Original article

Effects of the use of foam rollers by high-performance athletes on range of motion, flexibility, strength and delayed onset muscle soreness

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Summary

Introduction: The Foam Roller (FR) is a self-induced myofascial release instrument to apply pressure directly on the target musculature. FR is widely used by athletes as a self-massage tool.
Objective: We evaluate the current evidence on the impact of FR on the musculoskeletal system in athletes, trying to identify the mechanisms that influence myofascial tissues.
Material and method: Based on the Preferred Reporting Item Guidelines for Systematic Reviews and Meta-Analyses (PRISMA), we systematically reviewed studies indexed in Web of Science, Cochrane, and PubMed to evaluate the effects of FR on joint range of motion (ROM), flexibility, strength, and delayed onset muscle soreness (DOMS) in high-performance athletes. Original articles published from 2018 through September 30, 2022, with controlled trial or pre-post intervention design, in which the FR intervention was compared to a control group, were included. The PEDro scale was used to assess methodological quality.
Results: Among the 141 records identified in the search, a total of 10 studies met the inclusion and exclusion criteria. In general, the use of FR, in high performance athletes, showed significant improvements on ROM and flexibility, and markedly beneficial effects on DOMS and strength, with no adverse effects on myofascial tissue. FR may act by improving myofascial tissue architecture, attenuating the inflammatory and nociceptive effect.
Conclusion: The use of FR seems to be safe; it is an effective tool for the improvement of the physical qualities of mobility, strength, and flexibility, and to decrease DOMS and increase sports performance.

Key words:
Foam roller. Myofascial induction. Flexibility. Range of motion. Strength. DOMS.

Efectos del rodillo de espuma o *foam roller* sobre el rango de movimiento, la flexibilidad, la fuerza y el dolor muscular de inicio retardado en deportistas de alto rendimiento

Resumen

Introducción: El rodillo de espuma o *Foam Roller (FR)* es un instrumento de liberación miofascial autoinducida, para aplicar presión de forma directa sobre la musculatura diana. *FR* es ampliamente empelado por deportistas como herramienta de auto-masaje.
Objetivo: Evaluar la evidencia actual sobre el impacto del *FR*, sobre el sistema musculoesquelético, en deportistas, tratando de identificar los mecanismos que influyen sobre los tejidos miofasciales.
Material y método: Basándonos en las directrices de los Elementos de Información Preferidos para Revisiones Sistemáticas y Metaanálisis (PRISMA), revisamos sistemáticamente estudios indexados en Web of Science, Cochrane y PubMed, para evaluar los efectos del *FR* en el rango articular de movimiento (ROM), la flexibilidad, la fuerza y el dolor muscular de inicio retardado (DOMS) en deportistas de alto rendimiento. Se incluyeron artículos originales publicados desde el 2018 hasta el 30 de septiembre de 2022, con diseño de ensayo controlado o pre-post intervención, en los que se comparó la intervención de *FR* con un grupo control. Se utilizó la escala PEDro para evaluar de la calidad metodológica.
Resultados: Entre los 141 registros identificados en la búsqueda, un total de 10 estudios cumplieron los criterios de inclusión y exclusión. En general, el uso de *FR*, en los deportistas de alto rendimiento, mostró mejoras significativas sobre el ROM y flexibilidad, y efectos notablemente beneficiosos sobre el DOMS y la fuerza, sin efectos adversos en el tejido miofascial. El *FR* puede actuar mejorando la arquitectura tisular miofascial, atenuando el efecto inflamatorio y nociceptivo.
Conclusión: El uso *FR*, parece seguro, es un instrumento efectivo para la mejora de las cualidades físicas de movilidad, fuerza y flexibilidad, y disminuir el DOMS incrementando del rendimiento deportivo.

Palabras clave:
Rodillo de espuma. Inducción miofascial. Flexibilidad. Rango de movimiento. Fuerza. DOMS.

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Introduction

Optimal musculoskeletal recovery is the key factor that will permit an athlete to train day after day and to assimilate the training loads with guarantees of increased performance[1]. Good musculoskeletal health is achieved by motivating the athlete to train flexibility, strength and maintenance of a correct Range of Motion (ROM) in a way that is functional and specific to the sport practised[2]. However, the more demanding physical training periods put the athlete at the limit of muscle dysfunction and sub-clinical pain[3]. Musculoskeletal alterations are progressively established and the athlete exhibits muscle stiffness, restriction and alteration of motion[4], conditioning their physical and sports activity. However, training loads are necessary in order to increase athletic performance[5] and they are associated with homeostatic biological processes of adaptation that not only include muscle tissue remodelling processes[6], but also affect the viscoelastic properties of the myofascial tissue, modifying its mechanical qualities[7]. In order to address the muscle and fascial disorders induced by the psycho-physical stresses resulting from strenuous, intense exercise, and to recover adequately, athletes use prevention, treatment and re-adaptation processes. These techniques promote the restoration of the musculoskeletal mechanical and physiological performance[1]. In the context of this entire process, intervention on the myofascial tissue could potentially permit the tolerance of intense athletic activity by modulating muscle adaptation[7].

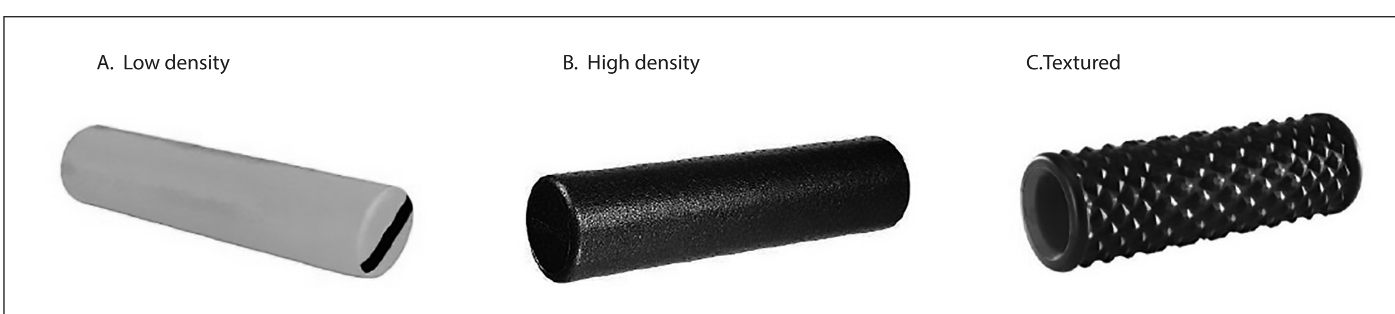
The Foam Roller (FR) (Figure 1) is a device that makes it possible to implement self-myofascial release, a technique by which the athlete can use the FR to directly self-apply pressure on the targeted musculature[8]. An FR is either a hollow or solid core cylinder covered in foam, available in different sizes and densities (Table 1). The FR allows the user to apply pressure, which is directly dependent on body weight, and to roll it over the target musculature to be treated, considering that direct pressure can change the viscoelastic properties of the myofascial tissue[9]. The FR is currently a device that is widely-used as a simulation therapy for myofascial release by elite and recreational athletes, although since the nineteen-eighties it has also been used as a self-massage tool[10].

It has been reported that the use of FR permits certain improvements in physically active, healthy adults with regard to flexibility[11,12], Delayed Onset Muscle Soreness (DOMS)[13,14], and ROM[15], although the gains in muscle strength were more limited following self-applied FR treatment[16]. However, elite athletes demand levels of mobility, strength and flexibility which, on occasions, exceed natural human capacity, and are determining physical factors on performance. The potential improvements on these physical capacities and DOMS could be

Table 1 Characteristics and recommendations for use of the different types of Foam Roller.

Types of *Foam Rollers*	Characteristics and recommendations for use
Low density	- Lightweight and soft contact with the body. Possible to use without feeling very intense pressure. - Recommended application in muscle areas with great muscle stiffness, delicate or painful areas. - For muscle groups such as those on the lateral thigh (vastus lateralis and tensor fasciae latae), the back, avoiding pressing down on the vertebral apophysis.
Firm density	- Hard contact with the body, and may even be painful due to the high pressure. - Application recommended for rapid recovery, given that it produces a very deep massage with a more effective muscle release, making it equivalent to days of recovery and specific masotherapy sessions. - For muscle groups that are more difficult to massage and requiring depth, such as the soleus muscles, hamstrings and/or the anterior tibialis.
Textured	- Featuring moderate ridges and knobs that distribute the pressure exerted over the FR. They are quite pleasant to use given that they have an intermediate density. - Application recommended for daily use in training sessions due to their low weight and small size. - They make it possible to release the fascial tissue and, specifically, to work on specific trigger points.

Figure 1. Foam roller



related to the changes in the stiffness of the muscle tissue and on its morphological structures[17,18]. Unfortunately, to date, the use of FR has been insufficiently studied and/or there is no critical review of the literature on the effects of the FR on high-performance athletes. Therefore, this study aimed to conduct a systematic review of the effects of the FR on the musculoskeletal system, ROM, flexibility, strength and DOMS, of highly-trained athletes, trying to identify the mechanisms that exert an influence on the myofascial tissues. We used the PICO model in accordance with the standard methods proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[19] as follows: Population: healthy male adults, competitive athletes or highly-trained; Intervention: self-myofascial release through the FR; Comparison: control/placebo group or group of before/after comparative data; Results: ROM, flexibility, strength and DOMS. The study followed the recommendations for the ethical publication of systematic reviews proposed by Wager and Wiffen[20] and the review protocol is published in the Prospective Register of Systematic Reviews (PROSPERO); reference CRD CRD42022367950.

Material and method

Search strategy

For the selection of articles, a structured search was conducted using the following electronic databases: M*edline (PubMed), Scopus, Cochrane and Web of Science (WOS)* for studies published from 2018 onwards up to 30 September 2022. The search strategy contained a combination of *Medical Subject Headings (MeSH)* and free words for related key concepts which included: *("foam rolling" OR "self-myofascial release" OR "roller massage" OR "foam roller") AND ("range of motion" OR "ROM" OR "flexibility) AND ("strength" OR "muscle strength") AND ("DOMS" OR "Delayed Onset Muscle Soreness") AND ("athletes" OR "elite athletes" OR" "high performance athletes" OR "high trained athletes") AND ("warm up OR "pre-exercise" OR "post-exercise".* Two authors (D.F.L. and C.I.F.-L.) independently performed the search of the studies published while a third reviewer (J.S.-C.) resolved any disagreements on the records. All the studies obtained in the 3 databases were compared in order to delimit the search as far as possible and to avoid the repetition of studies. A review was made of all the meta-analyses and systematic reviews existing in order to avoid a loss of studies due to the absence of search terms.

Selection of articles: inclusion criteria

For the selection of studies, we established the following inclusion criteria: a) healthy adults, elite or high-performance athletes, with no acute and/or chronic pathologies (excluding studies made on animals and *in vitro*); b) isolated use of the FR device, before, during or after exercise; c) original records with random and non-random trials, controlled double-blind or parallel design (not considering reviews, meta-analyses, editorials and non-original studies); d) studies that assess the relationship between the use of the FR for myofascial release and the physical factors (ROM, flexibility, strength and DOMS) either as the primary outcome of the study or secondary outcomes; e) studies with clear information on the intervention with FR, total duration of the myofascial treatment, precise moment of the intervention and the muscle area to which is was applied; f) documents published from 2018 onwards up to 30 September 2022; g) studies ≥6 points on the methodological quality scale of the *Physiotherapy Evidence Database* (PEDro)[21]. Any studies not meeting these criteria were excluded.

Data extraction and synthesis

The following information was extracted from each study included in the systematic review: the name of the first author, year of publication; country in which the study was conducted; study design; sample size; sex and age of the participants; height; body weight; intervention of FR, that is: duration, moment of the intervention, area of application; parameters analysed; and final outcomes. Two investigators (D.F.L. and C.I.F.-L.) performed the data extraction process using a spreadsheet. In the event of disagreements relating to the data extraction, a third reviewer author (J.S.-C.) took part in the process.

Evaluation of the methodological quality

The evaluation of the methodological quality of the records selected was conducted using PEDro[21]. The aim of this evaluation was to exclude any studies with poor methodology.

Results

Selection of studies

A total of 141 studies were identified, 134 studies came from 3 electronic databases, Cochrane, SCOPUS and PubMed, and 7 came from additional sources such as ResearchGate (n = 2) and reference lists of relevant studies (n = 5). Following the exclusion of 44 duplicates, a total of 90 articles identified in databases were examined. Following the assessment of the title and abstract, 31 articles were considered to be potential records. Following a review of the complete text and the assessment of the potential database records, 1022-31 studies were included in the systematic review (Figure 2).

Assessment of the methodological quality

Once the articles had been selected, their methodological quality was assessed using the PEDro scale[21]. With regard to the 10 studies included[22-31], 1 study 24 was rated as excellent while the methodological quality of the other 9 studies[22,23,25-31] was rated as good. Items number 5 and 6 were the least met, referring to the masking of the participant and the masking of the therapist, respectively (Table 2).

Characteristics of the participants and interventions

The characteristics of the participants are shown in Table 3. The total number of volunteers was 215 (111 men and 84 women), although one

Figure 2. Flow diagram showing the processes for the identification and selection of relevant studies based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

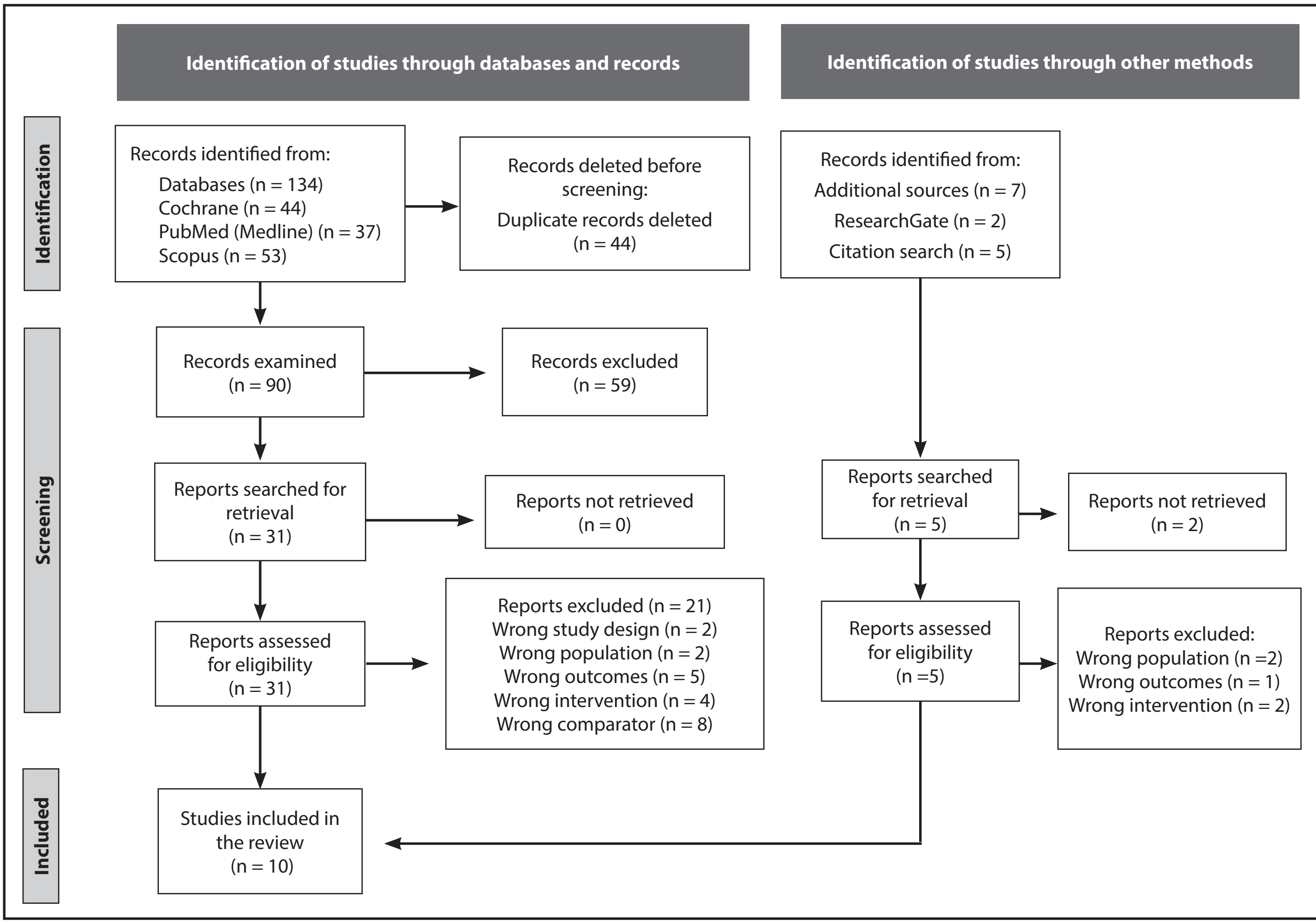


Table 2. PEDro scale for the assessment of the methodological quality.

Reference	Items											T_E	Quality
	1	2	3	4	5	6	7	8	9	10	11		
Lopez-Samanes *et al.*, 2021[29]	1	1	0	1	0	0	0	1	1	1	1	7	B
Maniatakis *et al.*, 2020[26]	1	1	0	1	0	0	1	1	1	1	1	8	B
Oranchuk *et al.*, 2019[25]	0	1	1	1	0	0	1	1	1	1	1	8	B
Rey *et al.*, 2017[27]	1	1	0	1	0	0	0	1	1	1	1	8	B
Richman *et al.*, 2018[31]	0	1	0	1	0	0	0	1	1	1	1	6	B
Romero *et al.*, 2019[24]	1	1	1	1	1	0	1	1	1	1	1	10	E
Scudamore *et al.*, 2021[23]	1	1	0	1	0	0	0	1	1	1	1	7	B
Siebert *et al.*, 2020[28]	1	1	0	1	0	0	0	1	1	1	1	7	B
Souza *et al.*, 2020[30]	1	1	0	1	0	0	0	1	1	1	1	7	B
Sulowska-Daszyk *et al.*, 2022[22]	1	1	1	1	0	0	0	1	1	1	1	8	B

Abbreviations: TE: Total items met per study: E: Excellent; G: Good; 1: Criterion met; 0: Criterion not met.

study did not specify the sex of its 20 subjects[23], all are healthy athletes (with no chronic conditions that would prevent the intensive practice of sport) with a high training level. The studies included high-performance athletes practising athletics[22,24] basketball[26,28,31], volleyball[25,28,31], tennis[28,29], football[27,28], lacrosse[25] and military competitions[23]. 7 studies were based on the intervention with the FR used in the pre-exercise warm-up[2,24,26,28-31], 2 studies used it in the post-training cool-down[23,27] and only Oranchuk *et al*.[25] used it between exercise sessions. The muscle groups targeted with the FR were mainly the lower extremities (LE), primarily the hamstrings, quadriceps, gluteals and gastrocnemius[22-25,27-31], and in the study made by Maniatakis *et al*.[26] on volleyball players, the FR was used in 3 areas of the shoulder. None of the studies included in this systematic review reported the density, length and texture of the FR[22-31]. No adverse effects resulting from the use of the FR were reported[22-31].

Evaluation of the outcomes

Table 3 summarises the outcomes of the studies included in this systematic review.

Range of Motion (ROM)

In the 5 studies measuring the ROM[24-26,28,29] and included in this review, significant improvements (P <0.05) were observed in the intervention group (IG) after the use of the FR for the muscle groups assessed: passive dominant leg raise (hip test))[25,29], shoulder external rotation and flexion[26], ankle dorsiflexion, hip extension and knee flexion 24 and flexion of the longitudinal section of the hip[28]. However, only the ROM significantly improved (P <0.05) in the longitudinal section of the hip extensors (femoral biceps and semitendinosus)[28] and in the knee flexion[24] when compared to the condition with no use of the FR. Furthermore, Romero *et al.*[24] found no significant differences (P >0.05) in the proprioceptive capacity of the knee joint.

Flexibility

Three of the studies included in the systematic review[22,27,31], assessed muscle flexibility following application of the FR. Two studies[27,31] used the Sit and Reach test and reported significant increases (P <0.05) in the IG. When the IG was compared with the control group (CG), flexibility only improved significantly in football players[27] and no changes were observed in basketball players[31]. Sulowska-Daszyk *et al.*[22] reported a significant increase (P <0.05) in the flexibility of the tensor fasciae latae muscles, and substantial non-significant increases (P >0.05) in the piriformis and adductor muscles in the IG following use of the FR. However, the flexibility in the IG was significantly lower (P <0.05) in the iliopsoas and rectus femoris muscles compared to the control group and for the iliopsoas from the start up to the end of the FR treatment.

Table 3. Studies included, interventions, description of the volunteers, parameters evaluated and outcomes reported.

First author, year of publication, country	Type of study	Participants (size and characteristics of the initial sample, excluded and size of the final group sample)	Intervention	Parameters evaluated	Outcomes
López-Samanes *et al.,* 2021, Spain[29]	Rando-mised crossover	9 ♂ professional women tennis players ATP ranking Age (mean ± SD): 20.64 ± 3.56 years Height (mean ± SD): 1.83 ± 0.05 metres Weight (mean ± SD): 75.55 ± 5.03 kg IG (n = 9): warm-up + TMT with FR CG (n = 9): warm-up + TMT with DE With no loss of participants	FR rolling massage on muscle groups: - Quadriceps - Hamstrings - Gluteals - Calves. 8 mins: 60 s x muscle group x each LE Warm-up	ROM hip test; - PSLR, DL - PSLR, NDL - TT, DL - T, NDL attempts maximum x test; 20 s rest between attempts Measurement inclinometer (º)	IG vs CG ↔ ROM hip test: PSLR & TT (NDL / DL) IG: Changes from baseline ↑^ EPSLR, DL ↔^ PSLR, NDL ↔ TT, DL ↔TT, NDL
Maniatakis *et al.,* 2020, Greece[26]	Piloto pre / post test	15 ♂ elite volleyball players Greek 1st division and competition in Europe Age (mean ± SD): 24 ± 4.54 years Height (mean ± SD): 177 ± 0.08 cm Weight (mean ± SD): 81 ± 7.71 kg The 15 players are treated simultaneously. Comparison with the baseline (pre / post- test)	FR self-mobilizations 3 areas of shoulder: - Anterior - Lateral - Posterior for 10 mins: 3 rep x 60 s x part of shoulder Rest x 20 s x part of shoulder Warm-up	ROM (º): - Flexion - IR - ER Both UE were measured, and the mean was calculated Measured with goniometer (º)	IG vs Changes from baseline ↑* Flexion ↑ IR ↑* ER

(continues)

Table 3. Studies included, interventions, description of the volunteers, parameters evaluated and outcomes reported (continued).

First author, year of publication, country	Type of study	Participants (size and characteristics of the initial sample, excluded and size of the final group sample)	Intervention	Parameters evaluated	Outcomes
Oranchuk *et al.*, 2019, United States[25]	Cross-over, randomized single blind	11 ♀ Lacrosse players + 11 ♀ basketball players. Competition NCAA II Age (mean ± SD): 19.4 ± 1.7 years; height (mean ± SD): 164.8 ± 9.2 cm Weight (mean ± SD): 61.4 ± 8.9 kg IG: TMT with FR CG: Passive rest	*FR* rolling massage on muscle group: - Hamstrings 3 sets x 1 min; 30 s rest between sets Between training sessions	Acute flexibility hamstrings using ROM in the hip flexion (º) Assessed with PSLR test using goniometer (º)	IG vs CG ↑ PSLR IG: Changes from baseline ↑* PSLR ↑*Δ % change: 7.3% +
Rey *et al.*, 2017, Spain[27]	Randomised control	18 ♂ football players. Professional Football League (1st and 2nd division) Experience 14.8 ± 2.6 years Age (mean ± SD): 26.6 ± 3.7 years; height (mean ± SD): 180.5 ± 4.55 cm Weight (mean ± SD): 75.8 ± 4.7 kg Body fat (mean ± SD): 10.2 ± 0.8% 1 x RM squat: 156.7 ± 24.9 kg VO_2 maximum: 61.2 ± 4.2 ml/kg/min CG (n = 9) 20 mins seated IG (n = 9): *FR* 20 mins	*FR* rolling massage on muscle group: - Quadriceps - Hamstrings - Adductors - Gluteals - Calves 2 rep of 45 s x muscle group x each LE 15 s rest On both legs After training	Flexibility - Lumbar spine - Hamstrings (Sit & Reach test" (cm) DOMS: - TQR - VAS	IG vs CG Flexibility ↑ Sit & Reach test DOMS: ↑ TQR ↓ VAS IG: Changes from baseline Flexibility: ↑* Sit & Reach test ↑*Δ % change: 18.79% + DOMS: ↑ TQR ↓ VAS
Richman *et al.*, 2018, United States[31]	Randomised crossover	14 ♀ n = 8 volleyball players + n = 6 basketball players. Competition NCAA II Age (mean ± SD): 19.8 ± 1.3 years; height (mean ± SD): 172 ± 24 cm Weight (mean ± SD): 69.3 ± 10.9 kg IG (n = 7) TMT with *FR* + DE CG (n = 7): light aerobic foot running + DE	*FR* rolling massage at constant pressure on muscle groups - Hip flexors - Quadriceps - Adductors - TFL - Gluteals - Hamstrings - Plantarflexors - Dorsiflexors 6 mins: 30 s x muscle group on each LE Warm-up	Flexibility (Sit & reach test (cm)) 3 times T1, T2, T3	IG vs CG ↔ T2 ↔ T3 IG: Changes from baseline ↑* T1 vs. T2 ↑* T1 vs. T3 ↑ T2 vs. T3
Romero *et al.*, 2019, Spain[24]	Randomised control	30 athletes; ♂ n = 18; ♀ n = 12 IG (n = 15; 8♂, 7♀): TMT with *FR* + aerobic foot running Age (mean ± SD): 24.2 ± 4.2 years; height (mean ± SD): 177.0 ± 7.0 cm Weight (mean ± SD): 70.1 ± 14.2 kg CG (n = 15; 10♂, 5♀): Aerobic foot running Age (mean ± SD): 25.0 ± 4.7 years; height (mean ± SD): 175.0 ± 8.0 cm Weight (mean ± SD): 67.5 ± 5.6 kg	*FR* rolling massage on muscles: - Anterior muscle - Posterior muscle - Gastrocnemius 6 mins: 45 s x muscle x each LE 15 s rest between each LE Warm-up	ROM Ankle: Dorsiflexion: Knee Extension / Flexion Hip: Extension Measured with inclinometer (º) Proprioception: Knee AAE, RAE, VAE 10 minutes later	IG vs CG ROM Ankle: ↑ Dorsiflexion: Knee: ↑ Extension / ↑* Hip Flexion: ↑ Extensión Proprioception: Knee ↔ (AAE, RAE, VAE) GI: changes from baseline ROM: Ankle: ↑* Dorsiflexion Knee: ↑ Extension / ↑* Flexion Hip: ↑* Extension Proprioception: Knee ↔ (AAE, RAE, VAE)

(continues)

Table 3. Studies included, interventions, description of the volunteers, parameters evaluated and outcomes reported (continued).

First author, year of publication, country	Type of study	Participants (size and characteristics of the initial sample, excluded and size of the final group sample)	Intervention	Parameters evaluated	Outcomes
Scudamore, *et al*., 2021, United States[23]	Rando-mised crossover	20 soldiers ♂and ♀ CMilitary resistance competitions ≥1 year Age (mean ± SD): 23.6 ± 4.1 years; height (mean ± SD): 176.4 ± 5.6 cm Weight (mean ± SD): 84.7 ± 13.4 kg IG: *FR* CG: passive in seated position	*FR* mrolling massage on muscle groups: - Gluteals - Hamstrings - Iliotibial band - Quadriceps - Adductors 20 mins: 45 s x 2 x muscle group for each LE; 15 s rest between LE After training	DOMS DOMS-inducing exercise protocol (DIP) 10 x 10 squats# 60% 1*RM #squat 5 s eccentric 1 s pause 2 2s concentric 1 s pause DOMS ratio (DR) (CR-11)	IG vs CG ↓ DOMS IG: Changes from baseline ↔ DOMS
Siebert *et al*., 2020, Germany[28]	Rando-mised crossover	14 ♂ athletes (tennis, swimming, gymnastics, basketball) national training level ≥3 days x week Age (mean ± SD): 23.7 ± 1.3 years Height (mean ± SD 182 ± 8 cm Weight (mean ± SD): 79.4 ± 6.9 kg IG: FR on bench CG: passive in seated position	Position of athlete seated on bench with horizontal rolling movement of FR on muscles - Biceps femoris - Semitendinosus 6 mins: 10 / 12 complete passes on hamstring x 30 s each Warm-up	Hip flexion ROM measured in sagittal plane with subjects lying in a lateral position Surface (EMG) of 2 representative hip extensors (biceps femoris and semitendinosus)	IG vs CG ↑* ROM longitudinal section ↔ ROM transverse section IG: Changes from baseline ↑* ROM longitudinal section ↔ ROM transverse section
Souza *et al.,* 2020, Brazil[30]	Randomi-sed control	14♀ female professional footballers 1st division, Esporte Club Vitoria IG (n = 7) FR + specific warm-up Age (mean ± SD): 22.3 ± 2.3 years; height (mean ± SD): 170 ± 0.1cm Weight (mean ± SD): 64 ± 10 kg CG (n = 7): football-specific warm-up Age (mean ± SD): 28.8 ± 4.3 years; Height (mean ± SD): 170 ± 0.1cm Weight (mean ± SD): 62 ± 7.6 kg	*FR* rolling massage on muscle groups: - Quadriceps - Hamstrings - Sural triceps 2 weeks TMT: 3 x week. 3 sets x 1 min x muscle; 30 s rest between muscles Warm-up	MS Peak torque of Extension on: - NDL - DL Flexion on: - NDL - DL Angular speed 60º/s.	IG vs CG Extension ↑ NDL ↑ DL Flexion ↑ NDL ↑ DL IG: Changes from baseline Extension ↔ NDL ↔ DL Flexion ↔ NDL ↔ DL
Sulowska-Daszyk *et al*., 2022, Poland[22]	Randomi-sed control	62 ♂ and ♀ Long-distance runners competing at national level IG (n = 30) (n = 18 ♂; n = 12 ♀): *FR* Age (mean ± SD): 34.09 ± 7.73 years Height (mean ± SD): 175.81 ± 8.73 cm Weight (mean ± SD): 69.88 ± 9.55 kg IG (n = 32) (n = 22 ♂; n = 10 ♀): passive in seated position Age (mean ± SD): 33.46 ± 7.33 years Height (mean ± SD): 177.60 ± 7.63 cm Weight (mean ± SD): 70.70 ± 8.79 kg	*FR* balance massage on muscle groups: - Hamstrings - Major gluteal - Hip Adductors - Quadriceps - TFL - Gastrocnemius On both LE: 2 mins x muscle group 2.5 cm/s, 10 x muscle Warm-up	Flexibility - ER (piriformis) - Iliopsoas - TFL - Rectus femoris - Adductors Measured with a tape measure (cm)	IG vs CG ↑ ER ↓* Iliopsoas ↑ TFL ↓ Rectus femoris ↑ Adductors IG: Changes from baseline ↑ ER ↓* Iliopsoas ↑* TFL ↓* Rectus femoris ↑ Adductors

Abbreviations: ↑: Non-significant increase; ↓: Non-significant decrease; ↔: no significant change. ↑*: Significant increase; ↓*: significant decrease; GC: control group; GI: intervention group; ^significant interaction between group-time; ²significant principal temporary effect; ¹significant principal effect of the group; SD: standard deviation; ♂: Male; ♀: Female; Kg: kilogrammes; cm: centimetres; ml: millilitres; *FR: foam roller*; ROM: joint Range of Motion ER: external rotation; IR: internal rotation; TFL: tensor fasciae latae; LE: lower extremities; UE: upper extremities; mins: minutes; s: seconds; rep: repetitions; PSLR: passive straight leg raise; DL: dominant limb; NDL: non-dominant limb; TMT: treatment; DE: dynamic exercises; TT: Thomas test; DOMS: delayed onset muscle soreness; AAE: absolute angular error; RAE: relative angular error; VAE: variable angular error; TQR: total quality recovery; VAS: visual analogue scale; NCAA: National Collegiate Athletic Association; RM: Repetition Maximum; CR-11: 11 item category rating scale; EMG: electromyography; ATP: Asociación Tenistas Profesionales (Professional Tennis Players Association); DIP: DOMS-inducing exercise protocol; DR: DOMS ratio.

Strength

Souza *et al.*[30] assessed the use of the FR on football players during the warm-up session, on the quadriceps, hamstrings and sural triceps muscle groups, achieving substantial improvements in extension strength in both limbs (dominant and non-dominant) after 2 weeks of treatment.

Delayed Onset Muscle Soreness (DOMS)

The 2 studies included in this systematic review[23,27] reported notable decreases in DOMS in the IG compared to the CG, rated using the visual analogue scale (VAS) for pain intensity[27] and an 11-item category rating scale (CR-11).

Discussion

With regard to the ten studies that met the pre-specified inclusion / exclusion criteria, the use of FR as a self-release therapy in high-performance athletes showed significant improvements for ROM and flexibility, and considerable beneficial effects for DOMS and strength, with no adverse effects or pathological alterations in the myofascial tissue.

The physical activity of highly trained athletes includes high-intensity workloads that induce alterations in the mechanical properties of the soft tissue that reduce the load tolerance threshold of the musculoskeletal system and promote a mechanical deterioration of the myofascial tissue that is particularly recurrent in sports that require a high density of movements with a high eccentric component[3,4]. Furthermore, the biological processes of the mechano-adaptation of the extracellular matrix of the connective tissue, in the face of repetitive strenuous physical loads that induce an inflammatory response mediated by inflammatory Interleukins (IL) such as IL-1β, IL-6 and the alpha tumoral necrosis factor (TNF-α). Additionally, transforming growth factor beta-1 (TGFβ-1) is released, which favours tissue fibrosis and stiffness through the differentiation and proliferation of fibroblasts and the excessive synthesis of collagen[32,33]. These adaptations lead to a pathological alteration of the mechanical behaviour of the connective tissue due to fascial restrictions, causing a loss of elasticity, increased stiffness and dehydration. When this occurs, fascia anastomosis occurs around the traumatised areas, causing fibrous adhesion. The adhesions interfere with functional development, impairing normal muscle mechanics and they can cause trigger points with muscle hyperactivity and a loss of: ROM, elasticity, strength, flexibility and muscle resistance[7,34]. These sub-clinical studies could be decisive in situations of high athletic demand.

To reverse this situation, myofascial techniques have been used to modulate muscle involvement and to take advantage of the thixotropic nature of fascia to return it to a softer and more pliable state[7,35]. The FR is a self-myofascial release tool that could potentially increase flexibility and biotensegrity in the short term[36]. This review included 2 studies[27,31] that significantly improved flexibility, assessed using the Sit and Reach test in the post-training of female football players[27] and in the warm-up of professional basketball players[31]. These results are consistent with those reported for healthy volunteers[37], using the same flexibility test, and those obtained with static stretching[15]. The improvement in flexibility could be due to the effect of the FR on the restoration of the fascial structure of the intermuscular septa, anchors and partitions, which would achieve optimal mechanical properties and alleviate muscle tightness[7,35]. Furthermore, the myofascial technique using the FR could stimulate the inverse myotatic reflex, which could provide a relaxation signal, facilitating flexibility[35]. However, in a study on volunteers practising physical activity, no effect on flexibility was observed in the Sit and Reach test[38]. The limitations of the Sit and Reach test that measures hamstring flexibility through flexion of the hip[39], could account for these differences in results. The study conducted by Sulowska-Daszyk *et al.*[22] showed contradictory results with regard to flexibility, with improvements in the tensor fasciae latae muscles, piriformis and adductor muscles with moderate decreases in the iliopsoas and rectus femoris muscles in long-distance athletes. Seco *et al.*[40] reported that, while muscle activation may influence training-induced hypertrophy, the mode of contraction seems to be a stronger driver of architectural changes in hamstrings, with excessive muscle stiffness, which could lead these athletes to exhibit ischiofemoral impingement, which causes extra-articular hip syndrome accompanied by compression between the less trochanter and the ischial tuberosity. This extra-articular hip syndrome is the most common injury suffered by athletes, restricting the action of these muscle groups[40], and may explain the differences found by Sulowska-Daszyk *et al*[22].

The pressure exercised by the FR on all the myofascial structures could cause changes in fascial adhesion, myofascial trigger points and viscoelastic tissue properties due to collagen and elastin remodelling[41], resulting in an increase of the tissue distensibility, facilitating the ability to slide between planes and, therefore, improving the ROM[7,35]. Furthermore, the increased blood flow due to vasodilation, by stimulating the release of nitric oxide and reducing vascular stiffness [42], could reintegrate the interstitial fluid into the systemic circulation, inducing a heating effect and facilitating motion[43]. Such mechanisms could be potentially responsible for the significant improvements in the ROM in the IG following the intervention with FR on the different muscle groups[24-26,28,29]. These results are similar to those described in 2 studies[44,45] and a review[35] in a non-athletic population that achieved significantly positive results in ROM with the use of FR (≥2 weeks). Furthermore, similar effects on the ROM were observed following conventional masotherapy techniques[46].

Analgesic neurophysiological[35] mechanisms have also been described, following self-myofascial release therapy and leading to a shift from the sympathetic to parasympathetic tone, which has been associated with increases in ROM. Moreover, pain tolerance may also play a part in improving ROM. This increase in the pain threshold could be due to the diffuse noxious inhibitory control that is activated by the reception of a sustained nociceptive stimulus that is able to suppress the nociception of the local and distant areas. In other words, the self-myofascial release using FR could combat pain in one area by creating it in another[7,47]. This contra-irritation phenomenon occurs in cryotherapy[1], and in the application of electric muscle stimulation (EMS) currents[48]. Although this mechanism would probably play a more significant role in the modulation of DOMS.

DOMS-related pain and muscle stiffness are a result of the inflammatory response generated by the continuous and intense physical loads on athletes[32,33]. The release of pronociceptive mediators such as bradykinin and substance *P* also contribute to DOMS, as they activate peripheral sensitization at a peripheral level, in the mechanical environment of the free nerve endings and at a spinal level[32]. Therefore, the effect of FR on DOMS would be determined by the synergic influence of self-release on tissue architecture and mechanics, inflammatory and pro-inflammatory molecular mediators and neurophysiological mechanisms of nociceptive control[18,49]. Of particular importance is the neurophysiological mechanism of diffuse noxious inhibitory control, a mechanism that utilises FR to reverse myofascial trigger point pain, known as Gate Control, where various stimuli are directed to the same level of the medulla, the pain and the pressure caused by the use of the FR, and there is a compromise for entry given that the information coming from the nociceptors lacks superiority over another stimulus, so that they are finally inhibited, although temporarily[50].

The different myofascial techniques[51], including FR, are able to re-establish and increase ROM, flexibility and reduce DOMS without affecting the intensity of activity or muscle performance[36]. In fact, Souza *et al.*[30] reported considerable improvements in the strength of the LE in the quadriceps, hamstrings and sural triceps muscle groups. These increases could confirm that myofascial release is responsible for improvements in strength, given that the transmission of strength to the tendon depends on muscle integrity during contraction and also on the mechanical properties of the connective tissue and the degree of pretension of the fascial system[52]. Additionally, the effects of the FR on increased blood flow[42] could provide a greater delivery of oxygen and substrates to perform muscle actions.

The authors of this review acknowledge a few limitations. Firstly, there were a limited number of articles that met the inclusion criteria. Despite this, our systematic approach followed the PRISMA method[19], the search was made using 3 key databases and covered grey literature. Furthermore, we used the PEDro tool for the assessment of the methodological quality[21] in order to ensure that all the records selected met the minimum quality criteria and included a series of outcomes that are commonly used in the assessment of sports medicine to explain the physiopathology of the intense and repetitive sports activity processes. Secondly, the studies are extremely heterogeneous with regard to the results, sport discipline, muscle groups of the intervention, and duration. We were therefore unable to make a meta-analysis. Although the great variability in the use of FR demands caution when interpreting the results, it has been suggested that it improves the physical qualities of ROM, strength and flexibility, providing benefits to the health and performance of athletes, and is extremely useful for high-performance athletes with regard to prevention, treatment and return to training.

In conclusion, the evidence presented in this systematic review showed that the use of the FR is safe. Given the significant improvements in ROM and flexibility, and the considerable beneficial effects on DOMS and strength, with no adverse effects or pathological alterations in the myofascial tissue, the use of FR could also be beneficial to adults with musculoskeletal pathologies. The pleiotropic effect of FR can act by improving the myofascial tissue mechanics and architecture, alleviating the effect of the pro-inflammatory cytokines and activating the neurophysiological nociceptive control mechanisms[18,49]. However, more investigation is required in order to confirm the possible benefits of the use of FR as a self-release tool with regard to the physical qualities of high-performance athletes.

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