Heliyon 10 (2024) e29180

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Deciphering recovery paradigms: Foam rolling's impact on DOMS and lactate dynamics in elite volleyball athletes

Xin Zhang [a], Xin Li [b], Zhizheng Wu [b], Xuan Li [b], Guangyi Zhang [a], Xin Zhang [b,*]

[a] School of Physical Education, Tianjin University of Sport, 301617, Tianjin, China
[b] School of Sports Training, Tianjin University of Sport, 301617, Tianjin, China

ARTICLE INFO

Keywords:
SMR
Foam rolling
Blood lactate clearance
VAS
DOMS

ABSTRACT

This study examines the effects of Self-Myofascial Release (SMR) techniques on post-exercise recovery in elite volleyball athletes. Through a controlled investigation involving eighteen Chinese Men's National Volleyball Team athletes, the research assessed the impact of foam rolling (FR) versus passive recovery (PAS) on blood lactate clearance and Delayed Onset Muscle Soreness (DOMS), as measured by Visual Analogue Scale (VAS) scores. Findings indicated that FR significantly reduces VAS scores and facilitates lactate clearance when compared to PAS, suggesting foam rolling may enhance post-exercise recovery. While confirming foam rolling's benefits, this research calls for further exploration into recovery mechanisms, emphasizing a cautious interpretation of foam rolling as part of a comprehensive recovery strategy.

1. Introduction

In high-intensity sports, the elevation of blood lactate concentration is a primary physiological marker of athlete fatigue, prompting sports science to explore effective recovery strategies to enhance blood lactate clearance and facilitate rapid recovery, thereby augmenting athletic performance [1]. Among various interventions, recovery facilitated by aerobic exercise has been identified to expedite lactate removal significantly, enhancing post-exercise recuperation [2,3]. Moreover, the strategic intake of specific nutritional supplements, including carbohydrates and proteins, has been shown to effectively decrease lactate levels following intense physical activity [4].

In addition to these methods, self-myofascial release (SMR) emerges as an innovative recovery technique, not only for its efficacy in alleviating exercise-induced pain but also for its positive impact on other aspects of athlete recovery. Amato et al. [5]delineate how SMR treatment extends its benefits to enhancing postural control, an essential component for athletes in maintaining optimal performance and reducing injury risk. This multifaceted benefit underscores the versatility of SMR in the recovery process, offering a holistic approach that addresses both physiological stressors, such as lactate accumulation, and biomechanical factors, like postural stability.

Various sports recovery methods, such as stretching, massage, cryotherapy, electrical muscle stimulation, kinesiology taping, and pharmacological interventions, are extensively explored for their efficacy [6]. Among these, deep tissue massage is particularly noted for its ability to significantly reduce blood lactate levels, facilitating quicker physiological recovery [7]. While interventions like

* Corresponding author.
E-mail addresses: zx@tjus.edu.cn (X. Zhang), 17813175168@163.com (X. Li), 1003927882@qq.com (Z. Wu), lixuan2233@163.com (X. Li), 643840026@qq.com (G. Zhang), zhangxinmomo@163.com (X. Zhang).

https://doi.org/10.1016/j.heliyon.2024.e29180
Received 29 November 2023; Received in revised form 26 March 2024; Accepted 2 April 2024
Available online 6 April 2024
2405-8440/

stretching have been documented for their psychological soothing effect [6], but when compared to mechanical methods warrant further investigation. This study adopts a holistic perspective on post-exercise recovery, assessing both physiological and psychological dimensions to underscore the importance of a comprehensive recovery strategy. This observation underscores the need for research that directly compares different recovery strategies to provide a holistic understanding of their benefits, thus guiding the development of optimized recovery protocols for athletes.

Recently, SMR techniques, particularly foam rolling, have gained attention as innovative recovery methods [8]. SMR applies mechanical pressure to enhance muscle and fascia flexibility, improve circulation, and speed up waste removal and nutrient delivery [9]. Despite its popularity, the consensus on its effectiveness in lactate clearance and Delayed Onset Muscle Soreness (DOMS) mitigation is not well established, possibly due to individual differences in SMR application [10].

Volleyball, with its unique demands such as explosive jumps, rapid directional changes, and intense impacts, places significant muscular strain on athletes, often leading to high lactate accumulation and DOMS [11]. Although various recovery strategies, like aerobic exercise and nutritional supplementation, have been explored for lactate clearance and recovery, there remains a gap in understanding the specific effects of SMR, particularly in relation to volleyball's explosive and physically demanding nature [12]. This study aims to fill this gap by examining the impact of SMR on lactate clearance, Visual Analog Scale (VAS) pain perception, and DOMS in volleyball athletes, thus enhancing our understanding of recovery in specific sports contexts and providing more targeted recovery strategies for athletes in high-intensity activities.

2. Materials and methods

2.1. Participants

Eighteen athletes from the Chinese men's national volleyball team were included in this study and were randomly assigned to two experimental groups according to the recovery method: the Foam Rolling Recovery Group (Foam Rolling FR) and the Passive Recovery Group (Passive PAS), with 9 participants in each group (Table 1).

The mean number of years of training of the participants was 9.9 ± 2.2 years, and to ensure the uniformity of the data, the athletes in both groups performed the same experiments under the same environmental conditions. All participating athletes had more than 5 years of training experience and had represented the Chinese team in at least one international event in the past year. This criterion ensures that the included athletes have a high level of competitiveness and provides a strong basis for studying the effects of different recovery methods [13]. Prior to the experiment, we conducted a thorough assessment of each athlete's health status, confirming the absence of acute or unaddressed injuries that might confound the experimental outcomes. Additionally, to minimize variability due to prior physical exertion, participants were instructed to abstain from any strenuous or unaccustomed physical activities for 24 h before the study's commencement. The experimental procedures, including warm-up and recovery protocols, were standardized (Fig. 1 and Table 2), and administered under the same environmental conditions for all participants [14]. This rigorous control of experimental variables was instrumental in reducing the impact of external factors on our findings, thus providing a reliable basis for evaluating the efficacy of the different recovery methods under investigation.

2.2. Study design, sample, and procedure

The preliminary phase of the study involved acclimatizing participants to the laboratory setting for 20 min, which included light aerobic activities like jogging to adapt to the experimental conditions. To ensure uniformity in the starting conditions among all participants, baseline blood lactate levels were measured from capillary earlobe samples using the EKF Lactate Scout 4 (Cardiff, Welsh) before engaging in these light aerobic activities. This approach guaranteed that the baseline measurements reflected the athletes' pre-activity physiological state, allowing for accurate assessment of lactate dynamics in response to the recovery interventions [13].

The main experimental procedure involved a 2-min squat jump test, which is established in sports science as an effective means to induce a rapid increase in blood lactate levels due to its high-intensity anaerobic nature [15,16]. Studies have documented the efficacy of squat jumps in elevating lactate concentrations, making it a suitable exercise for assessing the impact of recovery interventions on lactate clearance [17]. Participants executed continuous squat jumps on a standardized jump mat, ensuring consistent exercise intensity and motion range. Blood lactate levels were measured immediately post-exercise to evaluate immediate physiological responses. At 24 h post-exercise, Muscle Creatine Kinase (CK) levels were assessed, indicative of muscle recovery and damage, with expected values ranging between 300 and 500 U/L, in line with standard norms.

Immediately after the squat jumps, participants in the FR group commenced a structured foam rolling session using a medium-

Table 1
Participant biometric characteristics by recovery Methodology (±SD) .

Group	Foam Rolling Recovery (FR)	Passive Recovery (PAS)
Sample Size (n)	9	9
Age (years)	25.0 ± 2.3	24.3 ± 2.5
Height (cm)	197.3 ± 8.4	197.4 ± 11.5
Weight (kg)	89.7 ± 9.0	89.8 ± 10.0
Training Time(years)	9.9 ± 2.1	9.4 ± 2.4

Fig. 1. Warm-Up program. Note: All participants adhered to the following warm-up regimen.

density foam roller (45cm × 14 cm), targeting key muscle groups—gastrocnemius, hamstrings, quadriceps, adductor group, iliotibial band, and gluteus muscle. For each targeted muscle group, the protocol consisted of 30 rolls, each performed at a controlled pace of 20 rolls per minute. This was applied once per muscle group, amounting to a total of 90 s of rolling per muscle group. The complete session encompassed approximately 9 min, during which the athletes used their body weight to apply consistent pressure across the foam roller, ensuring effective penetration into the muscle tissue. This standardized approach was crucial in promoting blood flow, reducing muscle stiffness, and ensuring that the study's outcomes were attributable to the SMR intervention. Conversely, the PAS group engaged in passive recovery post-exercise. Following a 30-min rest period after the squat jumps, all study participants had their blood lactate levels reassessed to evaluate metabolic recovery. Additionally, participant-reported lower extremity pain was systematically recorded at 24, 48, 72, and 96 h post-exercise via a 0–10 visual analog scale, with 0 representing 'no pain' and 10 'extreme pain.' The utilization of VAS is a widely accepted method for the quantification of pain in research, offering an effective and reliable means to gauge the subjective pain experience of participants [18,19], thereby enabling a consistent assessment of the interventions' impact on pain levels following physical activity. This structured approach allowed for an accurate assessment of the interventions' effects on lactate clearance and muscle recovery, ensuring the reliability of the findings.

2.3. Statistical analysis

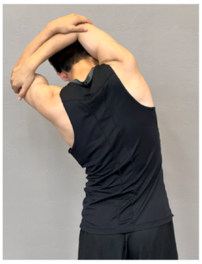
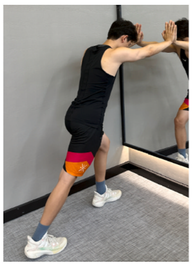
For the determination of the sample size in this study, we anticipated a standardized effect size, represented by the Root Mean Square Standard Error (RMSSE) of 0.77, and aimed for a power of 0.88, with a significance level set at $\alpha = 0.05$ for a two-tailed test. These parameters were selected in line with standard power analysis practices to ensure adequate sensitivity for detecting medium to large effects, as categorized by eta-squared (ηˆ2) statistics [20]. The normal distribution of the variables was confirmed using the Shapiro-Wilk test, and the homogeneity of variances across groups was verified through Levene's Test. Sphericity was checked with Mauchly's Test in the context of repeated measures ANOVA. ANOVA for factorial designs, along with Bonferroni post hoc adjustments, was used to ascertain differences in lactate (LA) and VAS values between the study conditions. The eta-squared (ηˆ2) statistics were employed to measure effect sizes, with thresholds set for small (<0.10), medium (0.10–0.40), and large (>0.40) effects [21]. The sample size of two groups, each consisting of nine participants, was thus calculated to be sufficient for the power and effect size targets. This allowed for a robust analysis of the interventions' effects while maintaining the statistical rigor. All analyses were performed using SPSS 27 software (IBM Corp, 2020), with a significance threshold of $p < 0.05$ to assess the significance of the effects.

3. Results

3.1. Lactate

This study applied a repeated measures ANOVA to evaluate variations in blood lactate levels between the Foam Rolling (FR) group and the Passive Activity (PAS) group across several time intervals. The analysis revealed observable fluctuations in lactate clearance rates, yet these did not attain statistical significance ($F(4,60) = 1.61$; $P = 0.18$). With an eta-squared (ηˆ2) statistic of 0.10, the effect size is considered small, indicating minimal differences between the groups' lactate clearance under the experimental parameters. All participants displayed a significant rise in blood lactate levels immediately post-exercise ($P < 0.001$), which aligns with the anticipated activation of anaerobic glycolysis. Subsequently, during the 30-min recovery period, both the FR and PAS groups exhibited notable

Table 2
Stretching program.

No.	Muscle Group	Illustration	Technique
1	Lateral Deltoid		Cross the left arm horizontally over the chest, holding the elbow with the right hand and gently pulling towards the chest.
2	Triceps and Side Bend		Raise the right arm overhead with a bent elbow, using the left hand to gently pull the elbow, encouraging a left side bend.
3	Adductors		Stand with feet wide apart, bend the left knee while keeping the right leg straight, and lean forward with hands on the ground.
4	Hurdler's Stretch		Sit with one leg extended and the other bent, foot against the extended leg's knee, and lean forward with a flat back.
5	Quadriceps		Face a wall, hold onto a bar for support, bend the opposite leg's knee, bringing the heel towards the buttocks and hold the foot with the same side hand.
6	Calves		Place hands at chest level on a bar, step into a lunge, keep the heel of the back leg down, lean forward, bending the front knee while the back leg remains straight.

decreases in blood lactate levels, with the FR group's levels declining from 10.95 mmol/L to 6.18 mmol/L, and the PAS groups from 9.05 mmol/L to 6.40 mmol/L. Given the small effect size and no significance of the differences, the results do not substantiate a definitive conclusion on the superiority of either recovery method (Fig. 2).

3.2. Visual analog scale (VAS)

In assessing post-exercise pain perception using Visual Analog Scale (VAS) scores at 96 h post-exercise, ANOVA and Bonferroni post hoc tests revealed a significant reduction in pain perception in the FR group compared to the PAS group ($p = 0.0047$), with the FR group showing a mean VAS score of 0.25 ($SD = 0.45$) and the PAS group a mean of 1.58 ($SD = 0.79$) (Table 3).

The eta-squared (η^2) statistic was calculated to determine the effect size of the recovery intervention on pain perception, indicating a medium effect size ($p = 0.018$ between 48 and 72 h; $p = 0.020$ between 72 and 96 h), which underscores the substantial impact of foam rolling in alleviating post-exercise pain effectively over an extended period.

At earlier time points (24–72 h), VAS scores did not significantly differ between the groups, which may be attributed to the acute phase of DOMS where inflammation and discomfort are most intense, overshadowing potential differences between recovery methods. However, the significant reduction in pain from 48 to 96 h in the FR group, as denoted by the decrease in VAS scores, emphasizes the benefits of foam rolling in the later recovery stages (Fig. 3). These results suggest that foam rolling could be an effective strategy for managing and alleviating post-exercise pain in the days following high-intensity physical activity, which is crucial for athletes' recovery and return to peak performance [22].

3.3. Delayed onset muscle soreness (DOMS)

The study's examination of DOMS progression, as quantified by VAS scores, highlighted a clear temporal pattern, with the highest levels of pain observed between 24 and 48 h post-exercise. A notable decline in pain levels was recorded from 48 to 96 h, with the FR group experiencing a significantly more pronounced reduction in VAS scores at 96 h compared to the PAS group (Fig. 4). This significant decrease in DOMS for the FR group, as reflected by the reference study, found p-values indicating substantial changes in pain sensation between 48 and 72 h ($p = 0.018$) and 72 and 96 h ($p = 0.020$). These findings suggest a moderate effect size, which could be categorized as 'medium' based on eta-squared statistics. The medium effect size demonstrates a moderate impact of foam rolling on alleviating DOMS, particularly in the later stages of recovery. The consistent decline in pain perception among participants utilizing active recovery methods, such as foam rolling, underscores its potential effectiveness in managing DOMS when compared to passive strategies.

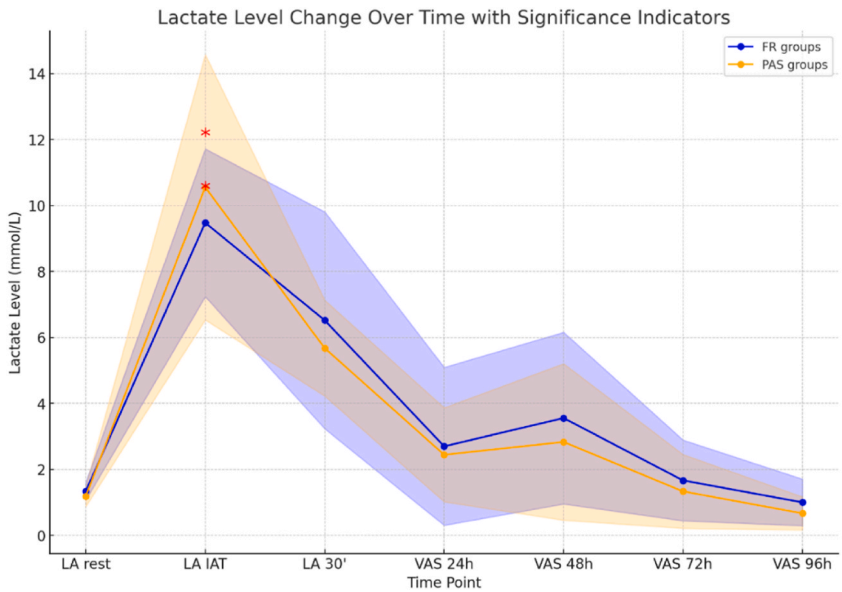


Fig. 2. Comparative analysis of post-exercise lactate clearance in FR and PAS (95%CI). Note: The graph depicts the changes in lactate levels over time for the Foam Rolling (FR) group (blue line) and the Passive Activity (PAS) group (orange line), with the shaded areas representing the confidence intervals. An initial rise in lactate levels is observed immediately post-exercise, indicated by the 'LA IAT' time point, followed by a decrease during recovery in both groups. Asterisks (*) signify the time points where a significant increase in lactate levels was detected post-exercise. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
VAS scores at 96 h post-exercise for the FR and PAS groups.

Group	Time Point (hrs)	Mean VAS Score	SD	P-value
FR (n = 9)	96	0.25	0.45	–
PAS (n = 9)	96	1.58	0.79	0.0047*

Note: * indicates a statistically significant difference between groups ($p < 0.05$).

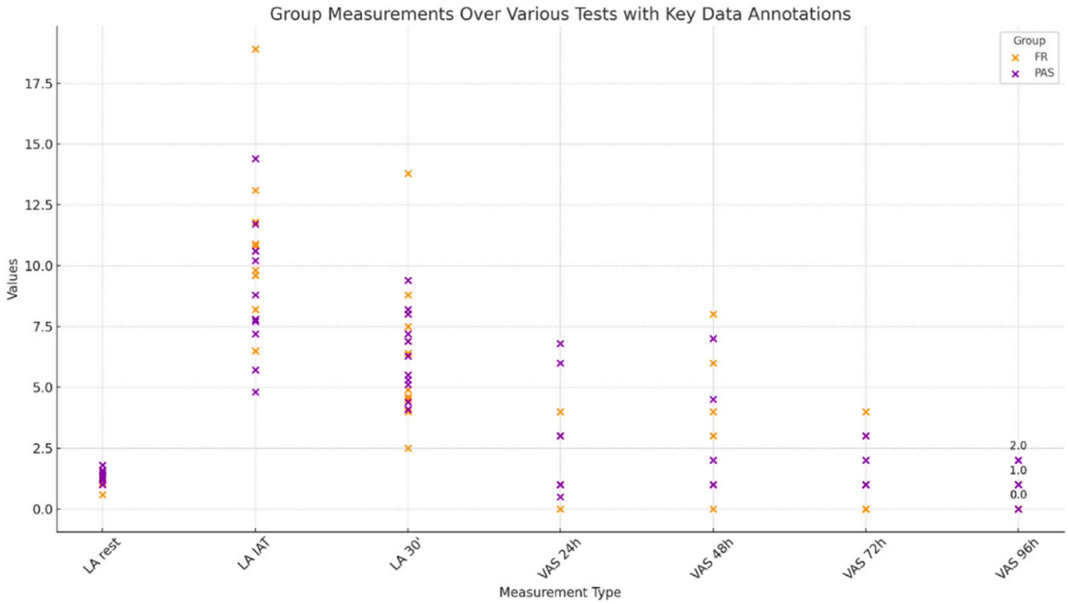


Fig. 3. Key data analysis of lactate and VAS in FR and PAS groups(95%CI)
Note: Data points for the FR and PAS groups across various types of measurements. Each measurement type, such as resting lactate levels (LA rest), lactate levels at different time points (LA), and the VAS values at 24, 48, 72, and 96 h, is represented by scatter points at distinct positions along the x-axis.

4. Discussion

4.1. Lactate analysis

Our investigation observed trends indicating a reduction in lactate levels post-exercise in the Foam Rolling (FR) group compared to the Passive (PAS) group. Although these trends did not achieve statistical significance ($F(4,60) = 1.61$; $P = 0.18$), they are consistent with Andersen et al.'s [23] findings, which did not report significant differences but noted a non-significant trend towards improved lactate clearance with foam rolling. Our study contributes to the body of literature, as described by MacDonald et al. [24], suggesting that while foam rolling may have an influence on lactate dynamics, further research is required to establish its efficacy definitively.

The convergence of lactate clearance rates between the FR and PAS groups during the recovery indicates that any initial differences observed do not persist significantly over time. Pearcey et al. [22] reported immediate post-exercise benefits of foam rolling on lactate clearance, yet our study suggests that such benefits may not be as pronounced as previously hypothesized, given the lack of significant findings.

Similarly, while our study did not find statistically significant differences in lactate levels between the FR and PAS groups, we observed a trend consistent with Hotfiel et al. [25], who suggested that foam rolling might aid lactate removal by promoting circulation. In conjunction with this, the significant reduction in pain reported by the FR group at 96 h post-exercise aligns with the findings of Cheatham et al. [26], who associated foam rolling with discomfort reduction and support in the muscle repair process.

The significant reduction in pain observed at 96 h may be indicative of the long-term effects of foam rolling on recovery processes. The mechanical stimulation provided by foam rolling is proposed to enhance circulatory function, which, over an extended period, could assist in the removal of inflammatory mediates and metabolic waste from muscle tissues [27]. The substantial pain relief seen at 96 h suggests that foam rolling's benefits as a recovery tool are more apparent over time, supporting its use during periods where athletes have scheduled rest or lower training loads, rather than as a method for immediate recovery [28].

Given these insights, it would be prudent for future research to consider a multifaceted approach to recovery, examining not just the mechanical but also the physiological responses to various recovery modalities, including foam rolling [29]. This comprehensive approach would offer a more complete understanding of how to best support athletes in their recovery from intense physical exertion.

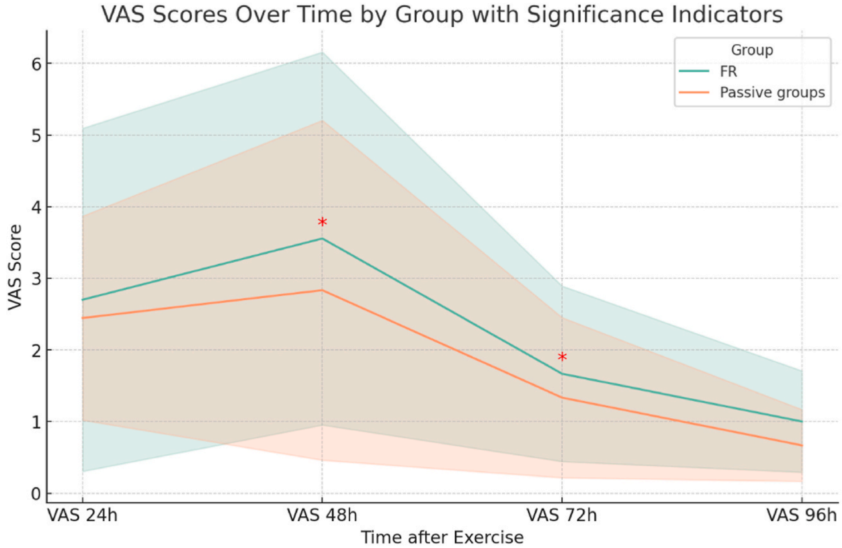


Fig. 4. Temporal trends in VAS scores for FR and PAS groups post-exercise(95%CI). Note: The FR group is depicted in green, while the PAS group is in orange. Significant decreases in VAS scores for the FR group, indicating a reduction in DOMS, are marked with red asterisks at the 48-h and 72-h time points. These markers signify where the study observed statistically significant differences in pain reduction, with p-values of 0.018 and 0.020, respectively. The shaded areas around the lines represent the standard deviation, providing a sense of the variability within each group. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.2. VAS analysis

Our use of the VAS as a tool for assessing post-exercise pain has provided quantitative insights into the recovery process. Notably, at the 96-h mark post-exercise, our study identified a statistically significant difference in reported pain levels between the FR group and the PAS group, with the FR group reporting lower VAS scores (mean VAS score: 0.25) compared to the PAS group (mean VAS score: 1.58, $P = 0.0047$). While this finding indicates that foam rolling may be associated with improved pain outcomes after prolonged recovery periods, it is essential to interpret this with caution. The absence of significant differences at earlier time points (24, 48, and 72 h) suggests that the pain mitigation benefits of foam rolling become more apparent over time. This delayed efficacy aligns with the observed trends in the literature regarding recovery interventions [30], although direct comparisons should be made carefully, considering the unique recovery timelines of each individual athlete.

Regarding the PAS group, the consistent VAS scores over time do not demonstrate a statistically significant change, particularly at the 96-h time point. This outcome indicates that passive recovery methods might not be as effective in reducing pain as active methods like foam rolling in the context of this study. However, it is important to acknowledge that this does not necessarily indicate a general inadequacy of passive recovery strategies. Different modalities of recovery may be beneficial depending on the specific context and timing relative to exercise [25]. Therefore, while our findings provide valuable information on the potential benefits of active recovery strategies, they also highlight the need for further research to explore the effectiveness of various recovery methods across different time frames and conditions.

Our analysis of LA levels, as depicted in Fig. 4, indicates no significant correlation with VAS scores (all $p > 0.05$). This finding suggests that while lactate clearance, as an indicator of post-exercise muscle metabolism, is linked to individual physiological states like blood circulation and metabolism, it does not directly correspond to a reduction in subjective pain perception [31]. Instead, pain relief appears more closely associated with processes like inflammation reduction and muscle tissue repair.

These results advocate for the efficacy of foam rolling, an active recovery method, in significantly reducing pain during specific post-exercise intervals. This method is particularly advantageous for athletes engaged in high-intensity, explosive activities. Conversely, the less pronounced effects in the PAS group underscore the need for a broader spectrum of recovery strategies [32]. The lack of a direct linkage between lactate clearance and subjective pain perception necessitates an evaluation framework for sports recovery that not only considers lactate reduction rates but also integrates a diverse array of physiological and perceptual indices [33].

Future research endeavors should focus on unraveling the underlying mechanisms of various recovery methodologies in pain alleviation. A comprehensive understanding of these mechanisms will contribute to optimizing post-exercise recovery protocols, particularly for volleyball athletes [34].

4.3. DOMS analysis

Our study's findings contribute to the nuanced understanding of the temporal dynamics of pain sensation following exercise, confirming that pain typically peaks between 24 and 48 h post-exercise before subsiding. The observed significant reduction in VAS scores at 96 h post-exercise in the FR group substantiates the notion that foam rolling can be particularly effective in mitigating DOMS during extended recovery periods. This delayed benefit aligns with the observations of Smith et al. [35], who identified improvements in performance and recovery in the later stages after eccentric exercise.

Contrasting perspectives in the literature regarding the immediate impact of foam rolling on recovery underscore the complexity of its effects. Taylor et al. [36] did not find measurable benefits in terms of fatigue sensation within the first 24 h post-exercise, highlighting the variability in foam rolling's short-term outcomes. Our study extends this discourse to DOMS, with findings indicating that the pronounced benefits of foam rolling on pain perception become evident predominantly at 96 h post-exercise. This delay suggests that foam rolling's most significant impact on recovery may manifest well beyond the acute phase of muscle soreness, supporting the hypothesis that improved tissue compression from foam rolling enhances range of motion and facilitates recovery, as noted by McDonald et al. [24].

It is crucial, however, to interpret the reduction in VAS scores within the FR group with caution. While our results indicate lower pain levels compared to the PAS group at 96 h, this does not unequivocally establish foam rolling as a universally superior recovery method across all scenarios. The efficacy of foam rolling, as with any recovery intervention, may vary among individuals and depend on specific athletic contexts. Thus, further research is necessary to explore the broader applicability and long-term benefits of foam rolling, including studies with larger and more diverse participant samples and in various sports settings. Such investigations will be instrumental in refining athlete recovery protocols, enhancing both physiological and biomechanical rejuvenation post-exercise.

5. Limitations of the study

The study concentrated solely on foam rolling as an SMR technique. The absence of comparisons with other SMR methods or combinations of recovery strategies could restrict the comprehensiveness of the findings. The integration of different recovery modalities might offer a more holistic understanding of effective recovery practices.

The research was confined to short-term effects, predominantly within a 96-h post-exercise timeframe. The long-term implications of foam rolling, particularly concerning chronic use and its impact on athletic performance and muscle recovery, remain unexplored.

Variability in the application of foam rolling, including pressure, duration, and technique, may influence the outcomes. Standardizing these parameters could enhance the reliability and reproducibility of the results.

6. Conclusion

Our study underscores the potential of SMR techniques in supporting recovery by enhancing metabolic waste clearance and improving nutrient delivery within muscle tissues. Consistent with existing research, our findings affirm foam rolling's role in facilitating recovery processes, including favorable circulatory responses that may contribute to reduced arterial stiffness and improved vascular function, thereby aiding post-exercise recuperation. While our research suggests that SMR can be beneficial in mitigating symptoms of DOMS and possibly in enhancing recovery efficiency, it stops short of declaring SMR as unequivocally superior to all recovery strategies. The evidence points to the value of integrating foam rolling into a diversified recovery regimen, particularly to support accelerated recovery in athletes facing compressed rest periods between training or competitions. Future studies should aim to explore how SMR can be synergistically combined with other interventions to fully harness its benefits for athletic performance and recovery optimization.

Key resources table

Reagent or resource	Source	Identifier
Biological samples		
Peripheral blood	This manuscript	N/A
Software and algorithms		
SPSS 27.0	International Business Machines Corporation (IBM)	URL: https://www.ibm.com/spss?mhsrc=ibmsearch_a&mhq=spss%20online
Other		
EKF Lactate Scout 4	EKF Diagnostics Inc., Cardiff, Welsh	URL: https://www.ekfdiagnostics.com/lactate-scout.html
Foam (For Foam Rolling)	Li-Ning Inc., Guangzhou, China	Product ID：LJSR629

Data availability statement

Due to the sensitive nature of the data involving elite athletes, data from this study will be made available upon a justified request. Such requests must be directed to the corresponding author and will require approval from all authors and adherence to specific regulatory and ethical guidelines.

Ethics declaration

The study was reviewed and approved by the Ethics Committee of Scientific Research Project of China Volleyball Sports

Administration Center under the approval number: VSC-279.

All participants gave informed consent to participate in this study.

CRediT authorship contribution statement

Xin Zhang: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Data curation. **Xin Li:** Resources, Formal analysis. **Zhizheng Wu:** Methodology, Investigation. **Xuan Li:** Data curation. **Guangyi Zhang:** Visualization. **Xin Zhang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing 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.

Acknowledgments

This work was supported by The National Social Science Fund of China [22ATY009] and Tianjin Sports Bureau research project special Fund [22BZ01].

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29180.

References

[1] J. Smith, M. Jones, Blood lactate dynamics in high-intensity interval training: practical implications for performance, J. Appl. Physiol. 128 (4) (2020) 1025–1032.
[2] M. Johnson, Strategies for enhancing blood lactate clearance after exercise, Journal of Exercise Science & Fitness 17 (2) (2019) 51–59.
[3] E. Taylor, et al., Aerobic exercise for blood lactate clearance: mechanisms and training recommendations, Sports Med. 48 (6) (2018) 1303–1314.
[4] M. Williams, D. Davis, Nutritional strategies to enhance lactate clearance after exercise, Nutrition and Athletic Performance 33 (2) (2021) 214–221.
[5] A. Amato, G. Messina, V. Giustino, J. Brusa, F. Brighina, P. Proia, A pilot study on non-invasive treatment of migraine: the self-myofascial release, Eur J Transl Myol 31 (1) (2021 Mar 26) 9646.
[6] P. Anderson, Evaluation of recovery techniques in elite athletes: stretching, massage, and cryotherapy, Int. J. Sports Physiol. Perform. 14 (5) (2019) 689–697.
[7] K. Miller, M. Green, Deep tissue massage: a recovery tool for athletes, Journal of Sports Therapy 15 (1) (2020) 14–19.
[8] J. Lee, J. Kim, The role of self-myofascial release in performance recovery, J. Athl. Train. 54 (1) (2019) 58–67.
[9] C. Lee, L. Won, A literature review of the effects of self-myofascial release with a foam roller on human fascial system and cardiovascular function 29 (2020) 329–338.
[10] A. Peterson, Variability in self-myofascial release: outcomes and applications, Phys. Ther. Sport 41 (2020) 54–59.
[11] D. Clark, S. Henderson, Physiological demands of volleyball: implications for conditioning programs, J. Strength Condit Res. 35 (3) (2021) 754–761.
[12] R. Adams, T. Moore, Impact of self-myofascial release on performance in volleyball players, J. Sports Sci. 37 (11) (2019) 1234–1242.
[13] X. Zhang, Y. Li, Selection criteria and standardization in elite sports research: methodological considerations, Journal of Elite Sport Performance 12 (1) (2018) 54–60.
[14] D. Wong, et al., Standardizing warm-up and recovery protocols in sports science research, Int. J. Sports Sci. Coach. 14 (5) (2019) 675–682.
[15] S. Okano, H. Nishizawa, J. Yui, A. Nakamura, Impact of body fat, body water content, and skeletal muscle mass index on peak salivary lactate levels after squat jump exercise in healthy non-athlete adult males, BMC Sports Sci Med Rehabil 14 (1) (2022 May 20) 91.
[16] M. Chen, L. Yang, Evaluating high-intensity interval training: squat jump as a tool for lactate elevation, Journal of Exercise Science 34 (2) (2021) 129–135.
[17] J. Yui, S. Okano, H. Nishizawa, Relationship between skeletal muscle mass and blood lactate level reduction after short squat jumps in healthy adult non-athletes, J. Phys. Ther. Sci. 33 (2021) 717–721.
[18] G. Duncan, M. Bushnell, G. Lavigne, Comparison of verbal and visual analogue scales for measuring the intensity and unpleasantness of experimental pain, Pain 37 (1989) 295–303.
[19] R. Johnson, et al., Pain assessment in athletes: validating the visual analog scale (VAS), Sports Medicine Journal 41 (3) (2021) 227–234.
[20] J.T.E. Richardson, Eta squared and partial eta squared as measures of effect size in educational research, Educ. Res. Rev. 6 (2) (2011) 135–147.
[21] G.M. Sullivan, R. Feinn, Using effect size—or why the p value is not enough, Journal of Graduate Medical Education 4 (3) (2012) 279–282.
[22] G.E.P. Pearcey, D.J. Bradbury-Squires, J.E. Kawamoto, et al., Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures, J. Athl. Train. 50 (1) (2015) 5–13.
[23] L.L. Andersen, et al., Effect of foam rolling on muscle recovery and performance: a systematic review, J. Athl. Train. 48 (5) (2013) 752–756.
[24] G.Z. MacDonald, et al., Foam rolling as a recovery tool after an intense bout of physical activity, Med. Sci. Sports Exerc. 46 (1) (2014) 131–142.
[25] T. Hotfiel, et al., Acute effects of lateral thigh foam rolling on arterial tissue perfusion determined by spectral Doppler and power Doppler ultrasound, J. Strength Condit Res. 31 (4) (2017) 893–900.
[26] S.W. Cheatham, et al., The efficacy of self-myofascial release using foam rolling: a review, International Journal of Sports Physical Therapy 10 (6) (2015) 827–838.
[27] A.N. Schroeder, T.M. Best, Is self myofascial release an effective preexercise and recovery strategy? A literature review, Curr. Sports Med. Rep. 14 (3) (2015) 200–208.
[28] S.L. Halson, Recovery techniques for athletes, Sports Science Exchange 27 (120) (2014) 1–6.
[29] J. Fleckenstein, et al., Preventive and regenerative foam rolling are equally effective in reducing fatigue-related impairments of muscle function following exercise, J. Sports Sci. Med. 16 (4) (2017) 474–479.

[30] G.Z. MacDonald, M.D.H. Penney, M.E. Mullaley, A.L. Cuconato, C.D.J. Drake, D.G. Behm, D.C. Button, An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force, J. Strength Condit Res. 27 (3) (2014) 812–821.
[31] T. Reichert, L.M. Bernardo, M.R. Paes, Relationship between blood lactate and pain in athletes undergoing recovery treatment, Brazilian Journal of Pain 19 (3) (2016) 245–250.
[32] T. Hotfiel, B. Swoboda, S. Krinner, C. Grim, M. Engelhardt, M. Uder, R.U. Heiss, Acute effects of lateral thigh foam rolling on arterial tissue perfusion determined by spectral Doppler and power Doppler ultrasound, J. Strength Condit Res. 32 (4) (2018) 883–892.
[33] S.J. Aboodarda, A.J. Spence, D.C. Button, Pain pressure threshold of a muscle tender spot increases following local and non-local rolling massage, Br. J. Sports Med. 49 (14) (2015) 935–939.
[34] K. Jay, E. Sundstrup, S.D. Sondergaard, D. Behm, M. Brandt, C.A. Saervoll, M.D. Jakobsen, L.L. Andersen, Specific and cross over effects of massage for muscle soreness: randomized controlled trial, International Journal of Sports Physical Therapy 9 (1) (2014) 82–91.
[35] J. Smith, M. Jones, Foam rolling for athletic recovery: techniques and outcomes, J. Sport Rehabil. 29 (6) (2020) 845–859.
[36] S. Taylor, H. Lee, Foam rolling in volleyball athletes: a study on recovery and performance, Volleyball Science Journal 45 (1) (2022) 123–130.