High-pressure intermittent pneumatic compression applied immediately after physical exercise effectively reduces fatigue and enhances performance: a preliminary study

La compresión neumática intermitente de alta presión aplicada inmediatamente después del ejercicio físico reduce eficazmente la fatiga y mejora el rendimiento: un estudio preliminar

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Abstract

Introduction: The use of intermittent pneumatic compression (IPC) has gained popularity in the sports world as one of the appropriate recovery methods to improve athlete performance and accelerate recovery. However, the benefits of IPC as a recovery method are still very limited.
Objective: This study aims to further investigate the effects of high-pressure IPC use on fatigue recovery and performance after physical exercise.
Methodology: Fourteen subjects were divided into two groups, each consisting of seven subjects: the intermitten pneumatic compression (IPC) group, which received the IPC intervention and the passive recovery (PR) group, which did not receive any intervention. Both groups performed plyometric training, with measurements of blood lactate levels, leg explosive power and vertical jump height taken before and after recovery. Descriptive statistical analysis, paired sample t-test, and independent sample t-test were used in data analysis.
Results: The results showed significant differences in blood lactate levels (p=0.002) and vertical jump height (p=0.006) between the IPC recovery group and the PR group after recovery. Although an increase in leg explosive power was observed after recovery, no statistically significant difference was found between the IPC recovery group and the PR group (p=0.496).
Conclusion: The use of high-pressure IPC after physical exercise is significantly more effective than passive recovery in terms of reducing blood lactate levels and enhancing vertical jump height. Although there was a slight increase in leg explosive power, this change was not statistically significant; nonetheless, it is still noteworthy.

Keywords

Blood lactate; intermittent pneumatic compression; muscle fatigue; performance; exercise.

Resumen

Introducción: El uso de la compresión neumática intermitente (CNI) ha ganado popularidad en el mundo del deporte como uno de los métodos de recuperación adecuados para mejorar el rendimiento de los atletas y acelerar la recuperación. Sin embargo, los beneficios de la CNI como método de recuperación son aún muy limitados.
Objetivo: Este estudio tiene como objetivo investigar más a fondo los efectos del uso de la CIP de alta presión en la recuperación de la fatiga y el rendimiento después del ejercicio físico.
Metodología: Catorce sujetos se dividieron en dos grupos, cada uno compuesto por siete participantes: el grupo de compresión neumática intermitente (CNI), que recibió la intervención de CNI, y el grupo de recuperación pasiva (PR), que no recibió ninguna intervención. Ambos grupos realizaron entrenamiento pliométrico, y se efectuaron mediciones de los niveles de lactato en sangre, de la potencia explosiva de las piernas y de la altura del salto vertical antes y después de la recuperación. En el análisis de datos se utilizaron análisis descriptivos, la prueba t de muestras pareadas y la prueba t de muestras independientes.
Resultados: Los resultados mostraron diferencias significativas en los niveles de lactato en sangre (p=0.002) y en la altura del salto vertical (p=0.006) entre el grupo de recuperación con CNI y el grupo de PR después de la recuperación. Aunque se observó un aumento en la potencia explosiva de las piernas tras la recuperación, no se encontraron diferencias estadísticamente significativas entre el grupo de recuperación con CNI y el grupo con PR (p=0.496).
Conclusión: El uso de CIP de alta presión después del ejercicio físico es significativamente más eficaz que la recuperación pasiva en términos de reducción de los niveles de lactato en sangre y de mejora de la altura de salto vertical. Aunque se produjo un ligero aumento de la potencia explosiva de las piernas, este cambio no fue estadísticamente significativo; no obstante, sigue siendo digno de mención.

Palabras clave

Lactato en sangre; compresión neumática intermitente; fatiga muscular; actuación; ejercicio.

Introduction

High-intensity physical exercise increases lactic acid levels in the blood and muscles, which is a direct indicator of fatigue. (McDougle et al., 2023; Theofilidis et al., 2018). Muscle fatigue is characterized by a reduced capacity of the muscle to produce or maintain its maximal strength (Razeghi & Nouri, 2015). In sports, muscle fatigue is often regarded as a risk factor for injury(Vermeulen et al., 2023). This is due to the fact that fatigued muscles are unable to contract maximally. Muscle fatigue has been shown to impair athlete performance by decreasing range of motion (ROM) (Wong et al., 2020), decreasing leg muscle strength (Gao et al., 2023), and lowering vertical jump height (Cooper et al., 2020). An increase in blood lactate levels can be problematic for performance in training and subsequent competitions (Cairns, 2006). Therefore, the use of appropriate recovery methods after exercise is essential. Recovery after training is essential to restore physical condition, especially regarding sports performance (Malm et al., 2019). Recovery after physical exercise or competition can effectively reduce blood lactate levels (Nalbandian & Takeda, 2016), so athletes need a fast recovery method. Additionally, faster recovery from sports training and competition is a crucial component to enable greater performance in preparation for the next training or competition (Byrd et al., 2020; Galaz-Campos et al., 2021). If muscle recovery is not conducted properly, it may result in decreased physical performance and raise the risk of injury (Kaesaman & Eungpinichpong, 2019).

Intermittent Pneumatic Compression (IPC) is one of the many recovery methods that have been suggested to speed up recovery (Edholm et al., 2024; Maia et al., 2024b). IPC is an emerging recovery modality, gaining popularity among practitioners and athletes over the past few years (Cochrane et al., 2013; Hoffman et al., 2016). The mechanism of IPC resembles massage therapy, as it applies rhythmic, air-pressurized compression to the limbs, which aims to stimulate circulation, reduce pain, and alleviate muscle stiffness, making it beneficial for physically and psychologically active individuals (Draper et al., 2020). Physiologically, IPC enhances blood circulation and metabolic recovery by mimicking the natural muscle pump, thereby increasing venous return, lymphatic drainage, and metabolic waste removal (Artés et al., 2024; Yanaoka et al., 2022). The cyclic compression stimulates endothelial shear stress, promoting nitric oxide (NO) release, which improves vasodilation, capillary perfusion, and oxygen diffusion, supporting the transition from anaerobic glycolysis to oxidative metabolism for optimal recovery (Tan et al., 2006; Zuj et al., 2018). Additionally, IPC may aid neuromuscular recovery by influencing muscle fiber recruitment, proprioceptive signaling, and reducing post-exercise edema, further enhancing muscle function restoration (Maia et al., 2024).

Several prior research has revealed that the use of intermitten pneumatic compression (IPC) can reduce muscle soreness (Sands et al., 2015; Winke & Williamson, 2018), increase flexibility (Sands et al., 2014; Winke & Williamson, 2018), reduces muscle swelling and stiffness (Winke & Williamson, 2018), improves the recovery of the cardiovascular system (Artés et al., 2024) and increase blood flow while facilitating the removal of metabolic wastes from the muscles (Hanson et al., 2013). In contrast, studies have shown the use of intermittent pneumatic compression (IPC) to be ineffective in decreasing lactic acid concentration (Keck et al., 2015; Overmayer & Driller, 2018). Interestingly, one study reported that IPC use led to higher lactic acid concentrations during subsequent performance (Marcello et al., 2019). This discrepancy may be due to inconsistent methodology, duration and recovery stress. As previously described, intermittent pneumatic compression (IPC) works in a similar way to massage. It is known that the use of massage has been shown to be one of the strategies that can accelerate recovery after physical exercise, one of which is reducing lactate levels in the blood. (Avandi et al., 2024; Welis et al., 2023), so the use of intermittent pneumatic compression (IPC) may serve as a mechanical method to mimic such responses. Recently (Maia et al., 2024a) showed that the use of intermittent pneumatic compression (IPC) with high pressure effectively increased blood flow after recovery, this is thought to help decrease lactic acid concentration so as to optimize recovery after physical exercise.

Although several previous studies have reported favorable effects of IPC, its impact on blood lactate levels and athletic recovery requires further investigation due to its critical role in optimizing post-exercise performance. Therefore, this study aims to investigate the effects of high-pressure intermittent pneumatic compression on fatigue recovery and athletic performance following physical exercise. Specifically, this study seeks to determine whether high-pressure IPC enhances post-exercise recovery by accelerating blood lactate clearance and improving neuromuscular performance, particularly in leg explosive power and vertical jump height. By addressing this question, the study is expected to provide new insights for coaches and athletes on optimizing recovery strategies. The findings will contribute to a deeper understanding of the role of recovery in athletic performance, ultimately enhancing performance and reducing the risk of injury.

Material and Methods

Study participants

A total of 14 young adults with an average age of 19 to 24 years old, actively exercising, no history of chronic diseases, and voluntarily consented to take part in this research. The subject were divided into two groups: the intermittent pneumatic compression group (IPC, n = 7) and the passive recovery group (PR, n = 7). All subjects received information both verbally and in writing before the implementation of the study and respondents also expressed their willingness to participate in this study by signing informed consent. This study was approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Airlangga, with the number: 49/EC/KEPK/FKUA/2024.

Protocol study

Subjects were instructed to undergo an eight-hour fasting period, during which they were only allowed to consume mineral water, and not to perform any physical exercise for twenty-four hours prior to the start of the study. The fatigue-inducing exercises were specifically designed to focus on the lower extremities and these exercises were implemented and supervised by professionals. Subjects were asked to perform countermovement jumping plyometric exercises in five sets of twenty repetitions, with a one-minute rest interval allocated between each set and repetition (Mirzaei et al., 2014). During the rest, subjects were allowed to drink mineral water and then continue until the last set of repetitions.

After the physical exercise intervention, the intermittent pneumatic compression (IPC) (Normatec Recovery System, Watertown, MA, USA) recovery intervention was continued. IPC recovery was applied for 20 minutes with 110 mmHg high pressure on the lower extremities, while subjects maintained a comfortable supine position. This protocol was in accordance with the manufacturer's recommendations and aligned with previous studies (Draper et al., 2020; Hoffman et al., 2016; Winke & Williamson, 2018). Passive recovery (PR) was performed with the subject in the supine position for 20 minutes without being given any interventions.

Data collection

All measurements were taken twice: (1) pre-recovery and (2) post-recovery. In this study, blood lactate levels were measured using the Accutrend Plus Meter (Accutrend® lactate meter, Roche Diagnostics, Mannheim, Germany) with a concentration unit of mmol/L after a capillary blood sample was taken from the fingertip of the subject (Avandi et al., 2024).

Countermovement jump (CMJ) with a dual force plate device (Forcedecks, FDLite V.2, VALDHUB, Australia) measures leg explosive power and vertical jump height (Collings et al., 2024; Heishman et al., 2018; Wiriawan et al., 2024). Each trial begins with the subject standing still with each foot on the dual force plate platform. Subjects started in an upright standing position, with feet placed hip to shoulder width apart and hands placed on hips during the jump. We limited the arm swing to minimize the influence of upper body movement, by limiting arm movement, we were able to focus more on the forces generated through the lower extremities. After initiating the movement, subjects tried to jump as high vertically as they could. The subjects were told to jump as high as they could, drop their bodies as fast as they could, and then stand back up after landing. Subjects returned to the starting position after each jump, and this procedure was performed for two trials with the highest score results calculated automatically and in real time using the Forcedecks device from VALDHUB. The highest value of the highest leg explosive power and jump height used in research data (Heishman et al., 2019; Lees et al., 2004). All testing sessions were supervised by a skilled instructor.

Data analysis

The Shapiro-Wilk test was utilized to assess the normality of the data distribution. Differences between the pretest and posttest results in the IPC and PR groups were analyzed using a paired sample t-test. Furthermore, an independent sample t-test was used to compare the differences between the PR and IPC groups. Statistical significance was set at $P < 0.05$. SPSS version 26 was used for all analyses in this study. Effect size analysis was applied using Cohen's d. Cohen classified effect sizes as small (d = 0.2), medium (d = 0.5), and large (d ≥ 0.8) (Sullivan & Feinn, 2012).

Results

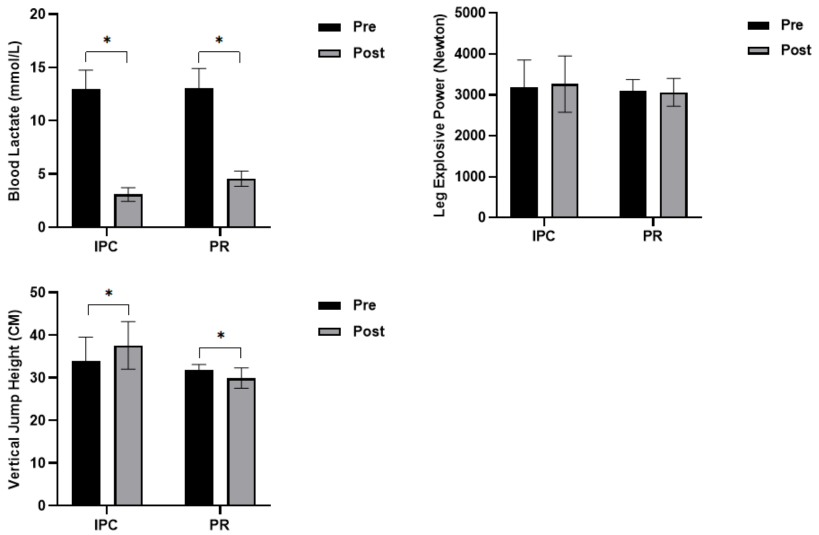
The characteristics of the respondents are normally distributed among the participants. The results of statistical analysis of participant characteristics data in general show that there are no significant differences in the average age, weight, height, and body mass index (BMI) between the two groups which can be seen in Table 1. The results of analysis of blood lactate levels, leg explosive power and vertical jump height pre- and post-recovery in both groups can be seen in Figures 1, while the differences between groups are presented in Table 2.

Table 1. Participant Characteristics Data

Variables	IPC (*n* = 7)	PR (*n* = 7)	95% CI	p-Value
Age (years)	21.00 ± 0.53	21.14 ± 0.34	-1.52 to 1.24	0.825
Weight (kg)	63.28 ± 2.56	63.14 ± 1.62	-6.47 to 6.75	0.963
Height (cm)	170.14 ± 2.40	168.71 ± 1.71	-5.01 to 7.86	0.637
BMI (kg/m^2)	21.65 ± 0.55	22.12 ± 0.35	-1.90 to 0.96	0.486

Description: IPC: Intermittent pneumatic compression; PR: Passive recovery; P-value obtained from independent sample t-test; All data are presented as mean ± standard deviation (SD).

Figure 1. Assessment blood lactate levels (mmol/L), leg explosive power (Newton), and vertical jump height (cm) in both group. Description: (*)Significant at pre-recovery (p ≤ 0.05). All data are presented as mean ± standard deviation (SD). P-value obtained from paired sample t-test.



Based on our analysis, there was a significant decrease in average blood lactate levels pre- and post-recovery in both the IPC group (95% Confidence Interval of the Difference (95% CI): 8.35 to 11.39; p = 0.001; Effect size (ES): 7.312) and the PR recovery group (95% CI: 6.71 to 10.24; p=0.001; ES: 5.976) (Figure 1). In contrast, leg explosive power exhibited an increase in average pre- and post-recovery in the IPC group, although this change was not statistically significant (95% CI: -181.74 to 33.17; p=0.142; ES: 0.111). Conversely, the PR group demonstrated a decrease in average leg explosive power pre- and post-recovery, which was also not statistically significant (95% CI: -125.86 to 203.86; p=0.584; ES: 0.126) (Figure 2). Additionally, we observed a significant increase in average vertical jump height pre- and post-recovery in the IPC group (95% CI: -7.45 to -0.22; p=0.041; ES: 0.684), while the PR group experienced a significant decrease in average vertical jump height pre- and post-recovery (95% CI: 0.41 to 3.36; p=0.020; ES: 0.971) (Figure 3). Furthermore, we noted significant differences in blood lactate levels (p=0.002) and vertical jump height (p=0.006) between the IPC and PR groups post-recovery, while no significant difference was found in limb explosive power (p=0.496) (Table 2).

Table 2. Differences in average blood lactate levels, isometric strength of leg muscles, leg explosive power and vertical jump height between the two groups.

Parameters	IPC (*n* = 7)	PR (*n* = 7)	p-value	95% CI	Effect size
Blood Lactate Levels (mmol/L)					
Pre-recovery	12.95±0.68	13.04±0.70	0.932	-2.22 to 2.05	0.131
Post-recovery	3.08±0.24*	4.57±0.27	0.002	-2.28 to -0.69	5.833
Leg Explosive Power (Newton)					
Pre-recovery	3190.71±249.67	3101.00±103.74	0.746	-533.59 to 713.02	0.469
Post-recovery	3265.00±259.25	3062.00±127.84	0.496	-453.70 to 859.70	0.993
Vertical Jump Height (CM)					
Pre-recovery	33.75±2.12	31.80±0.49	0.338	-2.96 to 7.31	1.267
Post-recovery	37.58±2.10*	29.91±0.91	0.006	2.41 to 12.94	4.739

Description: IPC: Intermittent pneumatic compression; PR: Passive recovery; P-value obtained from independent sample t-test; All data are presented as mean ± standard deviation (SD); (*) Significant vs. PR (p ≤ 0.05).

Discussion

This study aimed to further investigate the effects of high-pressure intermittent pneumatic compression (IPC) on fatigue recovery and performance after physical exercise. The primary findings indicated that high-pressure IPC was more effective than passive recovery in enhancing recovery, as evidenced by lower blood lactate levels and increased vertical jump height after physical exercise. However, it is important to consider leg explosive power, even though the results were not statistically significant.

Intermittent pneumatic compression (IPC) is an innovative technique in sports that is expected to improve recovery, especially in reducing pain and fatigue (Maia et al., 2024b). Muscle fatigue is usually caused by the accumulation of lactic acid in the muscles, which is regarded as the end product of metabolism after physical exercise (Bartoloni et al., 2024; Lee et al., 2023). Lactate elimination from the bloodstream and muscles is essential for recovery after exercise and for enabling further physical activity (Kang et al., 2017). This study demonstrated that IPC significantly reduced blood lactate levels after a 20-minute recovery period at a high pressure of 110 mmHg. This finding supports previous research indicating that the application of IPC at high pressure effectively enhances blood flow after recovery (Maia et al., 2024a). The compression pressure effect produced by intermittent pneumatic compression (IPC) enhances blood circulation by mimicking the natural muscle pump mechanism, thereby increasing venous return and lymphatic drainage (Artés et al., 2024). This process reduces the accumulation of metabolic byproducts, including lactic acid, and facilitates faster clearance through increased perfusion of metabolically active tissues, such as the liver and skeletal muscles (Yanaoka et al., 2022). The cyclic compression and decompression of IPC generate external mechanical forces that modulate intramuscular pressure gradients, effectively stimulating endothelial shear stress, a key physiological stimulus for nitric oxide (NO) release (Tan et al., 2006), which plays a role in vasodilation, capillary recruitment, and improved microvascular function. Enhanced capillary perfusion following IPC application may improve oxygen diffusion rates (Zuj et al., 2018), supporting a transition from anaerobic glycolysis to oxidative metabolism, which is crucial for post-exercise recovery. Additionally, IPC-induced mechanotransduction effects may influence muscle fiber recruitment and proprioceptive signaling, both of which contribute to neuromuscular recovery and muscle tone regulation (Maia et al., 2024). By reducing post-exercise edema and optimizing interstitial fluid balance, IPC may further enhance metabolic waste removal and substrate redistribution, ensuring efficient glycogen resynthesis and mitochondrial recovery. However, while these physiological mechanisms are well-documented in the literature, it is important to acknowledge that this study did not directly measure endothelial function, nitric oxide levels, proprioceptive responses, or mitochondrial adaptations. The discussion of these effects is based on established theoretical models and prior research on IPC and recovery physiology. Future studies should incorporate biomarker analysis, electromyographic (EMG) assessments, and hemodynamic measurements to empirically validate the extent to which IPC influences these physiological processes. Nevertheless, the observed reductions in blood lactate levels following IPC application suggest a potential interplay between circulatory, metabolic, and neuromuscular mechanisms, reinforcing IPC's role as a multifaceted recovery tool that extends beyond simple metabolic clearance (Martin et al., 2015; Zuj et al., 2018).

This study presents interesting findings regarding blood lactate after physical exercise. Although the IPC group and the PR group significantly reduced blood lactate levels. Our results showed that the IPC group was much better at reducing blood lactate levels than the PR group after physical exercise. These results are in line with research cightonducted by (Hanson et al., 2013) which proved that the use of IPC for 20 minutes was as effective as active recovery which could reduce blood lactic acid levels after performing the Wingate test compared to passive recovery. Increased limb blood flow resulting from intermittent pneumatic compression may enhance exercise performance and recovery (Zuj et al., 2018).

While no statistically significant difference in leg power was observed between the IPC and PR groups, the IPC group exhibited a 2% increase in leg explosiveness, whereas the PR group experienced a 1% decline. Although this difference did not reach statistical significance, such marginal improvements could hold practical relevance in competitive sports, where even small gains in explosive power may influence athletic performance outcomes. In high-performance settings, minor enhancements in force production and neuromuscular efficiency can contribute to improved agility, acceleration, and overall movement proficiency. Therefore, despite the lack of statistical significance, the observed trend suggests that IPC may still offer potential benefits in optimizing post-exercise recovery. In terms of vertical jump height, the results showed that the IPC group was more effective in increasing vertical jump height than passive recovery. Specifically, the IPC group produced an 11% increase, while the PR group produced a 6% decrease. The results of our study differ from the research conducted by Cochrane et al. (2013), which demonstred that the use of intermittent pneumatic compression (IPC) had no significant effect on vertical jump performance after a 30-minute recovery period at a pressure of 60-80 mmHg. This difference is believed to stem from variations in the pressure applied. Lower pressure provides fewer benefits compared to higher pressure (Waller et al., 2006). This is aligns with recent research demonstrating that IPC at high pressure is significantly more effective in enhancing blood flow than moderate pressure (Maia et al., 2024a). Use compression can increase blood flow, thereby improving nutrient delivery to the muscles, which accelerates the muscle recovery and repair process (Broatch et al., 2018; Needs et al., 2023). Muscle recovery after exercise can take up to 72 hours to fully return (Thomas et al., 2018).

Intermittent Pneumatic Compression (IPC) has emerged as a promising tool for post-exercise recovery; however, its specific effects on performance-related outcomes, such as leg explosive power and vertical jump height, remain underexplored. These two metrics are critical indicators of neuromuscular function and are particularly relevant in sports that require rapid force production (Cooper et al., 2020), such as sprinting, basketball, and weightlifting. While our findings suggest that IPC contributed to improvements in these parameters, the mechanisms underlying these effects warrant further discussion. One potential explanation lies in IPC's ability to enhance blood flow and metabolic clearance, which can accelerate muscle recovery and optimize neuromuscular readiness for subsequent high-intensity movements. The relationship between leg explosive power and jump height has been well-documented (Almeida et al., 2021), indicating that improvements in force production capabilities typically translate to enhanced jumping ability. However, neuromuscular performance is influenced by multiple factors beyond muscular power alone. For example, body composition and anthropometric characteristics, including muscle fiber composition, tendon stiffness, and limb segment length, play integral roles in determining movement efficiency and force transmission (Nasrulloh et al., 2021). Therefore, while IPC may facilitate recovery, its impact on explosive movements likely depends on individual physiological attributes, which future research should consider.

The findings of this study provide novel insights into IPC's role as a recovery modality, particularly in mitigating muscle fatigue and enhancing subsequent athletic performance. The significant reduction in blood lactate levels observed in the IPC group compared to passive recovery suggests that IPC accelerates lactate clearance, which is a key factor in restoring metabolic homeostasis and delaying fatigue onset (Maia et al., 2024a). Additionally, vertical jump height improvements following IPC application indicate potential benefits for neuromuscular recovery, particularly in sports requiring repetitive maximal-effort movements. These findings align with prior studies suggesting that increased peripheral blood flow from IPC may support muscle repair by enhancing nutrient and oxygen delivery (Zuj et al., 2018). However, despite these benefits, the impact of IPC on leg explosive power was not statistically significant, which raises important considerations regarding the distinction between statistical significance and practical relevance in sports science. Even minor performance improvements can be meaningful in elite athletic settings, where marginal gains can determine competitive success (Haff & Nimphius, 2012).

Therefore, while the observed 2% increase in leg explosive power in the IPC group did not reach statistical significance, it remains relevant from a practical application standpoint. Athletes and coaches may leverage IPC as a complementary recovery strategy, particularly when paired with active recovery methods, proper hydration, and individualized training regimens to optimize post-exercise muscle function.

Despite its promising results, this study has several notable limitations that warrant further investigation. The study design focused exclusively on acute recovery effects, limiting the ability to extrapolate findings to long-term training adaptations. Future research should adopt longitudinal methodologies to determine whether regular IPC use leads to sustained physiological improvements, such as enhanced muscular endurance, reduced injury risk, or increased power output over time. Furthermore, the optimization of IPC protocols, as pressure settings, duration, and timing relative to exercise may impact recovery efficacy. Given that higher IPC pressures (≥110 mmHg) demonstrated greater benefits in this study, future research should seek to determine the optimal pressure ranges for different athletic populations, considering factors such as sport specificity, training intensity, and individual recovery rates.

In conclusion, this study highlights high-pressure IPC as a viable recovery intervention that may aid post-exercise metabolic clearance and neuromuscular function. The observed benefits in blood lactate reduction and vertical jump performance suggest that IPC could be integrated into post-training recovery protocols, particularly in high-intensity sports. While improvements in leg explosive power were not statistically significant, they remain relevant in the broader context of athletic performance optimization. To further validate these findings, future research should explore the long-term applications of IPC, investigate its mechanistic effects at the cellular level, and refine practical implementation strategies tailored to specific athletic demands.

Conclusions

This study provides new insights into recovery methods for athletes and coaches after training. Recovery methods are crucial for athletes to achieve optimal training progress and prevent injuries. The findings indicate that high-pressure intermittent pneumatic compression (IPC) effectively reduces blood lactate levels and increases vertical jump height. Additionally, a modest increase in leg explosive power was observed after recovery; however, these changes did not reach statistical significance. It is essential for coaches and athletes to prioritize recovery methods, as effective recovery can enable athletes to enhance their performance in both training and competition.

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