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REVIEW ARTICLE

Effects of pulsed electromagnetic field (PEMF) therapy on blood pressure regulation, autonomic modulation, and its potential hypotensive effect: an integrative review

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Abstract

Background: Blood pressure regulation is essential for cardiovascular health, and although physical exercise is widely recommended for this purpose, adherence may be limited in populations with functional impairments. In this context, Pulsed Electromagnetic Field (PEMF) therapy has emerged as a promising alternative, acting on autonomic, vascular, and inflammatory mechanisms, with potential hypotensive effects both at rest and in the post-exercise period. **Methods:** An integrative review was conducted using the PubMed, Scopus, Web of Science, and Embase databases, employing descriptors related to PEMF, blood pressure, and post-exercise hypotension. Randomized clinical trials, acute studies, and systematic reviews addressing the effects of PEMF on hemodynamic regulation, autonomic response, and blood pressure were included. **Results:** Evidence suggests that PEMF can induce significant reductions in systolic blood pressure (up to −11 mmHg, $p < 0.001$), enhance flow-mediated vasodilation, and increase heart rate variability. These beneficial effects have been attributed to increased nitric oxide release, reduced sympathetic activity, and improved endothelial function. Additionally, PEMF demonstrated potential in accelerating autonomic recovery following physical exertion. **Conclusion:** PEMF has shown positive effects on blood pressure regulation, potentially resulting in sustained hypotensive responses. Nonetheless, further research is required to confirm these findings. Moreover, it is suggested that PEMF may influence vagal modulation and the consequent reduction of sympathetic activity.

Keywords: Pulsed Electromagnetic Fields; blood pressure; post-exercise hypotension; heart rate variability.

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BACKGROUND

The regulation of blood pressure is a critical factor for cardiovascular health, and various interventions have been proposed to improve blood pressure control in individuals with hypertension and other associated conditions. Physical exercise has been widely recommended by international guidelines as an effective strategy for reducing blood pressure, as it induces beneficial adaptations in the cardiovascular system, including improvements in endothelial function, increased availability of nitric oxide (NO), and reduced sympathetic activity[1, 2]. However, adherence to exercise may be limited in populations with physical restrictions, such as the elderly and individuals with reduced-mobility, necessitating the development of complementary approaches for blood pressure regulation[3].

Within this context, pulsed electromagnetic field (PEMF) therapy has emerged as a promising therapeutic intervention[4], with the potential to modulate hemodynamics and reduce blood pressure through mechanisms distinct from those promoted by exercise. Studies indicate that PEMF may influence autonomic regulation, promoting a sustained hypotensive effect by reducing sympathetic activity and increasing parasympathetic activity, in addition to stimulating the release of endogenous vasodilators, such as nitric oxide (NO)[5, 6]. Recent meta-analyses suggest that PEMF may amplify the hypotensive response following exercise and contribute to the reduction of basal blood pressure, thereby reinforcing its potential as an alternative or complement to physical exercise[7, 8]. Additionally, PEMF may directly influence blood perfusion, endothelial function, and the inflammatory response, making it a viable alternative for chronic conditions such as hypertension and peripheral vascular diseases[9, 10].

Despite advancements in understanding the effects of PEMF on hemodynamic regulation, significant gaps remain in the literature regarding the magnitude and specific mechanisms of this intervention. Clinical studies present heterogeneous results, and the standardization of PEMF application protocols continues to pose a challenge for its clinical validation. Furthermore, the interaction between PEMF and other therapeutic approaches, such as physical exercise, requires further investigation to determine potential synergies and optimize intervention strategies for hypertensive individuals[11, 12]. Considering this context, the current study intends to conduct a comprehensive review of the literature regarding the effects of PEMF on blood pressure regulation and the hypotensive response after exercise, with the aim of consolidating existing evidence and identifying prospective avenues for future research in this domain.

METHODS

For the construction of this review, rigorous criteria for the search and selection of evidence were followed by two independent researchers (A.S) and (A.T) across the main journal databases, including PubMed, Scopus, Web of Science, and Embase, to identify relevant studies published in English. The descriptors employed included terms such as 'Pulsed Electromagnetic Fields,' 'Blood Pressure Regulation,' 'Exercise-Induced Hypotension,' 'Systematic Review,' and 'Meta-Analysis,' combined using boolean operators (AND, OR). The searches were conducted using filters to identify exclusive articles, with a priority given to randomized clinical trials, systematic reviews, and meta-analyses to ensure the robustness of the evidence. The inclusion criteria involved studies that assessed the effects of PEMF on hemodynamic regulation, the hypotensive response following exercise, and cardiovascular outcomes. As exclusion criteria, observational studies, case reports, and articles lacking peer review were deemed ineligible for this review's construct. Screening was conducted based on the reading of titles and subsequently abstracts. Meeting the inclusion and exclusion criteria, the selected articles were read in full, from which the following data were extracted from each study: a) authors and publication date, b) study type, as this review addresses studies with distinct designs, c) randomization and control, d) intervention variables, and e) outcomes. In case of any disagreement regarding the exclusion or inclusion of articles, a third researcher was consulted (P.A.I).

RESULTS

This review identified seven articles that were considered eligible for its final scope, one of which constitutes a systematic review[3], Four randomized controlled clinical studies[5, 11, 13, 14], two studies with acute analyses[6, 15]. The results, as well as the characteristics of the articles, are presented in Table 1.

Table 1. Characteristics of the main articles on PEMF and cardiovascular and hemodynamic changes.

Authors and Year	Type of Study	Participants	Intervention Variables	Outcome Variables and Results
Kim et al., 2020[5]	Chronic (12 weeks)	PEMF: 23 SHAM: 21	PEMF with blood pressure measurements and NO	NO↑ (16.5±5.6 to 22.2±12.5 µmol, p=0.04); SBP during exercise↓ (191.9±11.5 to 182.9±10.5 mmHg, p=0.04); Resting SBP↓ in hypertensive subgroup (135.8±8.1 to 130.0±5.7 mmHg, p=0.02)
Rikk et al., 2013[14]	Chronic (12 weeks)	PEMF: 42 SHAM: 12	PEMF (60 sessions in 12 weeks); blood pressure measurements	SBP↓ (144.8±18.7 to 133.7±9.7 mmHg, p<0.001); Pulse pressure↓ (69.1±15.0 to 59.3±25.8 mmHg, p<0.001)
Kwan et al., 2015[13]	Chronic (3 weeks)	PEMF: 7 SHAM: 6	PEMF (12 Hz, 12 Gauss, 14 sessions of 60 min); microcirculation and healing	Capillary blood velocity↑ 28% (p=0.004); Capillary diameter↑ 14% (p=0.011); Wound depth↓ (2.91±0.95 to 1.47±1.23 mm, p=0.021)
Stewart et al., 2020[11]	Chronic (12 weeks)	PEMF: 24 SHAM: 15	PEMF (3 times/day, 12 weeks); peripheral vascular function and NO	Arteriolar diameter↑ 9% after 2 min and 8.7% after 60 min (p<0.001)
Smith et al., 2004[15]	Acute	PEMF: 15 SHAM: 11	PEMF (localized for 2 min and 1 h); arteriolar diameter measurements	SBP↓ (144±15 to 133±10 mmHg, p<0.01); DBP↓ (85±7 to 80±6 mmHg, p<0.05); MAP↓ (104±8 to 98±6 mmHg, p<0.01); FMD↑ (4.88% to 7.09%, p<0.01)
Grote et al., 2007[6]	Acute	PEMF: 12; SHAM: 12	PEMF (20 min) immediately after a 4-minute stress test on a cycle ergometer	PEMF reduced resting heart rate (↓ 5 bpm, p<0.05) and increased heart rate variability (RMSSD↑, p<0.05) only in individuals with higher baseline parasympathetic tone
Pakhan et al., 2024[3]	Review systematic	8 studies	PEMF and aerobic exercises; blood pressure and quality of life	Systematic review: PEMF associated with ↓BP and ↑NO; PEMF and aerobic exercise are effective in reducing blood pressure.

Acute Effects

Firstly, only one study analyzed the impact of PEMF therapy on the acute responses of blood pressure (BP), and this study used an animal model to determine its outcomes. In the acute study conducted with Smith et al[15].The researchers investigated the immediate effects of PEMF (pulsed electromagnetic field) therapy on microcirculation in rats, using the cremaster muscle as an experimental model. The procedure involved the local application of PEMF, using a pair of Helmholtz coils positioned above and below the cremaster muscle. Measurements of arterial diameters were performed in vivo, before and after stimulation, allowing the evaluation of effects at two time intervals: after 2 minutes and after 60 minutes of exposure. The results demonstrated that stimulation with PEMF produced a significant vasodilation in the arterioles of the analyzed muscle. Specifically, after 2 minutes of application, there was an approximately 9% increase in vessel diameter, while prolonged exposure for 60 minutes resulted in an increase of about 8.7% – both results being statistically significant ($p < 0.001$). In contrast, the control group subjected to a sham simulation (without field emission) showed no significant changes in vessel diameter, and there was no impact on systemic parameters, such as blood pressure or heart rate. This acute intervention highlights that local application of PEMF can induce an immediate vasodilator response. However, we cannot extrapolate these results to humans, suggesting caution in this observation.

However, it appears that the application of PEMF is associated with an immediate increase in flow-mediated vasodilation (FMD) and improved tissue oxygenation. These effects are attributed to the greater bioavailability of NO, which acts as a potent vasodilator, facilitating the relaxation of vascular smooth muscle and increasing local blood flow[5]. The impact of PEMF therapy on the cardiovascular system may predominantly occur through the activation of voltage-dependent calcium channels, directly at peripheral sites, resulting in an increase in local bioavailability of nitric NO[16]. This regulation of endothelial vasodilation has been extensively studied and correlated with significant improvements in microvascular function[5, 11]. In accordance with Bragin, Statom[10], the increase in microcirculation promoted by PEMF also plays a significant role in reducing oxidative stress and improving tissue oxygenation. Although the literature still lacks information on this topic, some observations can be highlighted and inferred based on exercise physiology. For example, in a cross-sectional clinical trial conducted by Trofe, Piras[17], PEMF stimulation significantly increased the amplitude of muscular activity in both muscles during warm-up and exercise. This increase in muscle response amplitude is associated with greater recruitment of motor units and improved neural synchronization, favoring a more efficient pattern of muscle activation[18]. Therefore, there is an increase in local metabolic demand, reflected through a greater oxygen consumption from skeletal muscle, which requires a vascular adaptation to meet this metabolic need[19].

This phenomenon can be explained by the relationship between muscle recruitment and energy metabolism, as muscle activation requires an increase in blood flow to meet the energy demand and remove metabolites accumulated during contraction[20]. Physiologically, the increased need for oxygen in muscles triggers coordinated hemodynamic adjustments, including local vasodilation mediated through metabolic factors such as NO, adenosine, and changes in local pH, promoting an increase in blood flow to the active muscle and optimizing the diffusion of oxygen to the muscle fibers[21, 22].

Thus, from the perspective of cardiovascular physiology, these changes can directly affect the blood pressure response[23, 24]. More efficient muscle activation leads to greater venous return, increasing cardiac output[25]. Despite the study of Trofe, Piras[17] Although not directly investigating the blood pressure changes, it is speculated that the effect of PEMF therapy on muscle activation may have implications not only for neuromuscular performance[26, 27], as well as in the hemodynamic response in humans.

In summary, the underlying mechanisms of the acute effects include the activation of voltage-dependent calcium channels, increasing the entry of Ca2+ into endothelial cells and, consequently, the activation of endothelial nitric oxide synthase (eNOS), leading to an immediate improvement in capillary perfusion and a reduction in peripheral vascular resistance[28].

Chronic Effects

Chronic studies seem to provide more relevant findings in the context of blood pressure response, for example Stewart, Wheatley-Guy[11].

They investigated the effects of PEMF therapy on peripheral vascular function, blood pressure, and nitric oxide levels in hypertensive individuals over a period of 12 weeks. For this, 30 participants diagnosed with systolic hypertension greater than 130 mmHg and/or mean arterial pressure above 100 mmHg were randomized into two groups: one group underwent PEMF therapy and the other served as a control group. Before the intervention began, all participants were assessed for FMD, blood pressure, and nitric oxide levels. The experimental group used a portable PEMF device three times a day throughout the study period, while the control group received no active intervention.

After 12 weeks, the results demonstrated that PEMF promoted significant improvements in peripheral vascular function, evidenced by the increase in FMD, and normalized FMD for hyperemia, indicating a better endothelial response to vascular stimulation. Additionally, there was a significant reduction in systolic blood pressure values from 150 mmHg to 135 mmHg ($p < 0.01$) and a decrease in mean arterial pressure from 95 mmHg to 85 mmHg ($p < 0.05$) in the PEMF group, while the control group showed no changes in these parameters. However, nitric oxide levels did not show significant variations between the groups at the end of the study, suggesting that the beneficial effects of PEMF on endothelial function may be related to other mechanisms beyond the nitric oxide pathway. Based on these findings, it appears that repeated application promotes a structural and functional adaptation in blood vessels, resulting in greater vasodilator capacity and improved systemic blood flow. The authors also conclude that PEMF therapy may represent a promising non-pharmacological strategy to improve vascular function and reduce blood pressure in hypertensive individuals. However, they emphasize the need for additional studies to elucidate the exact mechanisms by which PEMF influences vascular regulation and to confirm its long-term clinical benefits.

Rikk et al[14], They investigated the effects of PEMF therapy on resting blood pressure in older adults. The randomized, double-blind clinical trial included 54 participants with a mean age of 59.8 years, allocated into two groups: PEMF (n = 42) and control (n = 12), which underwent a sham intervention. The intervention consisted of daily sessions of 15 minutes of exposure to PEMF, five times a week, for 12 weeks, totaling 60 sessions. The magnetic field was generated with the emission of low-frequency asymmetric waves (33.3 pulses/minute) and a maximum intensity of 100 microteslas.

At the end of the protocol, the PEMF group showed a significant reduction in systolic blood pressure, with mean values decreasing from 144.8 ± 18.7 mmHg to 133.7 ± 9.7 mmHg ($p < 0.001$). A significant decrease in pulse pressure was also observed, dropping from 69.1 ± 15.0 mmHg to 59.3 ± 25.8 mmHg ($p < 0.001$). Although diastolic blood pressure exhibited a slight reduction (75.5 ± 10.0 to 74.5 ± 12.2 mmHg), this difference was not statistically significant ($p = 0.063$), as well as the reduction in arterial stiffness index, which showed a trend toward significance (78.5 ± 33.2 to 64.2 ± 5.1; $p = 0.062$). No significant changes were observed in the sham group. These findings indicate that chronic application of PEMF may be effective in reducing systolic blood pressure and pulse pressure in older adults, suggesting a possible improvement in peripheral vascular resistance, without detectable adverse effects.

Additionally, studies such as the one Kwan, Wong[13] showed that PEMF therapy promotes a significant improvement in peripheral microcirculation, including increased capillary flow velocity and vessel diameter, favoring tissue oxygenation. The authors focused on the effects of PEMF on peripheral microcirculation, evaluating patients with chronic ulcers on the feet. After 8 weeks of application, there was an average increase of 20% in capillary diameter and a 15% increase in capillary flow velocity ($p < 0.001$). The significant reduction in local inflammation and the increase in tissue perfusion indicate that PEMF may be used as an effective adjunct in vascular treatments.

Another important aspect is the chronic reduction of oxidative stress and vascular inflammation, which are important factors in the pathogenesis of hypertension and cardiovascular diseases. PEMF is capable of modulating the gene expression involved in the degradation of free radicals and the synthesis of inflammatory mediators, contributing to a healthier vascular environment[28]. Additionally, the ability to activate intracellular signaling pathways, such as the vascular endothelial growth factor (VEGF) pathway, which has been associated with angiogenesis and vascular remodeling[8] offer evidence for the chronic effects of PEMF on the cardiovascular system.

DISCUSSION

This study explores the applicability of PEMF therapy on hemodynamic responses, with an emphasis on blood pressure regulation and associated hypotensive effects. Initially, the impacts of PEMF on blood pressure reduction (hypotensive effect) are addressed, highlighting its effectiveness in hypertension management. Next, the effects of this therapy on blood flow modulation are discussed, demonstrating its influence on vascular function. Finally, potential improvements in heart rate variability associated with PEMF use, as well as the underlying physiological mechanisms, are analyzed. The discussion also considers the potential of this technology as a non-invasive tool to promote beneficial cardiovascular adaptations in both clinical and healthy populations.

Post-Exercise Hypotension

Post-exercise hypotension (PEH) is a phenomenon characterized by the transient reduction of blood pressure following physical exercise, being particularly evident in hypertensive individuals and elderly populations[1, 2].

According to the meta-analytic review Whelton, Carey[1] The magnitude of PEH varies according to the intensity, duration, and type of exercise performed, with reductions in systolic blood pressure between 5 to 10 mmHg and diastolic pressure between 2 to 5 mmHg, which can persist for up to 24 hours. Our analyses indicate that PEMF appears to induce an increase in Ca2+ influx in endothelial cells and, consequently, the activation of endothelial eNOS, leading to immediate improvement in capillary perfusion and effect on peripheral vascular resistance. It is known that one of the main phenomena related to the post-exercise hypotensive response is the reduction in peripheral vascular resistance, associated with greater availability of NO and delayed autonomic recovery after physical exertion[29]. Thus, although we do not have a concrete answer, the mechanisms associated with PEMF intervention appear to resemble those of traditional resistance training[30].

The physiological mechanisms underlying PEH involve multiple systems, including autonomic regulation, endothelial modulation, and post-exercise blood flow redistribution. During physical exertion, there is an increase in sympathetic activity to sustain cardiac output and muscle perfusion. Following the cessation of exercise, a decline in sympathetic activity and an increase in parasympathetic activity are observed, which favors the reduction of blood pressure[29]

Moreover, the hypotensive response is also mediated by the increased bioavailability of vasodilatory substances, such as prostaglandins and natriuretic peptides, which promote the relaxation of vascular smooth muscle and reduction of peripheral resistance[1, 2].

Pakhan et al., (2024) in their systematic review, it is noted that individuals who regularly engage in aerobic exercise exhibit a greater hypotensive response, suggesting a cumulative effect over time[3].

PEMF therapy may enhance the effects of PEH by acting on autonomic regulation and endothelial function. PEMF can amplify FMD and reduce peripheral vascular resistance, resulting in a more prolonged and stable hypotensive response[5, 8]. Furthermore, evidence suggests that PEMF influences the activation of eNOS, promoting greater release NO and optimizing post-exercise hemodynamic recovery[6, 31].

Heart rate also appears to be affected by PEMF intervention, resulting in a reduction of myocardial workload and consequently impacting the resting blood pressure response. Studies such as the one conducted from Pakhan, Jawade[3] They suggest that the combination of PEMF with aerobic exercise enhances the beneficial effects on blood pressure and potentially its hypotensive effect, reinforcing the idea that the therapy can be an effective complement to traditional cardiovascular rehabilitation strategies.

Points and Counterpoints of Exercise and PEMF in the Hypotensive Response

Physical exercise is one of the most effective strategies for reducing blood pressure, being recommended in international guidelines for hypertension control[1]. However, its application may be limited by patient adherence, the presence of comorbidities, and physical restrictions. In this sense, PEMF emerges as a viable alternative, capable of providing similar benefits without the need for active physical effort[11].

On the other hand, the heterogeneity of PEMF protocols complicates the standardization of therapy and direct comparison with physical exercise. While the effects of HPE are widely replicable and supported by robust evidence, the specific mechanisms of PEMF on hemodynamic regulation still need to be further investigated for definitive clinical validation[3, 12]. Additionally, some reviews indicate that the response to PEMF can be influenced by individual factors, such as age, health status, and specific application parameters, such as intensity and frequency of the magnetic field[7] . Therefore, although both exercise and PEMF offer benefits in reducing blood pressure, the combination of both strategies may represent an optimized approach for hypertensive individuals, maximizing hypotensive effects and promoting better long-term blood pressure control.

Effects on Heart Rate Variability

Heart rate variability (HRV) is a non-invasive measure that reflects the oscillations in the intervals between consecutive heart beats, providing an assessment of the modulation of the autonomic nervous system (ANS) over the heart, according to Vanderlei et al[32], a high HRV is indicative of a good autonomic balance and efficient physiological mechanisms, while a low HRV may signal dysfunctions in the ANS and an increased risk of cardiovascular events. Several studies suggest that exposure to exercise can positively modulate HRV, promoting an increase in vagal activity and improving blood flow regulation, which can be beneficial for cardiovascular health[33].

In this sense, Grote, Lackner[6] For example, they investigated the effects of PEMF exposure on HRV after physical exertion, focusing on autonomic modulation and the impact of exposure intensity. HRV is widely recognized as a sensitive marker of cardiovascular recovery post-exercise, being regulated by the dynamic interaction between sympathetic and parasympathetic components. Thirty-two healthy men underwent controlled laboratory tests, where each participant went through four sessions of standardized physical stress, followed by exposure to different intensities of PEMF (0 T/s – placebo, 0.005 T/s, 0.03 T/s, and 0.09 T/s).

The results demonstrated that PEMF exposure significantly modulated the spectral components of HRV, particularly the very low frequency (VLF) range, a physiological marker associated with sympathetic control of blood flow and thermoregulation. Individuals exposed to the intensity of 0.005 T/s showed accelerated recovery of HRV compared to the placebo group, suggesting that PEMF at lower doses may favor a quicker restoration of autonomic balance after exercise. Additionally, the authors noted that the response to PEMF varied according to the participants' baseline autonomic state. Individuals with lower VLF power before exposure demonstrated greater benefit from magnetic stimulation compared to those with high baseline VLF power, suggesting an interaction between individual autonomic responsivity and the effects of PEMF.

From a practical perspective, the findings of Grote, Lackner[6] Provide preliminary evidence that PEMF might serve as a non-invasive tool to facilitate autonomic recovery after exercise, which might be particularly relevant for populations where a reduction in cardiovascular load is required. However, as this is an acute study, the observed effects were transient, suggesting that the application of PEMF might require a continuous protocol to ensure sustainable benefits.

Although this study was conducted in healthy individuals, its results underscore the need for further research to assess the effects of PEMF in populations with lower autonomic regulation capacity, such as the elderly, individuals with hypertension, or those recovering from cardiovascular events. Additionally, future investigations should explore the optimal combination of exposure parameters, including duration, intensity, and frequency of stimuli, to optimize the effectiveness of PEMF therapy in autonomic modulation.

Although studies on the effects of PEMF on HRV are still limited, the available evidence points to its therapeutic potential in promoting cardiovascular health[28] . Figure 1 summarizes the main reported effects of PEMF use and possible cardiovascular modulations.

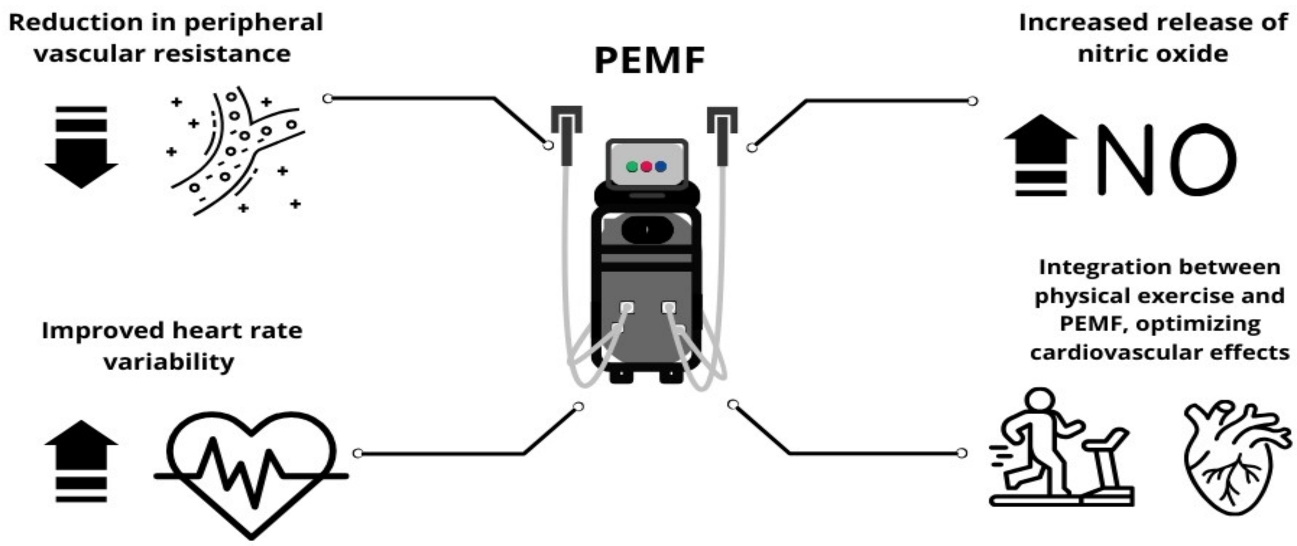

Figure 1. Principal effects of PEMF application and cardiovascular adaptations.

CONCLUSION

PEMF therapy has demonstrated positive responses on blood pressure regulation, which may result in sustained hypotensive responses. Despite this, this information still requires extensive investigation. Additionally, it is suggested that PEMF might act on vagal modulation and the respective reduction of sympathetic activity. The increased release of NO and improved endothelial function, resulting in lower peripheral vascular resistance and greater blood perfusion, are mechanisms linked to PEMF therapy and may explain the hypotensive effect.

Complementarily, PEMF has shown a reduction in oxidative stress and systemic inflammation, which could benefit individuals with hypertension and vascular diseases. Finally, the integration of PEMF with physical exercise emerges as a complementary strategy to optimize cardiovascular effects. However, the heterogeneity of application protocols still limits the clinical validation of PEMF.

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