Quadriceps strength (N· m· Kg^{-1})	Hamstrings strength (N· m· Kg^{-1})
Foam rolling				
Pre	119.13±16.50	32.85±12.00	2.17±0.44	1.41±0.29
Post	130.30±13.85*	36.73±10.13*	2.34±0.43*	1.43±0.31
Post-pre	11.17±7.22	3.88±3.77	0.17±0.28	0.02±0.11
ES	1.55	1.03	0.59	0.22
Static stretching				
Pre	119.40±13.66	33.56±11.19	2.33±0.38	1.44±0.30
Post	126.07±13.36*	35.54±10.84*	2.33±0.44	1.44±0.31
Post-pre	6.67±6.63[a]	1.99±2.30[a]	0.00±0.15	0.00±0.07
ES	1.00	0.86	0.02	0.01
Dynamic stretching				
Pre	120.53±14.03	33.58±11.33	2.33±0.38	1.44±0.30
Post	123.27±14.57*	35.69±10.28*	2.44±0.38*	1.46±0.27
Post-pre	2.73±5.89[a]	2.10±1.91[a]	0.11±0.25	0.02±0.13
ES	0.46	1.10	0.45	0.14

Values are mean ± standard deviation. Effect size (ES) is calculated by Cohen *d*.

*Significant difference ($P < 0.05$) compared with pretest.

[a]Significant difference ($P < 0.05$) compared with foam rolling.