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The effects of foam rolling on ankle dorsiflexion range of motion in healthy adults: A systematic literature review

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Background: Reduced ankle dorsiflexion is associated with lower limb injury and dysfunction, with static stretching mostly used to increase ankle range of motion. Foam rolling is an alternative intervention, shown to immediately increase ankle range of motion, while the long-term application has conflicting evidence.
Aims: To assess the effects of single and multiple foam rolling interventions on ankle dorsiflexion range of motion in healthy adults and appraise the methodological quality of the included studies.
Design: Systematic literature review.
Methods: Five electronic databases were systematically searched to identify randomised controlled trials reporting the effects of foam rolling on ankle dorsiflexion. Data was extracted from studies that met the inclusion criteria and independently appraised by each reviewer using the PEDro scale.
Results: Thirty-two articles were identified; six studies included foam rolling compared to other interventions on ankle dorsiflexion range of motion. Five of the six studies reported a significant increase ($p < 0.05$) in ankle dorsiflexion within groups compared to baseline measurements, after a single foam rolling intervention. One study found a significant within group increase in long-term effects after foam rolling on ankle dorsiflexion over seven weeks. The mean PEDro score for all studies was 6/10 indicating a high-quality level of evidence.
Conclusion: There is strong evidence suggesting that foam rolling may be effective in increasing range of motion in a healthy adult population in the short term up to 30 min; however, definitive conclusions on long-term effects cannot be drawn due to a lack of evidence, with further research recommended.

1. Introduction

Decreased ankle range of motion (ROM) may cause inefficient and undesirable movements increasing the prevalence of lower-limb injuries, falls risk and negatively affecting balance (Somers et al., 2020; Menz et al., 2006; Mecagni et al., 2000). A significant cause of reduced ankle dorsiflexion ROM is decreased gastrocnemius and soleus muscle complex flexibility which is suggested to increase forefoot pressure during impact activities, leading to conditions such as plantar fasciitis and Achilles tendinopathy and predispose individuals towards lower extremity injuries (Grieve and Palmer, 2017; Baumbach et al., 2016; Knapik et al., 2019).

Static stretching is a commonly used to increase ankle dorsiflexion and reduce the occurrence of lower-limb injuries, through decreasing muscle-tendon unit stiffness and increasing stretch tolerance (Opplert and Babault, 2019; Behm and Chaouachi, 2011). The long-term application of static stretching is associated with increases in flexibility, performance and decreased delayed onset muscle soreness (Medeiros and Martini, 2018). However, the literature suggests that pre-activity static stretching may have a negative implication on muscle strength and function through decreasing maximal voluntary contraction (MVC) and peak torque (Maeda et al., 2017; Behm and Chaouachi, 2011).

A foam roller (FR) is a lightweight cylindrical foam-covered tube available in various sizes, surface textures and densities (Cheatham and Stull, 2018). Foam rolling (FR) is a form of self-myofascial release (SMR) used to increase muscle flexibility, reduce delayed onset muscle soreness and modulate autonomic nervous system

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activity (Beardsley and Škarabot, 2015). Participants use their bodyweight to exert pressure between the device and selected musculature in a continuous motion, but its acute effects on range of motion are dependent on the volume, intensity and muscle groups selected (Smith et al., 2019).

Previous systematic literature reviews (SLRs) have reviewed FR and joint ROM in general. Cheathem et al. (2015) found that FR had a short-term effect on improving joint ROM without compromising muscle power output. Moreover, Beardsley and Škarabot (2015) established that FR increased joint ROM, flexibility and enhanced recovery in the short-term. However, Hendricks et al. (2020) identified FR to have short and long-term benefits which increased when combined with dynamic stretching. Wiewelhove et al. (2019) found that FR had both pre/post-exercise improvements on muscle flexibility and strength in an athletic population. More recently, Wilke et al. (2020) found that FR was an effective method to induce acute/short term improvements in joint ROM but was not superior to stretching.

These SLRs highlight the range of benefits that FR can provide; however, a broad inclusion criteria underlines heterogeneity in their findings. Moreover, the studies included had a varied methodological design showing the effects across several joints with numerous outcomes. Current evidence on FR highlights a gap in the literature and the need to further explore the effects of FR specifically on ankle dorsiflexion (DF) in order to develop the best evidence-based practice, implement clinical guidelines and inform consensual guidance for lower-limb injury prevention.

The aims of this review were to assess the effects of single and multiple FR interventions on ankle DF ROM in healthy adults and to appraise the quality of the included studies.

2. Methods

2.1. Protocol and registration

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009)

2.2. Search strategy

An online database search was conducted using the medical databases; Medline, CINAHL, SPORTDiscus, EMBASE and AMED of studies published from 2010 to March 2020. Snowballing of reference lists from full-text studies was also used to ensure inclusion of all related papers. The following search terms were applied: “self-myofascial release,” “foam roll*,” “self-massage,” “roller massage,” “self-soft tissue therapy,” AND “ankle dorsiflexion” OR “ankle range of movement/motion” OR “ankle ROM” OR “plantarflexors flexibility” OR “gastrocnemius/soleus flexibility” OR “triceps surae flexibility”.

2.3. Inclusion and exclusion criteria

Studies were included that met the following criteria: peer reviewed journal articles, published in English; RCT of either parallel or crossover design; RCT investigating FR and SMR focussing only on ankle joint ROM; RCT investigating FR and/or comparing to other interventions on ankle joint ROM and healthy recreationally active adults aged 18–60. Observational studies, grey literature or studies recruiting participants with injuries or comorbidities were excluded.

2.4. Study selection

Screening of the search results was initially performed independently by each reviewer against the specific inclusion/exclusion criteria. If reading the abstracts and titles was not enough to distinguish inclusion/exclusion, then the full text study was screened. Any discrepancies regarding the selection criteria were resolved through group discussion until an agreed decision was reached. Studies that did not meet the agreed inclusion criteria resulted in exclusion from the review.

2.5. Data extraction

A data extraction table was developed to record extracted data from each of the six included studies and included study design, participant demographics, intervention protocol, outcome measures and results. The data was extracted by two of the reviewers (CC, OK) and finalised by the remaining review authors.

2.6. Quality appraisal

The strengths and limitations of the included studies were determined using the Physiotherapy Evidence Database (PEDro) scale (https://pedro.org.au/).

The PEDro scale was used as it has demonstrated excellent inter and intra-rater reliability and validity in the assessment of RCT's (Cashin and McAuley, 2019). The PEDro scale, is an 11-item point score, with the first question being excluded from the overall rating as it relates to external validity, making the score out of 10. A study with a score of six or more indicates high quality, a score of four to five is moderate, and a score of below four indicates poor methodological quality (Maher et al., 2003; Hendricks et al., 2020). Each reviewer independently appraised the included papers using the PEDro scale and then compared the results in pairs before gathering as a group to discuss. To reduce researcher bias, the group agreed not to consult the PEDro database prior to appraising the quality of each selected study (Table 2).

3. Results

3.1. Identification of studies

The initial search of the databases yielded 32 articles. After reviewing the abstracts, 10 duplicates were removed leaving 22 potentially relevant full text journals articles to be screened against the eligibility criteria. After further screening of the full text articles, 16 studies failed to meet the inclusion criteria with six studies finally included in this systematic review (Fig. 1).

3.2. Characteristics of included studies

The six included studies were published between 2014 and 2020. The characteristics of the included studies are shown in Table 1. The six included studies were all RCTS, with three of crossover design and all included healthy asymptomatic university students. The sample size ranged from between 14 and 44 participants, with a mean age range between 19.5 and 26.1 years old. Five studies adopted similar FR protocols, with participants seated on the floor, using their arms for motion and bodyweight to exert pressure onto the FR. Whereas for Halperin et al. (2014), participants were seated in a chair with pressure applied to the calf muscles using their arms. Ankle DF ROM was assessed by weight bearing standing lunge in 5/6 studies with passive ankle DF ROM measured in only one study (Yoshimura et al., 2019). Five studies looked exclusively at the immediate short-term effects (<60 min post-intervention) of FR on ankle DF ROM dorsiflexion, except for Smith et al. (2019), who investigated both short and long-term effects over seven weeks.

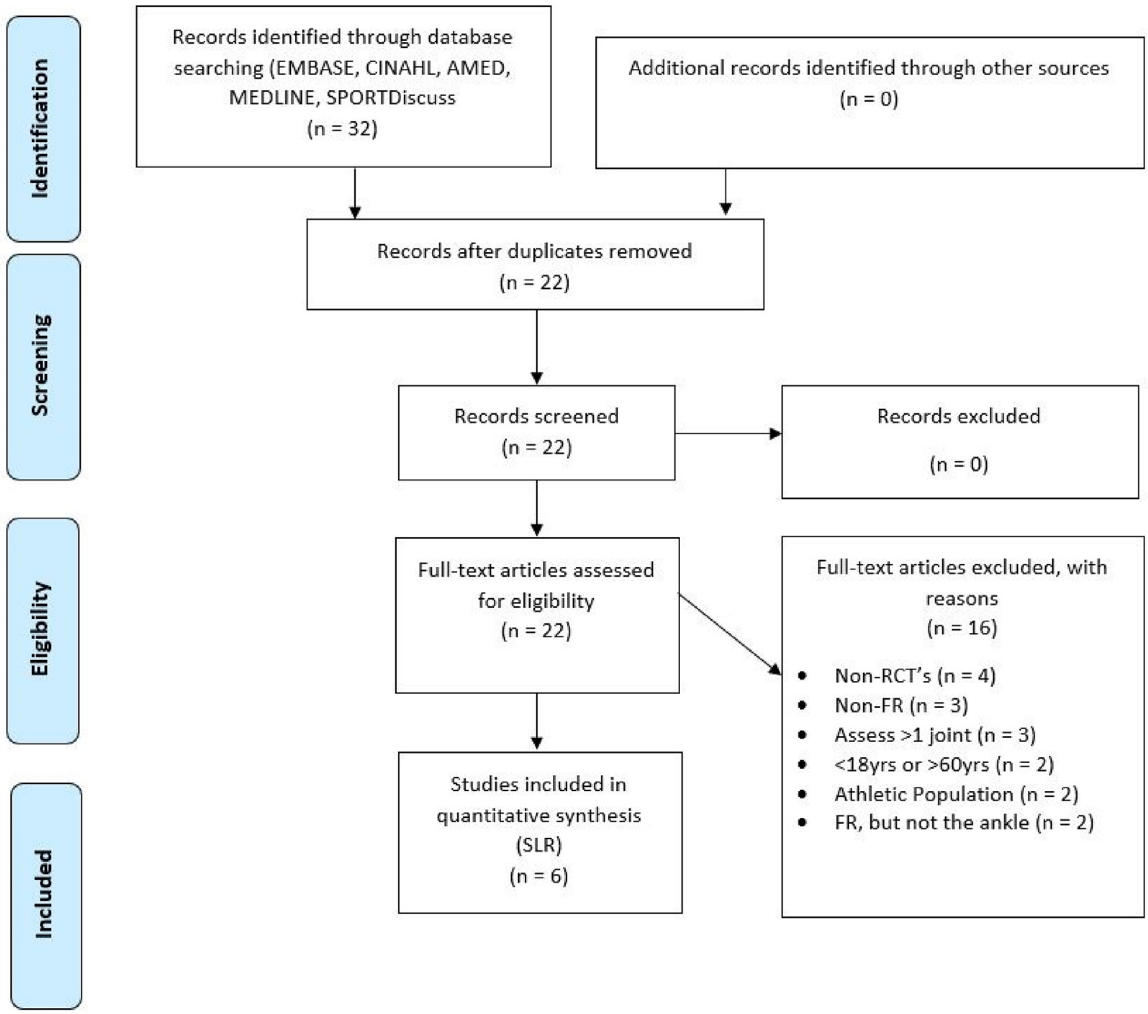

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram of the search strategy.

3.3. Short term effects of FR on ankle DF ROM

All six included studies identified a short-term increase in ankle DF ROM, lasting up to 30 min post a single intervention. Five studies reported a significant difference ($p < 0.05$) for FR within groups compared to baseline measurements except for Somers et al. (2020). The results of DF ROM short term effects should also be viewed in respect of studies investigating only FR compared to a control group (Kelly and Beardsley, 2016; Yoshimura et al., 2019), FR compared to stretching interventions (Halperin et al., 2014; Smith et al., 2019; Somers et al., 2020) or FR with a vibration frequency (Garcia-Gutierrez et al., 2018).

3.3.1. FR only compared to control group

Two studies compared the use of FR only against a control group. Kelly and Beardsley (2016) found a significant within-group effect ($p < 0.05$) in the FR group between baseline and all post-treatment time-points (0, 5, 10, 15 and 20 min). An increase in ankle DF ROM improvements lasting for 20 min in the dominant leg and up to 10 min in the non-dominant leg showing a cross-over effect. However, no significant between-group differences ($p = > 0.05$) were found between the intervention and control groups on follow up.

In a crossover RCT design, Yoshimura et al. (2019) found a significant ($p < 0.01$) increase in ankle DF and plantarflexion ROM between the FR and control interventions for up to 30 min. This study also investigated morphological changes (fascicle length related to SMR) and found no significant change in morphology of the triceps surae muscle after FR intervention.

3.3.2. FR compared to stretching

Three studies compared the effects of FR and SMR to either static or dynamic stretching. Two studies compared the effects of FR to static stretching (Halperin et al., 2014; Smith et al., 2019). Halperin et al. (2014) found a significant increase in ankle DF ROM immediately ($p = 0.004$) and 10 min post-intervention ($p = 0.006$) with both FR and static stretching with a medium effect size (0.24 and 0.26). The FR intervention increased, and static stretching decreased maximal voluntary contraction (MVC) force output, during the post-test measurements, with a significant difference occurring between the two interventions at 10 min post-test. Smith et al. (2019) compared the acute (short term) and long-term changes in ankle DF ROM, between three intervention groups, FR, static stretching and a combination of FR and static stretching. However, no statistically significant effects were seen at baseline/week one. In the Somers et al. (2020) RCT, participants were allocated into one of

Table 1
Characteristics of included studies.

Authors	Study Type	Participants	Protocol	Variables Studied	Outcome Measures	Results
Garcia-Gutierrez et al. (2018)	Crossover RCT	38 (19 M + 19 F) Recreationally active university students. Mean age M = 21.8 F = 19.5	3 × 20s (10secs rest) with 48hrs rest between sessions. Only dominant leg	Ankle ROM Maximal Isometric Contraction (MVC) DF/PF Strength	Standing Lunge MVC & Strength (Force Device)	• Ankle DF ROM significant difference in FR (6%) and FR & vibration (7%) group ($p < 0.001$) in ipsilateral leg. ↑ ankle DF ROM contralateral leg (6%). • No synergistic effect of FR & vibrations on ankle ROM.
Halperin et al. (2014)	Crossover RCT	14 (12 M + 2 F) Active adults Mean age M = 23 F = 22	FR – 3 × 30s (10s rest) seated to roll plantar flexors at 7/10 VAS. SS – 3 × 30s (10s rest) wall stretch	Ankle DF ROM MVC and Force produced (100 ms) SL Balance	Standing Lunge Boot with EMG electrodes. Stork Balance	• FR - 3.6% ↑ (p - .004) immediately after and 4.4% ↑ (p - .006) 10-mins in ankle DF ROM. • SD (p - .005) in force output versus SS.
Kelly and Beardsley (2016)	RCT	26 (16 M + 10 F) University students Mean age FR group = 24.8 Control = 24.4	FR – 3 × 30s of plantar flexors (10s rest) Control – 2mins rest	Ankle DF ROM assessed at 5-min intervals for 20 min	Standing Lunge	• SD identified in FR group ($p < 0.05$) for ankle DF from 0 to 20 min in dominant & 10 min in non-dominant. • Small treatment effect in dominant (↑ 1.12 cm) and non-dominant limbs (↑ 0.72 cm).
Smith et al. (2019)	RCT	44 (26 M + 18 F) University students Mean age M = 21.7 F = 21.3	FR – 3 × 30s @ 60bpm using a metronome and their bodyweight. SS - 3 × 30s lunge x2/7 session (48hrs rest between each).	Acute & Chronic Ankle ROM x2 weekly over 7/52	Standing Lunge - Digital Torpedo Level	• Chronic ROM ↑ by 18.3% across all 3 groups from Week 1–7 (p – 0.003). • Acute ↑ ROM (4%) across 3 groups. No SD between each other. SS = 4.7% FR = 3.2% FR + SS = 4.3% • Acute ↑ ROM at 6/52 ($p = 0.004$).
Somers et al. (2020)	RCT	42 (24 M + 18 F) Recreationally active students Mean age = 26.1	FR – 2 × 60s across whole plantar flexors (own pace) DS – 2 × 60s downward dog using metronome (30bpm).	Right ankle DF ROM pre/post FR.	Standing Lunge	• No SD between 3 groups pre-test vs post-test ($p = 0.82$) • Mean values from pre to post-test were 0.479 (FR), 0.7 (DS) and 0.907 (FR + DS) ↑ in ankle DF ROM.
Yoshimura et al. (2019)	Crossover RCT	22 male university students Mean age = 21.5	FR – 3 × 60s (30s rest) 25 cycles per minute putting 15–25% body weight on force plate) Control – lay resting for 3 min	PROM Ankle Calf Morphology	Passive PF & DF. Fascicle Length & Fascial movement	• SD in ROM (p - .000) found after FR, ankle DF ↑ by 22% and plantarflexion by 9%. • DF ROM was significantly higher 30 min post-intervention. • No change in muscle morphology.

Abbreviations: DF = dorsiflexion, FR = foam rolling, PROM = passive range of movement, RCT = randomised controlled trial.
ROM = range of movement, SD = significant difference, SS = static stretching.

three intervention groups; FR, dynamic stretching or a combination of FR and dynamic stretching group. The results indicated that although all three interventions improved absolute ankle DF ROM, there was no significant difference between the three groups in all pre–post measurements ($P = 0.82$).

3.3.3. FR with a vibration frequency

In a cross-over RCT (Garcia-Gutierrez et al., 2018) participants undertook all three conditions, FR, FR + Vibration and no FR or Vibration (control). Immediately after each condition, ankle DF ROM was significantly higher in FR and FR + Vibration compared to control group for both legs ($p < 0.001$). A cross-over effect was also identified in the non-stimulated legs contralateral legs. Measures of maximal voluntary isometric contraction (MVIC) were not affected by FR intervention for plantarflexion and DF force.

3.4. Long term effects of FR on ankle DF ROM

Only one included study, focussed on both the short and long-term effects of FR on ankle DF ROM. Smith et al. (2019) found a significant main effect for time ($p = 0.002$) across all three intervention groups (FR, static stretching, and combined FR and static stretching) twice weekly for six weeks. Within group increases in ankle DF ROM, were only seen from week three to week seven ($p=<0.001$) and were not significantly different between groups. Overall, Smith et al. (2019) reported a 25.1% increase in ankle DF ROM after FR and showed long term effects after seven weeks in recreationally active university students.

3.5. Quality appraisal

The mean PEDro score (Table 2) for each study was 6/10 (range: 5–7 points) and of ‘high’ methodological quality overall. There was minimal variation in methodological quality amongst studies with only Yoshimura et al. (2019) scoring ‘moderate’.

Four of the six included studies did not blind participants, assessors and therapists, except for Somers et al. (2020) for assessor blinding and allocation concealment and Smith et al. (2019) for

Table 2
Methodological quality of included studies using the PEDro tool.

	Halperin et al. (2014)	Kelly and Beardsley (2016)	Garcia-Gutierrez et al. (2018)	Smith et al. (2019)	Yoshimura et al. (2019)	Somers et al. (2020)
Eligibility criteria were specified	✓	✓	✓	✓	✓	✓
1. Subjects randomly allocated to groups	✓	✓	✓	✓		✓
2. Allocation concealed						✓
3. Groups similar at baseline for prognostic indicators	✓	✓	✓	✓	✓	✓
4. Blinding of all subjects						
5. Blinding of all therapists who administered the therapy						
6. Blinding all assessors who measured at least one key outcome				✓		✓
7. Measures of at least one key outcome from more than 85% of the subjects initially allocated to groups	✓	✓	✓	✓	✓	✓
8. All subjects for whom outcome measures were available received the treatment or control condition as allocated	✓	✓	✓	✓	✓	
9. Results of between-group statistical comparisons are reported for at least one key outcome	✓	✓	✓	✓	✓	✓
10. The study provides both point measures and measures of variability for at least one key outcome	✓	✓	✓	✓	✓	✓
Total Score	6/10	6/10	6/10	7/10	5/10	7/10
Validity of Papers	High	High	High	High	Moderate	High

assessor blinding. All included studies were marked positively for PEDro questions related to comparable baseline characteristics, follow up of participants and reporting results of between-group statistical comparisons, with only Yoshimura et al. (2019) failing to randomise group allocation or treatment order.

4. Discussion

This is the first systematic review that has specifically examined the influence of FR and SMR on ankle DF ROM. Previous SLR's and meta-analyses focussed on multiple joints, assessing various outcomes and investigating studies with different methodological design (Beardsley and Škarabot, 2015; Hendricks et al., 2020; Cheatham et al., 2015; Wiewelhove et al., 2019).

Overall, in reviewing the six included studies, the main findings from this SLR suggest: (a) the majority of studies (5/6) indicate a significant increase in ankle DF ROM after a single intervention and indicates these short term effects can last up to 30 min; (b) one study (Smith et al., 2019), also showed significant long term effects after multiple applications of FR over seven weeks; (c) the overall methodological quality of the current literature was of high-quality; with a mean PEDro score of 6/10, with all studies presenting with high-quality evidence except Yoshimura et al. (2019), which showed moderate quality.

4.1. Short term effects of FR

Linked to the above described short term effects of ankle DF ROM after a single intervention, in five of the six studies FR could also be a viable modality instead of static or dynamic stretching prior to exercise. Three of the included studies found no significant difference in ankle DF ROM between FR or stretching modalities (Halperin et al., 2014; Smith et al., 2019; Somers et al., 2020). One study (Halperin et al., 2014) reported dorsiflexion ROM significantly increased 10 min post a single FR intervention comparable to the static stretching intervention. Of clinical significance, FR compared to static stretching did not have the same negative influence on force output MVC of the plantar flexors (Halperin et al. (2014), that could impede acute maximal voluntary strength/power and explosive athletic performance like sprinting (Opplert and Babault, 2019; Haddad et al., 2014). Furthermore, in line with the review findings related to similarities between FR and stretching in increasing ankle DF ROM, Su et al. (2017) recommended that FR had a more significant effect than static and dynamic stretching. However, a recent SLR not just focussing on the ankle joint (Wilke et al. (2020), found that although FR was an effective method to induce acute/short term improvements in joint ROM, it was not superior to stretching. The above evidence, supports the application of FR in clinical practice while still not dismissing the positive effects stretching modalities can have on improving ROM.

The length of time at which FR was administered varied across the six included studies. A previous study suggests that FR for 2 min or less is not significant in increasing ROM (Couture et al., 2015). However, the findings of this SLR suggest otherwise. Four studies performed FR for 2 min or less except for Yoshimura et al. (2019) which performed FR for 3 min. This is supported by Wilke et al. (2020) which states duration does not influence effectiveness. This could have implications for clinical practice and time management advantages for the clinician and/or patient in a FR rehabilitation programme.

Apart from the identified significant increase in ankle DF and plantarflexion ROM for up to 30 min, the Yoshimura et al. (2019) study had clinical implication related to SMR and FR. The findings indicated, that although FR had an influence on ankle ROM, it did not influence the morphology of muscle in respect of fascicle length related to FR and SMR. These findings may challenge some of the current views and evidence related to the underlying mechanisms related to SMR and FR.

4.2. Long term effects of FR

As described above, Smith et al. (2019) was the only study to investigate the short and long-term effect of FR twice weekly for six weeks on ankle DF ROM. Overall, Smith et al. (2019) reported a 25.1% increase in ankle DF ROM after FR and showed long term effects after seven weeks in recreationally active university students. They identified a 25.1% increase ($p = 0.003$) within the FR group from baseline measurements that was not statistically significant from the between group improvements in ROM induced by static stretching alone or FR and static stretching, but higher than those induced from just static stretching. Only one previous study by Aune et al. (2018) examined the long-term effects of FR exclusive to ankle dorsiflexion ROM; they reported conflicting findings with a non-significant increase ($p = 0.090$ or 7%) following four weeks of 3×60 s of the dominant leg. Whilst an additional study by Hodgson et al. (2018) also reported a four-week FR programme of the quadriceps and hamstrings three or six times weekly failed to improve knee ROM. Both studies with non-significant findings performed their interventions for four weeks instead of six which may explain why their participants exhibited less of a physiological change in ROM. Yet research evidence has found long-term ROM improves following four weeks of intensive flexibility training, whilst a six-week programme of static stretching significantly increased ($p < 0.0001$) hamstring flexibility (Brusco et al., 2019). Therefore, due to the lack of evidence coupled with the inconsistency in findings surrounding the long-term effects FR has upon ROM; further research is warranted to determine the optimal frequency/volume to elicit significant physiological adaptations in ROM.

4.3. Quality appraisal

The mean PEDro score for all studies was 6/10 which is classed as 'high' quality, which was achieved by 5/6 studies in this SLR. Apart from the overall "high" of the included studies, there were some methodological issues of note.

Overall, there was a lack of single and double blinding in all six included studies with only two studies blinding the assessors (Smith et al., 2019; Somers et al., 2020).

This lack of blinding indicates a risk of bias and decreases the internal validity (Braithwaite et al., 2018). However, the difficulties of blinding from physiotherapy interventions are recognised due to the lack of easily administered placebos (Fregni et al., 2010).

The six included studies ranged from a sample size of 14–44 participants. Two studies reported the use of sample size calculations by power analysis (Halperin et al., 2014; Smith et al., 2019). Although, Smith et al. (2019) power-analysis was based on previous studies work, the use is beneficial in preventing Type I and Type II errors and helps draw better inferences about the whole population (Jones et al., 2004). Furthermore, two studies used convenience sampling (Kelly and Beardsley, 2016; Somers et al., 2020), affecting the external validity of the study (Paik and Shahani-Denning, 2017). The small sample size was stated as a limitation in two studies (Halperin et al., 2014; Kelly and Beardsley, 2016). Although all studies specified adequate eligibility criterion, the use of non-probability sampling of university-aged participants may reduce external validity.

Differences in application and method of FR between studies, should be taken into consideration when interpreting the results. The heterogeneity between studies' FR interventions are factors that may have contributed towards the inconsistency in findings.

While some interventions utilised a metronome to control the speed of the FR (Yoshimura et al., 2019; Smith et al., 2019), others allowed the participants to FR at a self-selected speed (Somers et al., 2020). The SMR force applied to the FR was non-standardised, while some interventions instructed the participants to apply as much pressure as possible (Garcia-Gutierrez et al., 2018), others requested 7/10 pain levels (Halperin et al., 2014). Skarabot et al. (2015) discovered that by increasing the pressure on the contralateral limb, it led to a significant increase in ROM when compared to a static stretch. Equally, Aune et al. (2019) and Cavanaugh et al. (2017) suggest it is plausible that increased force applied during FR may elicit an increase in parasympathetic nervous activity, while Schleip (2003) suggest this is through the stimulation of mechanoreceptors.

4.4. Limitations

The reviewers excluded grey literature from this review. The use of grey literature is supported by Adam et al. (2017), who suggest it allows for a wider variety of relevant sources and reduce the impact of publication bias (Adams et al., 2016). Further to this, a lack of researcher experience could mean that aspects of the appraisal and synthesis of findings may be less thorough. Furthermore, the risk of bias of each study was not assessed. Using a risk-of-bias tool would have helped document potential flaws and contribute to the certainty of the evidence found while avoiding misleading conclusions (Sterne et al., 2019).

4.5. Recommendations for future research

Due to the variation in methodology and lack of standardisation when administering FR, future studies should examine the optimal FR application and intervention for eliciting short and long-term improvements in ankle DF ROM. Future studies, should also attempt to conceal allocation towards treatment through blinding and control the application of both pressure and speed exerted onto the FR to improve the internal validity of findings. Further research is needed to examine the long-term effects FR has upon ankle DF ROM because of the limited number and conflicting results amongst studies. Finally, the sample recruited across all six studies of young healthy university students, may have reduced the external validity of the included research. Therefore, future research should investigate the physiological effects FR has upon DF ROM in participants with previous ankle or lower-limb injuries, athletes and elderly participants to increase the clinical impact and significance.

5. Conclusion

In conclusion, consistent with previous SLRs and meta-analysis, the findings of this review suggest there is strong evidence for the short-term increase in ankle DF ROM after a single application of FR in a healthy population. Furthermore, some of the evidence suggests that FR may be a more suitable alternative to static stretching prior to athletic activity, because it may not reduce calf complex force output.

In comparison, the review suggests conclusions on long-term effects cannot be drawn due to lack of evidence and differences in previous literature.

All six studies demonstrated methodological flaws, although overall were considered as high-quality evidence.

Clinical relevance

- This is the first systematic review that has specifically examined the influence of FR and SMR on ankle DF ROM. Overall, all six included studies in this review, were considered as high-quality evidence.
- Consistent with previous SLRs and meta-analysis, the findings of this review suggest there is strong evidence for the short-term increase in ankle DF ROM after a single application of FR in a healthy population.
- Of clinical relevance, some of the evidence suggests that FR may be a more suitable alternative to static stretching prior to athletic activity, because it may not reduce calf complex force output.
- This review suggests that conclusions on long-term effects cannot be drawn due to a continued lack of evidence in available literature.

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CRediT authorship contribution statement

Rob Grieve: Conceptualization, Supervision, Writing – review & editing. **Brendan Byrne:** Investigation, Writing – original draft.

Charlie Clements: Investigation, Writing – original draft. **Laura-Jayne Davies:** Investigation, Writing – original draft. **Edward Durrant:** Investigation, Writing – original draft. **Oliver Kitchen:** Investigation, Writing – original draft.

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