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Research article

Acute effects of foam rolling on ankle dorsiflexion and squat exercise patterns in extreme conditioning program practitioners: A randomized clinical trial

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Abstract: *Background/objectives*: Joint and muscle overloads commonly occur in extreme conditioning programs (ECP), which require great physical fitness for their practice. For its execution, good functional performance, mobility and adequate movement patterns are required. The fascial system plays a fundamental role in performance in ECP and one of the techniques used to improve joint mobility and movement pattern is the self-myofascial release using a foam roller (FR). Our objective of this study was to evaluate the effect of FR in ankle dorsiflexion (DF) range of motion (ROM), assessed with the Lunge Test, and also in the squat movement pattern, assessed using the Technique smartphone application, in ECP practitioners. *Methods*: The study was carried out with 18 ECP practitioners who practiced for over four months and had a mean age of 30.94 years. The participants were randomized and allocated into two groups: control and intervention. The FR was self-applied bilaterally in the sural triceps region for 90 seconds. Tests to assess DF ROM and squat movement pattern were applied before and immediately after using FR (intervention group) or after three-minute rest (control group). *Results*: The use of the FR promoted an immediate increase in ankle DF ROM during the Lunge Test and during the squat and a decrease in dynamic knee valgus during the squat. *Conclusion*: The FR can be used as a tool for an acute increase in DF ROM and a decrease in dynamic knee valgus, having a positive impact in improving movement patterns.

Keywords: dorsiflexion; myofascial mobilization; myofascial release; movement pattern

1. Introduction

ECP are composed by strength and conditioning exercises, which encompass the performance of high-intensity and regularly varied workouts that require maximum repetition of certain exercises, high volume training load, mobility and stability [1]. These programs are adaptable to everyone; however, they involve applying overloads to the musculoskeletal system [2]. The overload, associated to an inadequate load progression, increase the risk of injury, often in the shoulder, lumbar spine and knee, which may lead to functional limitations [3].

The squatting movement is widely used in ECP and its proper execution minimizes the aforementioned risks [4]. For optimal performance, good ankle DF ROM is required, guiding knee movement throughout the exercise execution [5,6]. In addition, performing the squat requires proper postural alignment and good muscle performance, which partly depends on force transmission throughout the active and passive structures involved in this movement [7]. A DF deficit reduces squatting ability by preventing sufficient forward knee excursion and adequate shifting of the center of mass. These factors can cause subtalar pronation or knee valgus and increase injury risk by altering lower extremity muscle stiffness [5].

Since the joints of the lower limbs work together in different planes of motion in a closed kinetic chain and are connected through the posterior myofascial chain, mobility deficits in any joint affect the transmission forces through the fascial system [8,9]. This system is able to adapt to mechanical stress and to remodel its structure as load keeps being systematically applied [10]. Therefore, the fascial system can change its physiological structure when it is overloaded [11,12] which leads to changes in muscle mechanics and, consequently, reduces load dissipation and movement restriction [12,13].

When repetitive mechanical stimulation is applied to the fascial tissue, there is an increase in blood flow and local intramuscular temperature, which modifies the response of mechanoreceptors and favors the structural adaptation of the fascial system, its hydration and the reduction of its stiffness [14–17]. The FR, a self-applying device that mechanically stimulates the tissues, could reduce tension and improve the sliding between tissues after application and appears to have an immediate effect on joint ROM of hip, knee and ankle [15]. These findings can be justified due to the viscoelastic and thixotropic properties of the fascial tissue, which optimize warm-up procedures that can improve physical and sports performance [15,18,19]. In this context, it becomes relevant to test the hypothesis that myofascial release with the FR may have beneficial effects on ankle DF ROM, as well as on the squat performance pattern, in ECP practitioners.

2. Methods

2.1. Study design

This is a randomized clinical trial in which a blinded simple randomization was carried out by draw (website: “research randomizer”). The study registration number in the Brazilian clinical trials registry (REBEC) is RBR-2mqbwbd. The study was conducted in two ECP training centres in the city of Divinópolis - Minas Gerais, during the year 2021, and was approved by the Ethics Committee and Research with Human Beings of the university (protocol number 5.029.869).

2.2. Participants

The study had 18 participants, 11 females and 7 males, randomized into two groups (control and intervention) with the same number of individuals (n = 9). The sample characteristics are presented in Table 1. The volunteers were recruited from two sports centers in October 2021 in the city of Divinópolis (Brazil), where they watched a presentation and were given an explanatory folder with the contact details of the researchers. After phone contact from interested practitioners of ECP, we explained about the research and a date/hour were scheduled to attend the training site for data collection and for the subjects to fill in the informed consent form (ICF).

All participants were be between 18 and 45 years old and practitioners of ECP with a frequency of at least two weekly sessions, with a total practice time of over four months. Participants who had a history of heart and/or neurological conditions, a history of previous injury or surgery in the lower limbs, felt pain while performing the tests, did not attend the place of data collection at the time scheduled, had trained or had undergone some myofascial technique within 24 hours prior to the data collection, were excluded.

Table 1. Sample characteristics of baseline.

	Control	Intervention
Age (years)	30.1 ± 4.1	31.8 ± 6.8
Weight (kg)	71.1 ± 12.0	76.0 ± 15.8
Height (m)	1.67 ± 0.08	1.70 ± 0.07
	Gender (%)	
Female	7 (77.7%)	4 (44.4%)
Male	2 (22.2%)	5 (55.5%)

2.3. Sample size calculation

The sample size was estimated by the GPower® program (Franz Faul, Universitat Kiel, Germany), version 3.1.9.2. For this, we used an A priori analysis, considering t-Test for comparisons between independent groups, for the variable ankle DF ROM. The number of study participants was obtained by sample estimation based on the data found by Stanek, Sullivan and Davis20, considering a power of 80% and alpha error of 5%. There were no withdrawals, so there was no need to analyze the data with the intention to treat.

A total of 18 subjects accepted to participate, from them, all individuals did attend the described inclusion criteria. Therefore, the subjects participated in all stages of the research (Figure 1). Of the total individuals, 61.1% were women and the mean age was 30.94 years (Table 1).

2.4. Outcome measures

Data collection was performed as follows (Figure 1):

1) The evaluations were carried out on specific days scheduled in each training center, according to the availability of the place, participants and examiners;

2) An initial interview was conducted for the collection of demographic data and randomization into two groups;

3) The Lunge Test and squat pattern tests (2D images) were performed pre and post intervention or control only in the dominant lower limb;

4) Data was collected before and immediately after foam rolling in the intervention group, or after rest in the control group, for comparison.

To ensure the confidentiality of the randomization, the three examiners stayed at different stations and without contact with each other. In addition, a single examiner was responsible for carrying out an anamnesis, the allocation of participants, explaining about the research, about the groups to which they were allocated and, for members of the intervention group, how to perform the technique. After this first contact, the research participant was directed to one of the test stations.

A second examiner was responsible for explaining and applying the Lunge Test (Figure 2) to measure the DF ROM of the ankle. It was performed in a weight-bearing position, using a smartphone inclinometer application (iHandy Level) available for the IOS system (iPhone Operating System) [21]. A 15cm marking was made below the anterior tibial tuberosity, where the smartphone was positioned. The subjects placed one foot anteriorly to the trunk, with the hallux at an initial standardized distance from the wall (10 cm) and the other foot positioned posteriorly to the trunk, at a distance chosen by the participant allowing a comfortable and stable posture. The subjects were instructed to support their hands on the wall and approach the knee to it, aligned with the second metatarsal, aiming to touch it without detaching the heel from the ground. When this movement was successful, the subjects moved the foot of the evaluated limb one centimeter backwards and performed the movement again. This was repeated until they were unable to touch the wall without their heels coming off the ground. After reaching this position, the measurement was performed three consecutive times and the mean of the values was calculated [22,23].

Lastly, a third examiner was responsible for recording the squat movement pattern for later analysis of DF ROM movements, knee valgus, knee flexion and trunk posture. All participants were instructed to first stand in front of the camera with their feet positioned on a mark made on the floor fixed two meters away from the camera to standardize the recording distance. After a signal to start, the assessed participant performed three squats with arms above the head holding a stick (simulating the overhead squat movement of the ECP). After performing the squat in front of the camera, the participant was instructed to position himself in the right sagittal view and performed three other squats in the same way. The images were later analyzed with a biomechanical analysis program (Technique®) and measurements were taken of the DF angles, dynamic knee valgus, knee flexion and trunk posture (anterior flexion).

The researchers were trained to perform each test described above. An intra-examiner reliability test was previously carried out using 10 individuals with two days of interval between measurements.

The Intraclass Coefficient Correlation (ICC) values and their respective 95% confidence intervals observed in the reliability tests were: ICC = 0.986 (95% CI: 0.938–0.997) for the DF ROM in the Lunge Test; ICC = 0.969 (95%CI: 0.874–0.992) for the DF ROM in the squat; ICC = 0.984 (95% CI: 0.937–0.996) for dynamic knee valgus in the squat; ICC = 0.970 (95%CI: 0.874–0.992) for knee flexion in the squat; ICC = 0.990 (95%CI: 0.960–0.998) for trunk flexion in the squat.

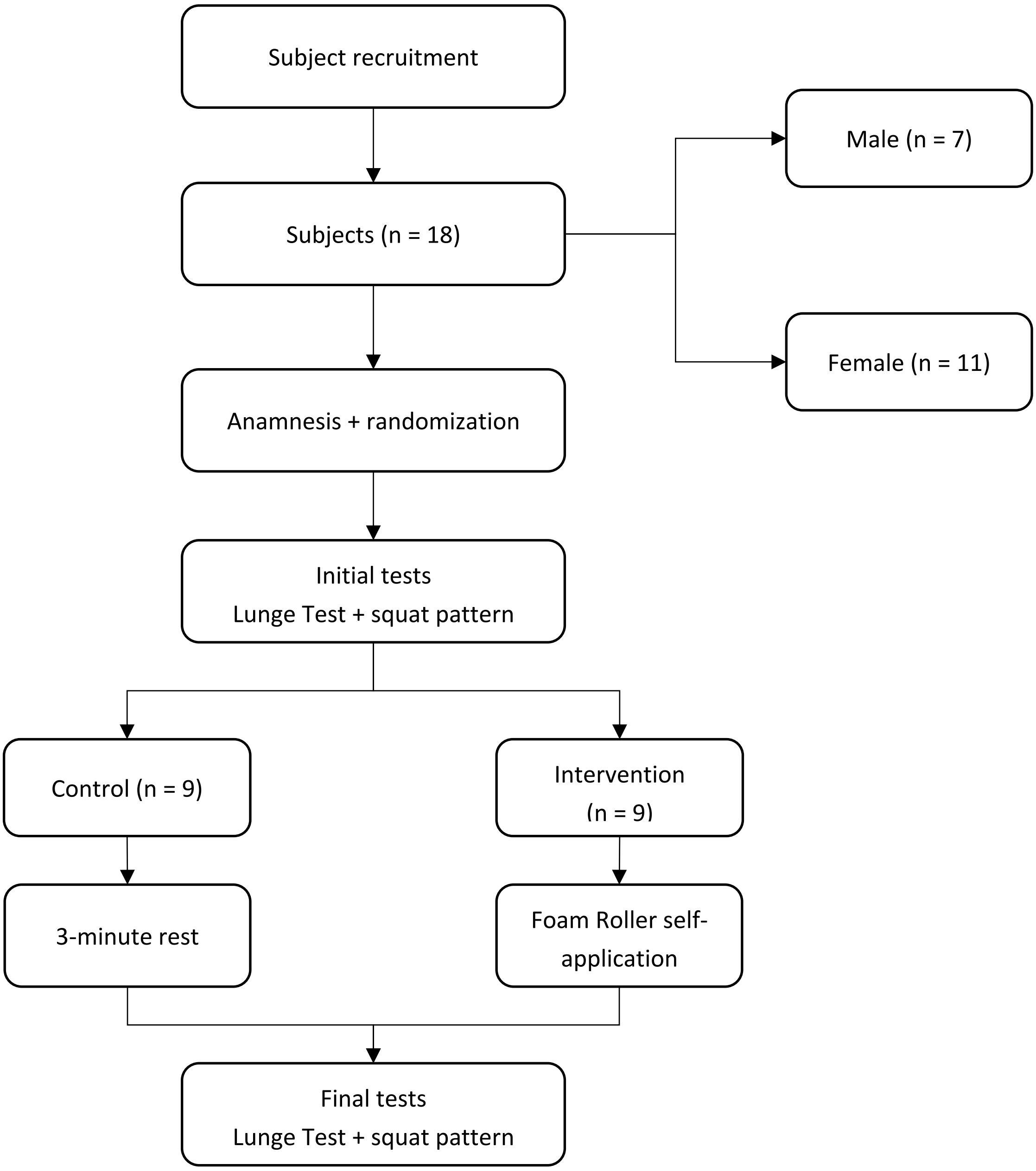

Figure 1. Design and flow of participants through the trial.

2.5. Interventions

After the first test battery, the participants of the intervention group were instructed to sit on the floor, position the roller in the sural triceps tendon of the dominant leg at first. The opposite lower limb remained with the foot firmly on the ground, knee and hip flexed, while the hands supporting the trunk were also on the ground and supporting the cyclic movements of the body forward and backward, in order to cause a FR motion across the sural triceps, using body weight associated with the cyclic motion to apply pressure (Figure 3). The application duration was of 90 seconds (three series of 30 seconds) bilaterally [24]. The roller model T141 by Acte Sports® (Shark Brasil S. A., São Paulo, Brazil) is a portable device with dense foam wrapped around a solid plastic cylinder. Once the FR self-application had ended, the participant returned to the testing stations.

The control group did not undergo the intervention, requiring a rest period between the application of the tests, with a time equivalent to the time of application of the myofascial technique (three minutes). Therefore, after the first battery of tests, they were directed to a room with a stopwatch and, after the stipulated time, the participant was directed again to the testing station to be reassessed.

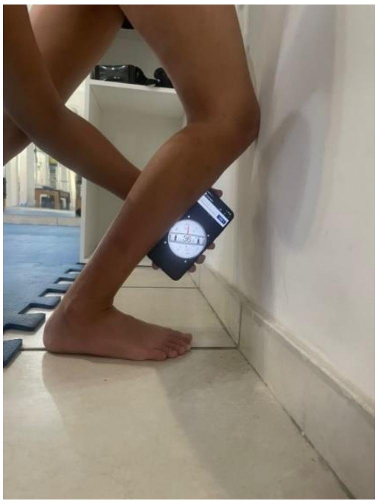

Figure 2. Lunge Test to measure the DF ROM of the ankle.

Figure 3. Self-applied myofascial release using Foam Roller.

2.6. Data analysis

Two-way analyses of variance (ANOVA), with one factor of repeated measures (pre- and post-intervention) and one independent factor (control and intervention groups) were used to compare the dependent variables of the study (DF ROM and the four variables of squat: ankle DF, dynamic knee valgus, knee flexion and trunk flexion) between groups and between pre- and post-intervention measures. The main effects of group, time (pre- and post-intervention) and the interaction "time x group" were tested. When a significant "time x group" interaction was observed, post-hoc analyses were performed to identify pairs where the difference was significant. Normality of the data was verified with Shapiro-Wilk test. A significance level of 0.05 was set in all analyses. All analyses were performed with SPSS Version 23.

3. Results

The ANOVA results of DF ROM assessed by the Lunge Test revealed a main effect of time and "time x group" interaction (p = 0.008 and p = 0.014, respectively), but there was no main group effect (p = 0.52). Post-hoc analyses identified that the DF ROM at the post-intervention assessment was significantly greater than the measure at the pre-intervention time only in the intervention group (p = 0.001). There was no difference between the pre and post measures in the control group (p = 0.85). Means and standard deviations of DF measurements for each group and time of assessment are shown in Figure 4.

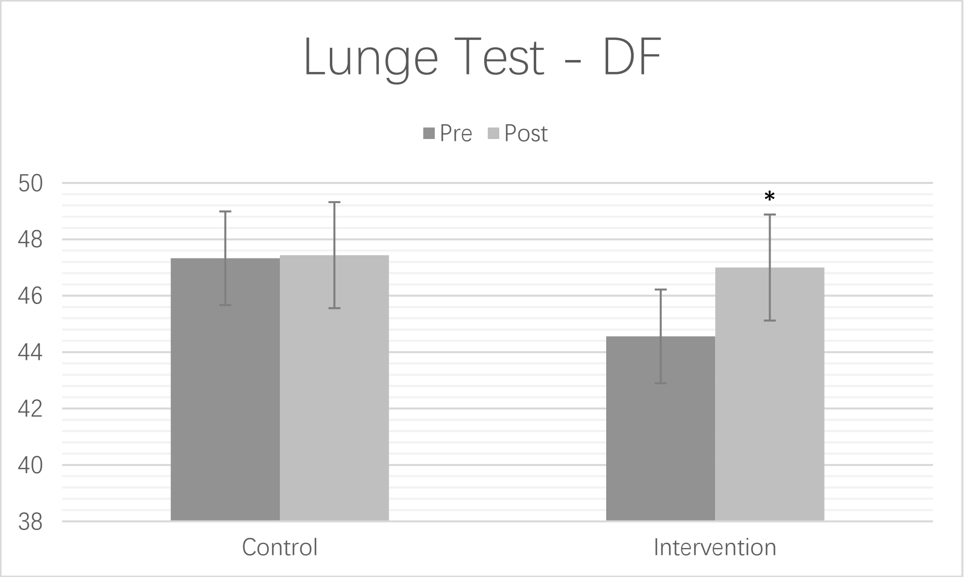

Figure 4. Means and standard deviations of DF measurements for each group.

When comparing the means of the DF angle in the squat pattern, significant effects were verified in the analysis by time (p = 0.001) and in the "time x group" interaction (p = 0.024). However, there was no significant difference between control and intervention groups (p = 0.581). Post-hoc analyses identified that only in the intervention group the DF angle during the squat in the post-intervention assessment was significantly greater than the measurement in the pre-intervention time (p = 0.001).

There was no difference between pre and post measurements in the control group (p = 0.165).

Table 2. Changes during the squat, pre and post intervention for control and intervention groups (means ± standard-deviation).

	Control		**Intervention**				
Movement	Pre	Post	Pre	Post	P (time)	P (group)	P (group x time)
Ankle Dorsiflexion (degress)	40.9 ± 7.2	43.2 ± 8.9	36.0 ± 7.5	44.0 ± 8.6	0.001*	0.581	0.024*
Dynamic Knee Valgus (degress)	16.0 ± 4.0	17.3 ± 3.8	15.0 ± 3.2	13.9 ± 1.8	0.844	0.146	0.043*
Knee flexion (degress)	80.7 ± 12.4	85.1 ± 13.5	86.3 ± 13.1	91.4 ± 13.3	0.001*	0.344	0.529
Trink inclination (degress)	89.2 ± 18.5	92.0 ± 17.2	86.2 ± 12.1	89.4 ± 13.9	0.044	0.344	0.873

ROM = range of motion; *statistically significant difference

In the analysis of dynamic knee valgus during the squat, there was no main effect of time (p = 0.844) or group (p = 0.146). A significant "time x group" interaction was observed (p = 0.043) and the post-hoc analyses identified that the dynamic valgus angle in the squat was significantly lower in the intervention group compared to the control group in the post-intervention evaluation (p = 0.025). There was no difference between groups in the pre-intervention assessment (p = 0.566).

When investigating the knee flexion angle while performing the squat, only the main effect of time was observed (p = 0.001), with an increase in the knee flexion angle in the post measurement, regardless of the group to which the volunteer belonged. However, no main group effect (p = 0.344) or "time x group" interaction (p = 0.529) was observed.

The results obtained when comparing the anterior trunk inclination angle in the squat pattern showed only the main effect of time (p = 0.044), with an increase in the trunk flexion angle in the post measurement, regardless of the group to which the volunteer belonged. There was no main group effect (p = 0.344) or "time x group" interaction (p = 0.873) (Table 2).

4. Discussion

Our purpose of this investigation was to verify the acute effects of self-applied myofascial release using the FR on the gastrocnemius and soleus muscles on ankle DF ROM and squatting pattern during the overhead squat. The results showed that there was an acute variation in the ROM of the DF after the myofascial release with the FR, with an increase of approximately 5% observed in the assessment using the Lunge Test. These findings are different from Smith et al. [25] and Škarabot, Beardsley and Stirn [26] but corroborate with the study by Aune et al. [27] who evaluated the effects of FR on DF ROM in 23 soccer players (11 women and 12 men) and obtained a significant increase in the Lunge

Test when assessing the effect of a single FR application 30 minutes after it was applied.

The overhead squat pattern is a screening method that comprehensively assesses the risk of injury associated with limited DF in closed kinetic chain [28]. In the present study, a 21% increase in the DF angle was observed, which is aligned with the findings of the study by Stanek, Sullivan and Davis [20] who analyzed the effects of a single session of a compressive myofascial technique (the Graston®) in active subjects, with positive results after the first analysis (30 minutes) in participants with DF restriction. Studies suggest an increase in fascial tissue perfusion and hydration, and an increase in the pain threshold due to changes in presynaptic transmission or alpha motor neuron excitability (reduced afferent excitability) during FR application, which are directly linked to increased ROM [16,17,29].

Another relevant result was obtained in the reduction of 17% of dynamic valgus during the squat in the intervention group compared to the control group. On the other hand, regarding the angle of anterior trunk flexion and knee flexion, no significant differences were found when comparing pre- and post-intervention measurements. In a cross-sectional study carried out with physically active adults, which compared the kinematics of the knee and ankle in dynamic tasks with and without ankle DF limitations, a relationship was verified between greater DF angles with a better performance in the execution of the overhead squat and the single-leg squat, with greater knee flexion angles (peak and excursion), in addition to greater varus displacement [30].

Previous studies indicate that an ankle DF ROM of less than 45º in a weight-bearing position can lead to unfavorable movement patterns and be a factor for several compensations in knee and hip movements. This DF ROM deficit may cause decrease in knee flexion (peak and excursion) and an impact in load absorption, also increasing ground reaction force and dynamic valgus [28,30,31]. In addition, an ankle mobility deficit in the sagittal plane results in increased soleus and decreased quadriceps activation during the eccentric squat moment, which implies changes in movement kinematics and static balance [32]. These compensations are risk factors for pathologies, such as patellar tendinopathy, calcaneal tendinopathy, chronic ankle instability, plantar fasciitis and anterior knee pain [31].

Nakamura et al. [19] assessed the local and non-local effects of FR on the passive properties of soft tissue and spinal excitability, and demonstrated that there is a variation in muscle activation in the execution of lower limb movements and an increase in joint ROM. This can be explained by the fact that myofascial techniques with FR promote changes in myofascial viscoelastic properties through tissue thixotropic mechanisms and also through neural factors [19]. From a physiological perspective, especially Ruffini corpuscles present in the superficial fascial tissue, which are known to be sensitive to tangential forces and stretching stimuli compatible with the slow application of FR, may explain reductions in tissue stiffness due to muscle relaxation, inhibiting the activity of the sympathetic nervous system [16,29]. In addition, this tissue has several mechanoreceptors and a sensory innervation that, when stimulated, promote the activation of the parasympathetic nervous system, altering the levels of serotonin, cortisol, endorphin and oxytocin, increasing muscle relaxation and decreasing perceived pain after the use of FR [16,17]. This may mean that the alterations observed in this study by the application of the FR are largely derived from neural mechanisms.

On the other hand, the sample participating in this research did not present DF ROM deficit prior to the study, with an average DF of 44.56° pre-intervention, which may explain the fact that no alterations were detected in the squatting pattern in 2D analysis [30]. The findings may also have been influenced by an insufficient application time of 90 seconds and only one area being treated. In a recent clinical trial, it was concluded that the time of two minutes of combined application of FR in two areas, produces more satisfactory results in increasing tissue temperature, blood flow and in reducing tissue stiffness, even though combinations of applications in variable dose-response conditions have cumulative effects on the results found in relation to ROM and movement pattern [29].

Regarding the heterogeneity of the sample in terms of age and gender, Nakamura et al. [19] found no significant differences in fascial tissue response between men and women, a meta-analysis by Wilke et al. [33] suggests that studies with only male samples do not report significant results compared to studies with female samples or with both sexes. Zugel et al. [12] suggest that there are meaningful sex-dependent differences in tissue composition and responses induced by mechanical stimulation. Furthermore, it is seen that myofascial tissues glide better and are less stiff in women [17]. Therefore, the effects of FR may have been different in each individual, directly affecting the results. New studies can be carried out using narrower age groups and a sample restricted to a group of the same gender and with more similar baseline physical characteristics.

4.1. Limitations

The heterogeneity of the sample related to age and gender and the small sample size may have limited the demonstration of an acute effect of the foam rolling on some squat pattern variables. The randomization of the sample did not guarantee the homogeneity between the groups, therefore the intervention group had more male participants. The fact that the control group had a larger number of women may have influenced the final value being close to the intervention group. Individual factors can also directly influence the results. Moreover, ROM effects by the FR intervention might depend on the time, muscle or the force/pressure used. Another point to consider is that biological tissues, after being submitted to repeated or continuous stress or load (creep and stress relaxation), respond with less resistance or stiffness and begin to allow more deformation [34]. Based on this, the repetition of the tests may have influenced the final result in both groups.

5. Conclusions

Myofascial release with FR on the sural triceps in ECP practitioners resulted in an acute effect on the DF ROM. FR also has an acute effect on the squat exercise, reducing dynamic valgus, but with no significant changes in knee anterior excursion and trunk anterior inclination. More studies are needed to understand the possible effects of FR on the musculoskeletal system and their immediate and long-term effects on sports practice, its systemic responses, a possible change in muscle morphology and how individual characteristics can influence the fascial system.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

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 paper. Redha Taiar is a guest editor for Mathematical Biosciences and Engineering and was not involved in the editorial review or the decision to publish this article. All authors declare that there are no competing interests.

References

1. J. G. Claudino, T. J. Gabbett, F. Bourgeois, H. de S. Souza, R. C. Miranda, B. Mezêncio, et al., CrossFit overview: Systematic review and meta-analysis, *Sports Med. Open*, **4** (2018), 1–14. https://doi.org/10.1186/s40798-018-0124-5
2. S. K. Bok, T. H. Lee, S. S. Lee, The effects of changes of ankle strength and range of motion according to aging on balance, *Ann. Rehabil. Med.*, **37** (2013), 10–16. https://doi.org/10.5535/arm.2013.37.1.10
3. C. M. Jones, P. C. Griffiths, S. D. Mellalieu, *Training load and fatigue marker associations with injury and illness: A systematic review of longitudinal studies*, *Sports Med.*, **47** (2017), 943–974. https://doi.org/10.1007/s40279-016-0619-5
4. R. Martínez-Gómez, P. L. Valenzuela, D. Barranco-Gil, S. Moral-González, A. García-González, A. Lucia, Full-Squat as a determinant of performance in crossfit, *Int. J. Sports Med.*, **40** (2019), 592–596. https://doi.org/10.1055/a-0960-9717
5. A. R.Mason-Mackay, C. Whatman, D. Reid, The effect of reduced ankle dorsiflexion on lower extremity mechanics during landing: A systematic review, *J. Sci. Med. Sports*, **20** (2017), 451–458. https://doi.org/10.1016/j.jsams.2015.06.006
6. S. Lorenzetti, M. Ostermann, F. Zeidler, P. Zimmer, L. Jentsch, R. List, et al., How to squat? effects of various stance widths foot placement angles and level, *BMC Sports Sci. Med. Rehabil.*, **10** (2018). https://doi.org/10.1186/s13102-018-0103-7
7. J. Bojsen-Møller, S. P. Magnusson, L. R. Rasmussen, M. Kjaer, P. Aagaard, Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures, *J. Appl. Physiol.*, **99** (2005), 986–994. https://doi.org/10.1152/japplphysiol.01305.2004
8. H. Maas, T. G. Sandercock, Force transmission between synergistic skeletal muscles through connective tissue linkages, *J. Biomed. Biotechnol.*, **2010** (2010). https://doi.org/10.1155/2010/575672
9. L. Mohr, L. Vogt, M. Behringer, J. Wilke, Myofascial force transmission between the ankle and the dorsal knee: A study protocol, *PLoS One*, **17** (2022), e0276240. https://doi.org/10.1371/journal.pone.0276240
10. L. R. Paulo, A. C. R. Lacerda, F. L. M. Martins, J. S. C. Fernandes, L. S. Vieira, C. Q. Guimarães, et al., Can a single trial of a thoracolumbar myofascial release technique reduce pain and disability in chronic low back pain? A randomized balanced crossover study, *J. Clin. Med.*, **10** (2021), 2006. https://doi.org/10.3390/jcm10092006

11. R. Schleip, D. G. Müller, Training principles for fascial connective tissues: Scientific foundation and suggested practical applications, *J. Bodyw. Mov. Ther.*, **17** (2013), 103–115. https://doi.org/10.1016/j.jbmt.2012.06.007
12. M. Zügel, C. N. Maganaris, J. Wilke, K. Jurkat-Rott, W. Klingler, S. C. Wearing, et al., Fascial tissue research in sports medicine: From molecules to tissue adaptation, injury and diagnostics: Consensus statement, *Br. J. Sports Med.*, **52** (2018), 1497. https://doi.org/10.1136/bjsports-2018-099308
13. M. Bernabei, H. Maas, J. H. van Dieën, A lumped stiffness model of intermuscular and extramuscular myofascial pathways of force transmission, *Biomech. Model. Mechanobiol.*, **15** (2016), 1747–1763. https://doi.org/10.1007/s10237-016-0795-0
14. N. Ikeda, S. Otsuka, Y. Kawanishi, Y. Kawakami, Effects of Instrument-assisted Soft Tissue Mobilization on Musculoskeletal Properties, *Med. Sci. Sports Exercise*, **51** (2019), 2166–2172. https://doi.org/10.1249/MSS.0000000000002035
15. S. W. Cheatham, M. J. Kolber, M. Cain, M. Lee, The effects of self-myofascial release using a foam roll or roller massager on joint range of motion, muscle recovery, and performance: A systematic review, *Int. J. Sports Phys. Ther.*, **10** (2015), 827–838.
16. D. G. Behm, J. Wilke, Do self-myofascial release devices release myofascia? Rolling mechanisms: A narrative review, *Sports Med.*, **49** (2019), 1173–1181. https://doi.org/10.1007/s40279-019-01149-y
17. J. Wilke, A. L. Müller, F. Giesche, G. Power, H. Ahmedi, D. G. Behm, Acute effects of foam rolling on range of motion in healthy adults: A systematic review with multilevel meta-analysis, *Sports Med.*, **50** (2020), 387–402. https://doi.org/10.1007/s40279-019-01205-7
18. C. B. Seffrin, N. M. Cattano, M. A. Reed, A. M. Gardiner-Shires, Instrument-assisted soft tissue mobilization: A systematic review and effect-size analysis, *J. Athl. Train.*, **54** (2019), 808–821. https://doi.org/10.4085/1062-6050-481-17
19. M. Nakamura, A. Konrad, R. Kiyono, S. Sato, R. Yoshida, K. Yasaka, et al., Local and non-local effects of foam rolling on passive soft tissue properties and spinal excitability, *Front. Physiol.*, **12** (2021). https://doi.org/10.3389/fphys.2021.702042
20. J. Stanek, T. Sullivan, S. Davis, Comparison of compressive myofascial release and the graston technique for improving ankle-dorsiflexion range of motion, *J. Athl. Train.*, **53** (2018), 160–167. https://doi.org/10.4085/1062-6050-386-16
21. S. L. Vohralik, A. R. Bowen, J. Burns, C. E. Hiller, E. J. Nightingale, Reliability and validity of a smartphone app to measure joint range, *Am. J. Phys. Med. Rehabil.*, **94** (2015), 325–330. https://doi.org/10.1097/PHM.0000000000000221
22. K. Bennell, R. Talbot, H. Wajswelner, W. Techovanich, D. Kelly, Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion, *Aust. J. Physiother.*, **44** (1998), 175–180. https://doi.org/10.1016/S0004-9514(14)60377-9
23. C. Venturini, N. Ituassú, L. Teixeira, C. Deus, Confiabilidade intra e interexaminadores de dois métodos de medida da amplitude ativa de dorsiflexão do tornozelo em indivíduos saudáveis, *Rev. Bras. Fisioter.*, **10** (2006), 407–411. https://doi.org/10.1590/S1413-35552006000400008
24. G. A. Hughes, L. M. Ramer, Duration of myofascial rolling for optimal recovery, range of motion, and performance: a systematic review of the literature, *Int. J. Sports Phys. Ther.*, **14** (2019), 845–859. https://doi.org/10.26603/ijspt20190845

25. J. C. Smith, B. R. Washell, M. F. Aini, S. Brown, M. C. Hall, Effects of static stretching and foam rolling on ankle dorsiflexion range of motion, *Med. Sci. Sports Exerc.*, **51** (2019), 1752–1758. https://doi.org/10.1249/MSS.0000000000001964
26. J. Škarabot, C. Beardsley, I. Štirn, Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes, *Int. J. Sports Phys. Ther.*, **10** (2015), 203–212.
27. A. G. A. Aune, C. Bishop, A. N. Turner, K. Papadopoulos, S. Budd, M. Richardson, et al., Acute and chronic effects of foam rolling vs eccentric exercise on ROM and force output of the plantar flexors, *J. Sports Sci.*, **37** (2019), 138–145. https://doi.org/10.1080/02640414.2018.1486000
28. A. Rabin, S. Portnoy, Z. Kozol, The association of ankle dorsiflexion range of motion with hip and knee kinematics during the lateral step-down test, *J. Orthop. Sports Phys. Ther.*, **46** (2016), 1002–1009. https://doi.org/10.2519/jospt.2016.6621
29. J. Schroeder, J. Wilke, K. Hollander, Effects of foam rolling duration on tissue stiffness and perfusion: A randomized cross-over trial, *J. Sports Sci. Med.*, **20** (2021), 626–634. https://doi.org/10.52082/jssm.2021.626
30. K. E. Dill, R. L. Begalle, B. S. Frank, S. M. Zinder, D. A. Padua, Altered knee and ankle kinematics during squatting in those with limited weight-bearing-lunge ankle-dorsiflexion range of motion, *J. Athl. Train.*, **49** (2014), 723–732. https://doi.org/10.4085/1062-6050-49.3.29
31. C. M. Fong, J. T. Blackburn, M. F. Norcross, M. McGrath, D. A. Padua, Ankle-dorsiflexion range of motion and landing biomechanics, *J. Athl. Train.*, **46** (2011), 5–10. https://doi.org/10.4085/1062-6050-46.1.5
32. E. Macrum, D. R. Bell, M. Boling, M. Lewek, D. Padua, Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat, *J. Sports Rehabil.*, **21 (**2012), 144–150. https://doi.org/10.1123/jsr.21.2.144
33. J. Wilke, H. Debelle, S. Tenberg, A. Dilley, C. Maganaris, Ankle motion is associated with soft tissue displacement in the dorsal thigh: An *in vivo* investigation suggesting myofascial force transmission across the knee joint, *Front. Physiol.*, **11** (2020). https://doi.org/10.3389/fphys.2020.00180
34. C. F. Aquino, S. O. Viana, S. T. Fonseca, Comportamento biomecânico e resposta dos tecidos biológicos ao estresse e à imobilização, *Fisioter em Mov.*, **18** (2005), 35–43.