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Impact of Novel Pulsed Electromagnetic Field Device on Competitive Athlete Performance

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Abstract

The interaction of pulsed electromagnetic fields (PEMF) with the human body may result in a variety of positive outcomes including analgesia, enhanced healing, chondroprotection, cognitive improvement and better quality of life. Previous human studies have also revealed the potential of PEMF to enhance muscle function and athletic performance. To further evaluate this potential, an open label pilot study was conducted with 19 competitive cyclists who repeatedly participated in 63 training routes. Cyclist performance was tracked before and during use of a novel and portable PEMF device that is worn as a wristband. Comparison of performance before and during use of the wristband revealed a significant association with improved muscle power. The odds ratio was 3.02 ($P < 0.01$) for experiencing increased muscle power while wearing the PEMF device. Among the cycling routes in which an increase was observed, the average increase in power was about 9.8%. The data suggests the novel PEMF technology may be a safe and effective therapeutic approach for improved physical performance and likely involves improved oxygen delivery due to reduced rouleaux (erythrocyte aggregation). These results warrant further investigation comprising larger studies and additional outcomes.

Keywords

Cycling, Performance, VO_2 Max, Oxygen Uptake, PEMF, Erythrocyte

1. Introduction

Competitive cyclists are constantly presented with opportunities to enhance their performance through equipment advancements that relate to reduced air resistance, friction, drive train, ergonomics, and overall equipment weight. While each equipment alteration may set a new benchmark, the greatest potential for peak enhancements is still in the ability to generate power in bursts and for extended periods through physical fitness improvement.

The global bicycle market was valued at 91 billion USD in 2021 [1]. While equipment improvements have largely plateaued in recent years, the search for physiological enhancements led to a trend in blood doping, which has since been banned from all sanctioned sports. This practice reached its pinnacle of abuse in the 117-year-old bicycle stage race, the Tour de France, and was also a factor in the 2020 Olympic ban on the entire Russian federation [2]. Blood doping involves boosting one's erythrocyte count for increased oxygen delivery, improving aerobic capacity, endurance, and recovery [3]. However, serious side effects, some of which are terminal, have been associated with doping, leading to its ban.

Biophysical stimulation via magnetic field therapy may prove to be a useful non-invasive and safe tool for improving athletic performance. Application of electromagnetic fields (EMF) has been found to exert some of their physiological effects by influencing voltage-gated ion channels within the cell membrane, such as calcium channels. Further, downstream responses may be mediated through Ca^{2+}/calmodulin stimulation of nitric oxide synthesis and nitric oxide-cGMP-protein kinase G pathway stimulation, upregulation of gene expression and enhancement of cellular differentiation. These are reportedly some of the mechanisms of action responsible for the widely reported EMF-stimulation of bone growth that has been observed experimentally and clinically [4] [5] [6] [7]. Pulse electromagnetic field (PEMF) therapy has been found to be a particularly unique modality for reparative osteogenesis and joint protection [8]. PEMF-mediated tissue engineering/tissue repair also involves osteogenic and chondrogenic differentiation of mesenchymal stem cells [9]. Reportedly, PEMF has been used to successfully treat non-union fractures since 1974 [10].

The effects of PEMF stimulation are not limited to bone and cartilage repair. Notable changes to vasculature performance have also been described previously. PEMF therapy improved flow-mediated dilation and reduced mean arterial pressure as well as systolic and diastolic blood pressure of hypertensive patients when compared to a control group [11]. PEMF also increases microvascular perfusion of the skin of healthy adults as well as improved healing of diabetic foot ulcers via improved microcirculation [12] [13]. In a 12-week, double blind, randomized study involving subjects with metabolic syndrome, PEMF application increased plasma nitric oxide levels and improved blood pressure at rest and during exercise [14].

These above-mentioned aspects of PEMF-induced improved hemodynamics may certainly benefit physical performance. But inhibition of red blood cell (erythrocyte) aggregations, or rouleaux, is likely another major mechanism by which PEMF may improve blood flow and subsequent oxygen deliver by erythrocytes. While rouleaux may often be caused by increases in certain serum proteins, PEMF application reduced rouleaux formation in the blood vessels of the hand of a healthy test subject [15]. Experimental modulation of PEMF changes erythrocyte transmembrane potential and influences the disaggregation of rouleaux [16]. We have previously observed consistent changes to rouleaux formation with application of a novel wristband imbedded PEMF device (cm^2, Nimbus Performance LLC and Pulse LLC., both of Sandy, Utah, USA). Thirty-eight university athletes (football, basketball, cross country, volleyball, and soccer) completed a study in which they volunteered to wear the device for 8 hours/day for 21 to 30 days [17]. These volunteers provided live blood smear samples before and after use of the PEMF device. The erythrocyte condition of each sample was visualized under light and magnification and photographed. At the end of the study period, comparison of before and after blood samples revealed that all participants experienced improved erythrocyte separation, with 35 experiencing clear measurable and distinguishable separation or absence of rouleaux or aggregation, see **Figure 1** for representative individual results. No adverse effects occurred during the study period. During follow-up interviews, 66% of volunteers restated they experienced at least one or more of the following: improved energy, improved sleep, faster recovery, and extended endurance in the first two weeks of use. Improved energy and sleep were the two most frequent comments.

These findings all demonstrate the potential of PEMF to positively influence erythrocyte circulation and subsequent oxygen delivery. Most of the athletes in our previous study reported improved energy status. Such an effect would be expected with improved oxygen availability via more efficient blood circulation. This technology may offer safe performance benefits to competitive athletes by way of increased energy and oxygen uptake. Endurance athletes require on-demand energy over a sustained period. Further, improved performance requires increased production of ATP within the mitochondria of each cell [18]. During aerobic respiration, glucose and oxygen are consumed to produce ATP. The more oxygen available, the more ATP may be produced and available for energy expenditure [19]. The energy pulse generated by the cm^2 PEMF device appears

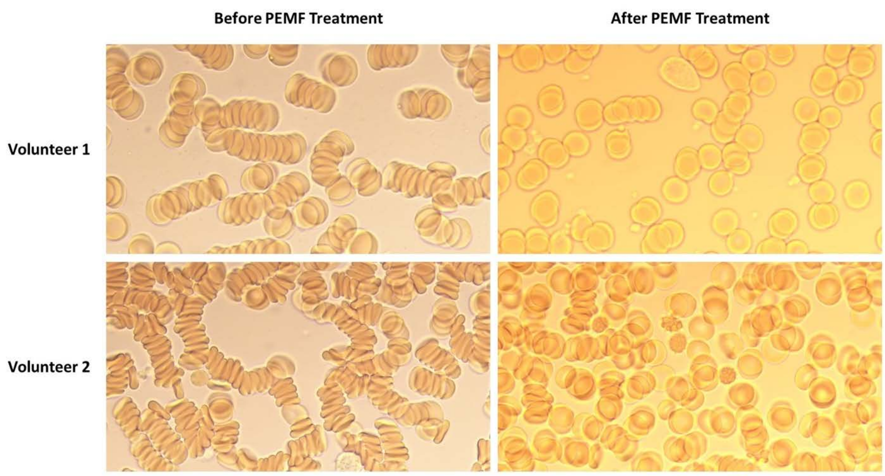

Figure 1. Examples of decreased rouleaux formation in blood samples of university athletes after 21 to 30 days of wearing a PEMF device (cm^2, Pulse, LLC) on the wrist for 8 hours/day.

to affect erythrocyte zeta potential [20], improving separation of the users' erythrocytes and, consequently, improving oxygen delivery and increased ATP production.

To further evaluate the potential of the novel PEMF device to increase athletic performance via improved circulation and oxygen deliver by erythrocytes, active cyclists were enrolled in a trial involving the use of the cm^2 PEMF wristband. Cyclist performance before, during and after use of the PEMF device was recorded and evaluated. Data from such real-life conditions help to establish whether the light microscopy observations are truly associated with more tangible benefits.

2. Materials and Methods

2.1. Subjects

Thirty healthy adults (28 males, 2 females, ages 25 - 65 yr.), all active or competitive cyclists from a select large bicycle racing club, volunteered for the study. Those meeting inclusion criteria were: avid and competitive cyclists that had access to cycle technology (Garmin or similar) that captured key fitness metrics; completed multiple rides/workouts weekly during the study period; had collected ≥ 30 days of pre-study data on performance; agree to wear the cm^2 BAND as instructed; agree to participate in an exit questionnaire; and agree to share honest, accurate, unmanipulated data and insights upon completion. A more thorough discussion of the design and function of the cm^2 wristband is found within the United States patent for this device [21].

2.2. Trial

Each participant in the study received a package containing instructions for use, compliance requirements, a new cm^2 wristband (see **Figure 2**) and general care instructions. Participants were instructed to wear the wristband for a minimum of 5 days per week, for at least 2 hours each day. Each participant was required to have historical data and times, pre-trial, that could be matched with data collected while using the wristband. Data collection was to be generated using a Garmin or similar tracking device as well as power meters attached to their bicycles. Each participant was asked to record specific ride times and wattage.

Figure 2. The cm^2 wristband, manufactured by Pulse, LLC.

2.3. Statistical Analysis

The average power generated (watts) for each training route, completed across different dates, was calculated for before and after wearing of the cm^2 wristband. For each individual training route, the averages were compared. The number of occurrences where the average power increased after the cyclist began wearing the wristband, as well as the number of times it did not, was used to create a contingency table. This data was used to calculate and odds ratio to measure the strength of the association between increased power and wearing of the wristband. The statistical significance of this association was further evaluated with Fisher's exact test. The mean percent increase in power was also calculated for training routes in which an average increase occurred. Data were also presented graphically in standard box plots with 25th percentile, median and 75th percentile values, as well as whisker boundaries representing values within 1.5 times the interquartile range.

3. Results

Initially, thirty (n = 30) participants were recruited for the study. At the conclusion of the study, only twenty-three athletes met the requirements for performance data reporting and were included in the quantitative data analysis. However, 25 participants successfully completed the exit survey.

3.1. Performance Data

Comparison of performance before and during use of the cm^2 wristband, across all training routes, revealed a significant association between increased muscle power and wearing the PEMF device. The odds ratio was 3.02 ($P < 0.01$) for increased muscle power while wearing the cm^2 wristband. This suggests that cyclists are 3 times more likely to experience an increase in muscle power while wearing the wristband than without. Among the cyclist training routes in which an increase was observed, the average increase in power was about 9.77%. **Figure 3** summarizes the distribution of changes in power and completion times for all training routes, as well as for the changes observed in those routes in which a positive response occurred. The mean percent increase in power for all training routes of all cyclists was 3.85%. As noted above, this average was more than doubled for routes where actual increases were observed. The average training route time, for all routes, decreased by 3.6%. Among the routes where a decrease in time occurred, the average change was 8.3%. This is equivalent to completing routes by an average of three minutes sooner while using the wristband.

3.2. Exit Survey Responses

Each study participant was required to complete a ten-question survey at the completion of the study to capture user experience data. The compiled data from the ten-question exit survey revealed data that supported the performance data. **Table 1** summarizes key survey findings.

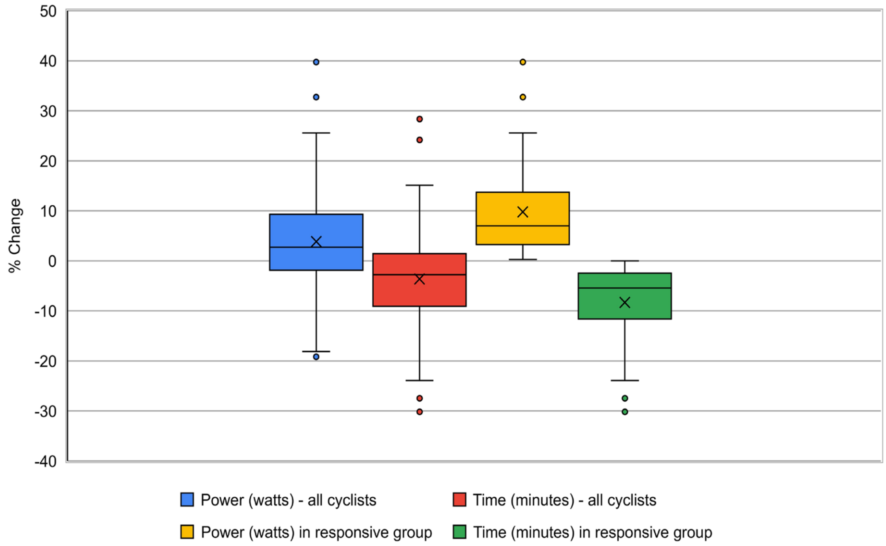

Figure 3. Box plots of changes in performance while wearing the cm^2 wristband. 25th percentiles, medians and 75th percentile values, whisker boundaries representing values within 1.5 times the interquartile range, and average values (denoted by an X) are included within the box plots.

Table 1. Percentage of cyclists reporting specified responses to the 10-question exit survey after using the cm^2 wristband.

Exit survey responses	% Respondents
Wore the wristband for at least two months	80.8
Wore wristband seven days a week	88.5
Experienced increased energy during non-work out daily activities	80.8
Experienced improved rest/sleep	73.1
Felt "improved cardio output"	95.2
Experienced "improved endurance"	92.3
Will continue using the cm^2 wristband going forward	92.3
Experienced no benefit from using	7.7

Cyclists' perception of improved physical performance following use of the cm^2 wristband was very positive. Just over 80% reported that they experienced an overall increase in energy levels. An even higher percentage reported improved physical endurance and output. These percentages, 92.3 and 95.2, are even greater than the increases measured in the performance data (power and training route times). While the survey responses are more subjective, they are useful in capturing the overall experience of the cyclists. Further, the perceived improvements in endurance do generally agree with the more objective comparison of the pre- and post-wristband muscle power data. Very few, less than 8%, felt that they received no benefit from using the wristband. It is also noteworthy that a clear majority of cyclists reported experiencing improved rest or sleep. This single effect alone could have a profound influence on physical performance [22]. When combined with improved oxygen deliver due to reduced rouleaux formation.

3.3. Adverse Events

No adverse health events were reported from any participants.

4. Discussion and Conclusions

Our findings indicate that the use of a novel PEMF device, the cm^2 wristband, resulted in significant improvements in muscle power output and cycling speed (as measured by reduced route completion times). These contributed to enhanced athletic performance. While the data clearly demonstrated an improvement in performance, the exit survey revealed that additional user benefits may be significant factor in the effectiveness of the technology for athletic performance and general wellness. Therefore, in future studies, evaluating user confidence could be considered an important aspect to investigate when assessing the impact of this technology on athletic performance and wellness.

This improved performance data warrants further research as a safe alternative to improving peak performance and general wellness. In addition, the improved wattage/power generated further suggests the effect of the technology upon the cardiovascular system. The measured data also confirmed improved oxygen delivery. The improved vascular effects suggest that improved delivery of essential nutrients within the plasma may have also increased to meet the demands of cell respiration and ATP generation [23].

In performance research, study subjects are often individuals who are in the top 10% of their field or fitness level, commonly referred to as the "ten-percenters." In this study, some participants even qualified for the top 1% within their age class. Improving performance and documenting the progress of these individuals is particularly challenging due to the narrow margins that often separate them from their competitors. If the cm^2 wristband can positively affect the "ten percenters", it is likely to have significant health benefits for the general population as well. Understanding that performance improvement, recovery and general wellness are desirable for the general population, even individuals functioning at the opposing spectrum of performance athletes. This fact alone signifies health relevance to the general population, in addition to athletes. This study's compelling data highlights the potential benefits of the technology for enhancing fitness, nutritional delivery, and overall health performance, and underscores the need for further research in this area including double-blind, placebo-controlled clinical trials.

The current study corroborates previously published work wherein the health benefits of electromagnetic therapy were evident. Multiple reviews are also available which discuss the various PEMF modalities for the treatment of a long list of conditions including, bone fractures, arthritis, osteoarthritis, tendonitis, acute and chronic inflammation, edema, chronic pain, and chronic wounds [24]. Several previous animal and human studies have suggested that magnetic field (MF) exposure influences blood perfusion and pressure, with vasodilatory or vasoconstrictive responses dependent upon initial vessel tone and mediated by nitric oxide effects [25]. As observed in the current trial, the microcirculatory effects may influence muscle power output.

PEMF modalities may include a range of low frequencies (typically less than 100 Hz), amplitudes and waveforms, with magnetic flux density usually being between 0.03 and 105 millitesla. Waveforms may be asymmetrical, biphasic, sinusoidal, quasi-rectangular, and trapezoidal [26] [27] [28]. The cm^2 PEMF device operates in accord with these overall parameters, while utilizing toroidal magnetic waves, and has been shown to provide a unique potential benefit regarding athletic performance.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Precedence Research (2022) Bicycle Market (By Product: Hybrid Bikes, Mountain Bikes, Cargo Bikes, Road Bikes, All Terrain Bicycle, E-Bicycle, Others; By Technology: Conventional, Electric; By Distribution Channel: Online, Offline; By End User: Men, Women, Kids; By Price: Premium, Mid Range, Low Range)—Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2022-2030. https://www.precedenceresearch.com/bicycle-market

[2] Dowling, M., Harris, S. and Washington, M. (2022) When a Ban Is Not a Ban: Institutional Work and the Russian Doping Scandal. *Journal of Sport Management*, **36**, 433-445. https://doi.org/10.1123/jsm.2021-0185

[3] Andersen, A.B., Nordsborg, N.B., Bonne, T.C. and Bejder, J. (2022) Contemporary Blood Doping—Performance, Mechanism, and Detection. *Scandinavian Journal of Medicine & Science in Sports*.

[4] Fitzsimmons, R.J., Ryaby, J.T., Magee, F.P. and Baylink, D.J. (1994) Combined Magnetic Fields Increase Net Calcium Flux in Bone Cells. *Calcified Tissue International*, **55**, 376-380. https://doi.org/10.1007/BF00299318

[5] Ciombor, D.M. and Aaron, R.K. (2005) The Role of Electrical Stimulation in Bone Repair. *Foot and Ankle Clinics*, **10**, 579-593. https://doi.org/10.1016/j.fcl.2005.06.006

[6] Cornaglia, A.I., Casasco, M., Riva, F., Farina, A., Fasina, L., Visai, L. and Casasco, A. (2006) Stimulation of Osteoblast Growth by an Electromagnetic Field in a Model of Bone-Like Construct. *European Journal of Histochemistry*, **50**, 199-204.

[7] Pall, M.L. (2013) Electromagnetic Fields Act via Activation of Voltage-Gated Calcium Channels to Produce Beneficial or Adverse Effects. *Journal of Cellular and Molecular Medicine*, **17**, 958-965. https://doi.org/10.1111/jcmm.12088

[8] Massari, L., Benazzo, F., Falez, F., Perugia, D., Pietrogrande, L., Setti, S., Osti, R., Vaienti, E., Ruosi, C. and Cadossi, R. (2019) Biophysical Stimulation of Bone and Cartilage: State of the Art and Future Perspectives. *International Orthopaedics*, **43**, 539-551. https://doi.org/10.1007/s00264-018-4274-3

[9] Varani, K., Vincenzi, F., Pasquini, S., Blo, I., Salati, S., Cadossi, M. and De Mattei, M. (2021) Pulsed Electromagnetic Field Stimulation in Osteogenesis and Chondrogenesis: Signaling Pathways and Therapeutic Implications. *International Journal of Molecular Sciences*, **22**, Article 809. https://doi.org/10.3390/ijms22020809

[10] Bassett, C.A., Pawluk, R.J. and Pilla, A.A. (1974) Augmentation of Bone Repair by Inductively Coupled Electromagnetic Fields. *Science*, **184**, 575-577. https://doi.org/10.1126/science.184.4136.575

[11] Stewart, G.M., Wheatley-Guy, C.M., Johnson, B.D., Shen, W.K. and Kim, C. (2020) Impact of Pulsed Electromagnetic Field Therapy on Vascular Function and Blood Pressure in Hypertensive Individuals. *The Journal of Clinical Hypertension*, **22**, 1083-1089. https://doi.org/10.1111/jch.13877

[12] Mayrovitz, H.N. and Larsen, P.B. (1992) Effects of Pulsed Electromagnetic Fields on Skin Microvascular Blood Perfusion. *Wounds*, **4**, 197-202.

[13] Kwan, R.L., Wong, W., Yip, S., Chan, K., Zheng, Y. and Cheing, G.L. (2015) Pulsed Electromagnetic Field Therapy Promotes Healing and Microcirculation of Chronic Diabetic Foot Ulcers: A Pilot Study. *Advances in Skin and Wound Care*, **28**, 212-219. https://doi.org/10.1097/01.ASW.0000462012.58911.53

[14] Kim, C., Wheatley-Guy, C.M., Stewart, G.M., Yeo, D., Shen, W. and Johnson, B.D. (2019) The Impact of Pulsed Electromagnetic Field Therapy on Blood Pressure and Circulating Nitric Oxide Levels: A Double Blind, Randomized Study in Subjects with Metabolic Syndrome. *Blood Pressure*, **29**, 47-54. https://doi.org/10.1080/08037051.2019.1649591

[15] Hwang, D.G. (2014) Change in Rouleau Formation of Red Blood Cells by Pulse Magnetic Field Stimulus in the Hand. *Journal of the Korean Magnetics Society*, **24**, 28-33. https://doi.org/10.4283/JKMS.2014.24.1.028

[16] Sebastian, J.L., San Martin, S.M., Sancho, M., Miranda, J.M. and Alvarez, G. (2005) Erythrocyte Rouleau Formation under Polarized Electromagnetic Fields. *Physical Review E*, **72**, Article 031913. https://doi.org/10.1103/PhysRevE.72.031913

[17] Gledhill, D., Anderson, G. and Huntsman, K. (2023) Nimbus cm2 Pulse BAND: Erythrocyte De-Aggregation. Influencing Zeta Potential of Cell Membrane for Improved Gas Exchange. OSF Preprints, 12 May 2023. https://doi.org/10.31219/osf.io/fv5pu

[18] Green, H.J. (1997) Mechanisms of Muscle Fatigue in Intense Exercise. *Journal of Sports Sciences*, **15**, 247-256. https://doi.org/10.1080/026404197367254

[19] Bassett, D.R. and Howley, E.T. (2000) Limiting Factors for Maximum Oxygen Uptake and Determinants of Endurance Performance. *Medicine and Science in Sports and Exercise*, **32**, 70-84. https://doi.org/10.1097/00005768-200001000-00012

[20] Choi, Y., Bang., S. and Lee, H. (2022) Observation of Red Blood Cell Membrane Charge Using Magnetic Beads under Pulsed Magnetic Field. *IEEE Transactions on Magnetics*, **58**, Article 5400105. https://doi.org/10.1109/TMAG.2021.3129887

[21] Anderson, G.S., Hunstman, K.E., Gledhill, D.C. and Jackson, M.E. (2021) Micro-Coil Wristband. U.S. Patent No. 11,191,975 B2, U.S. Patent and Trademark Office, Washington DC.

[22] Watson, A.M. (2017) Sleep and Athletic Performance. *Current Sports Medicine Reports*, **16**, 413-418. https://doi.org/10.1249/JSR.0000000000000418

[23] Hargreaves, M. and Spriet, L.L. (2020) Skeletal Muscle Energy Metabolism during Exercise. *Nature Metabolism*, **2**, 817-828. https://doi.org/10.1038/s42255-020-0251-4

[24] Luigi, C. and Tiziano, P. (2020) Mechanisms of Action and Effects of Pulsed Electromagnetic Fields (PEMF) in Medicine. *Journal of Medical Research and Surgery*, **1**, 1-4. https://doi.org/10.52916/jmrs204033

[25] McKay, J.C., Prato, F.S. and Thomas, A.W. (2007) A Literature Review: The Effects of Magnetic Field Exposure on Blood Flow and Blood Vessels in the Microvasculature. *Bioelectromagnetics*, **28**, 81-98. https://doi.org/10.1002/bem.20284

[26] Hu, H., Yang, W., Zeng, Q., Chen, W., Zhu, Y., Liu, W., Wang, S., Wang, B., Shao, Z. and Zhang, Y. (2020) Promising Application of Pulsed Electromagnetic Fields (PEMFs) in Musculoskeletal Disorders. *Biomedicine & Pharmacotherapy*, **131**, Article 110767. https://doi.org/10.1016/j.biopha.2020.110767

[27] Bachl, N., Ruoff, G., Wessner, B. and Tschan, H. (2008) Electromagnetic Interventions in Musculoskeletal Disorders. *Clinics in Sports Medicine*, **27**, 87-105. https://doi.org/10.1016/j.csm.2007.10.006

[28] Paolucci, T., Pezzi, L., Centra, A.M., Giannandrea, N., Bellomo, R.G. and Raoul Saggini, R. (2020) Electromagnetic Field Therapy: A Rehabilitative Perspective in the Management of Musculoskeletal Pain—A Systematic Review. *Journal of Pain Research*, **13**, 1385-1400. https://doi.org/10.2147/JPR.S231778