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A Novel Double-Coil rPMS Approach for Treating Joint Disorders of the Upper and Lower Extremities: A Pilot Study

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Abstract

Background: Repetitive peripheral magnetic stimulation (rPMS) is a non-invasive neuromodulatory approach used for chronic and acute pain. A novel double-coil configuration allowing angled parallel stimulation has the potential to improve energy delivery to deeper joint structures. **Materials and Methods:** Data from twenty-five patients with joint-related pain treated using a double-coil rPMS configuration were retrospectively analyzed in a pilot exploratory framework. The primary aim was to assess feasibility and estimate preliminary clinical effects. Outcome measures included pain intensity (VAS), functional disability (PSFS), quality of life (SF-12), and subjective improvement (PGIC), assessed at baseline and after completion of treatment. **Results:** The double-coil rPMS approach was feasible across all treated joints (knee, shoulder, elbow, hip). Improvements were observed across all outcome measures, with pain decreasing by 65.71%, functional ability improving by 84.46%, and SF-12 physical and mental component scores improving by 52.03% and 27.87%, respectively. Large within-subject effect sizes were observed, and most patients exceeded established minimal clinically important difference thresholds. **Conclusions:** This retrospective pilot analysis supports the feasibility of an adjustable double-coil rPMS configuration for large joints. The findings indicate a clinically meaningful signal of benefit, but should be interpreted as exploratory and used to inform future prospective, controlled studies.

Keywords

Neuromodulation, Peripheral Magnetic Stimulation, Joint-Related Pain, Non-Invasive Therapy, Musculoskeletal Rehabilitation

1. Introduction

Joints are essential structures that enable human movement and daily function. Any joint-related pain or dysfunction can significantly impair quality of life and limit physical independence. Joint disorders are broadly categorized into degenerative and inflammatory conditions, both of which involve inflammation as a key contributing factor to symptom development and disease progression [1]. Among inflammatory joint diseases, rheumatoid arthritis (RA) is one of the most prevalent and severe, characterized by autoimmune-mediated synovial inflammation and progressive joint destruction [2]. On the other hand, osteoarthritis (OA) is the most common form of joint disease globally and is considered a multifactorial degenerative disorder involving genetic, mechanical, metabolic, and biochemical pathways. These complex mechanisms contribute to the progressive deterioration of the synovial joint, particularly the articular cartilage, which is central to load-bearing and frictionless movement [3]. Despite its degenerative nature, OA is increasingly recognized as having a significant inflammatory component, especially in the later stages, which exacerbates cartilage breakdown, synovial membrane thickening, and pain perception [4]. While RA more commonly affects small joints of the hands and feet, OA typically targets large, weight-bearing joints such as the knees, hips, and shoulders. Both conditions are associated with chronic pain, which remains the primary complaint of patients and a major contributor to functional decline [1]. Globally, OA affected approximately 595 million people in 2020, accounting for 7.6% of the world population [5]. The prevalence is expected to rise with global population aging. Nearly 40% of people over 70 years suffer from knee OA, 80% experience movement limitations, and 25% report difficulty with routine daily tasks [6,1]. Although OA is frequently used as a representative example due to its high prevalence, joint-related pain encompasses a broader range of degenerative and periarticular conditions affecting large joints.

Current treatment of joint disorders primarily focuses on alleviating pain and improving joint function. This includes both pharmacological management - such as analgesic medications, topical analgesics, nonsteroidal anti-inflammatory drugs, and intra-articular corticosteroid injections - and non-pharmacological strategies. The latter include physical therapy to strengthen surrounding musculature, preserve joint mobility, weight reduction when appropriate, and comprehensive patient education [7]. When joint degeneration becomes severe and unresponsive to conservative treatment, total joint replacement remains the last-line intervention. In the United States, prevalence estimates from 2010 reported 0.83% for total hip replacements and 1.52% for total knee replacements, with higher prevalence in women. Among patients aged 80 and older, prevalence rises dramatically - up to 5.26% for hip and 10.38% for knee replacement surgeries [8]. These procedures have been shown to significantly reduce pain and restore function, enabling older adults to regain independence and quality of life [4]. However, not all elderly patients are ideal surgical candidates due to comorbidities, frailty, or other factors. In addition, long waiting times for orthopedic surgery

further emphasize the need for alternative treatment options. For example, in some health systems, the average wait time for hip replacement reaches 348 days, and 267 days for knee replacement, delaying access to definitive care and prolonging patient suffering [9].

One of the promising non-invasive approaches for managing joint-related pain is repetitive peripheral magnetic stimulation (rPMS). Unlike conventional low-frequency magnetotherapy, rPMS delivers high-intensity magnetic pulses capable of stimulating deep tissues and modulating neuromuscular activity [10]. Depending on stimulation parameters, rPMS can be used to promote muscle relaxation or strengthening [11] [12]. Research to date has focused primarily on neurological and spasticity-related conditions, such as stroke and cerebral palsy [11] [13]. However, there is a growing interest in its application to musculoskeletal conditions, including joint disorders, although current clinical evidence remains limited and heterogeneous [14].

The proposed mechanisms of rPMS include intense muscle contractions that may promote cellular responses, increased blood flow, and support tissue healing [15]. It has also been hypothesized that rPMS may modulate pain through enhanced proprioceptive input. This input may influence the excitability of the corticospinal tract, particularly in fronto-parietal brain regions, and alter intracortical facilitation and inhibition within the primary motor cortex (M1) [16].

Recent studies have reported positive clinical outcomes of rPMS in patients with knee OA [14] [15]. These studies most commonly used a standard single-coil configuration with a circular coil positioned perpendicular to the treatment area. Kamiue *et al.* reported complete pain relief and significant functional improvement of the lower limb following rPMS intervention in elderly patients with knee pain. Similarly, Lee and Nam observed a statistically significant improvement after hip replacement surgery [17].

Experimental and modeling studies have explored a double-coil rPMS setup designed to allow adjustable angulation between coils. These studies have suggested potential benefits of this configuration for targeting large joints, possibly through more effective and focused stimulation of deep tissues [18]. Building on these theoretical findings, the present retrospective pilot analysis aimed to explore the feasibility and preliminary clinical effects of the double-coil stimulation approach in the treatment of joint-related pain.

2. Materials and Methods

2.1. Study Design

This was a retrospective analysis of clinical data obtained from patients who underwent rehabilitation treatment with double-coil rPMS for joint-related pain in a private outpatient clinic. The study design and procedures were reviewed and retrospectively approved by the local ethics committee Comitato Etico Territoriale Regione Calabria (319/2025, 29.12.2025). All participants had been fully informed about the treatment protocol and potential risks as part of routine clinical

care, and had provided written consent for the use of anonymized data for research and publication purposes. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

2.2. Inclusion and Exclusion Criteria

Data were obtained from patients treated at a private outpatient physiotherapy clinic specializing in musculoskeletal disorders. Eligible cases included adults who had received rPMS therapy for acute or chronic pain in the knee, shoulder, hip, or elbow associated with measurable functional limitation. Patients were required to have adequate cognitive and physical capacity to provide informed consent and to comply with the treatment protocol during routine care.

Exclusion criteria comprised pregnancy; the presence of implanted electronic or metallic devices (e.g., pacemakers, defibrillators, neurostimulators, or metal-containing intrauterine devices); use of active drug infusion systems; a history of seizures or epilepsy; diagnosed malignancy; severe cardiovascular, pulmonary, or renal disease; systemic infections or febrile states; and open wounds at the target treatment site. Patients were also excluded if they had any unrelated neurological or musculoskeletal condition that could interfere with outcome assessment. For the present analysis, only patients fulfilling these eligibility criteria based on their medical records were included.

2.3. Concomitant Care and Documentation of Co-Interventions

Due to the retrospective real-world nature of this analysis, patients were not explicitly instructed to avoid additional treatments or medication changes during the intervention period. However, only patients for whom no concomitant therapies or medication changes were documented in the clinical records during the treatment period were included in the present analysis. Within the care provided at the clinic, no additional therapeutic modalities or medications were administered, and treatment sessions consisted exclusively of rPMS.

In routine clinical practice, therapists conduct structured dialogues with patients at each visit and systematically document ongoing or newly initiated treatments outside the clinic, including analgesic or nonsteroidal anti-inflammatory drug use, injections, physiotherapy, or exercise programs. Patients who reported initiation or modification of such concomitant interventions during the six-session rPMS program were not included in the final dataset. Despite this precaution, the influence of unreported co-interventions or natural symptom fluctuation cannot be fully excluded.

2.4. Intervention Protocol

Stimulation was administered using a double-coil applicator with an adjustable inter-coil angle (BTL Industries, Ltd.). The angle between the coils was individually set for each treated joint according to anatomical landmarks and soft-tissue morphology. The aim was to optimally conform to the treated anatomical region

and, whenever feasible, to maintain a mutual inter-coil angle close to 90˚. Across treatments, inter-coil angles typically ranged between 90˚ and 120˚, with configurations near 90˚ most commonly used, as illustrated in **Figure 1.** The total duration of stimulation typically ranged between 10 and 15 minutes. Stimulation was delivered using manufacturer-defined, indication-specific protocols integrated in the device software, each consisting of multiple sequential phases with predefined combinations of frequency, amplitude, and modulation patterns. Modulation patterns were progressively adjusted from none or constant modulation to alternating, sinusoidal, or trapezoidal waveforms, with varying frequencies in the range of 5 - 50 Hz and amplitudes set according to predefined ranges.

Figure 1. Treatment setup for treatment of the shoulder (left), hip (middle) and knee (right) using a double-coil applicator with adjustable angulation.

Patients were typically treated in a supine lying position, with the affected joint supported by a cushion if necessary to ensure comfort and stability (**Figure 1**). The center of the applicator was placed directly above the most painful site, at minimal distance from the skin surface, and in some cases the coils were positioned in light contact with the body. Stimulation intensity was individually adjusted during a configuration phase. Stimulation was initiated at a level at or slightly above the individual sensory threshold and was gradually increased toward the individual motor threshold. Motor threshold was defined as the intensity at which muscle activation could begin to occur. The intensity was not routinely increased beyond the level required to elicit visible muscle activation, and sustained muscle contractions were not a therapeutic goal. The primary aim of intensity adjustment was to elicit comfortable proprioceptive and sensorimotor stimulation without inducing pain or excessive muscle contraction.

The stimulation protocol used in routine clinical practice was based on pain-modulation principles derived from the gate control theory of pain. Frequency modulation was applied in certain protocol phases to prevent tissue habituation to the magnetic stimuli. Protocol selection and parameter progression followed a standardized clinical framework based on the treated joint and primary therapeutic goal (predominantly analgesia and functional improvement), while stimulation intensity and minor adjustments were individualized to patient tolerance. In

addition, the treatment was intended to support local blood perfusion and promote circulation, trophic effects, and tissue regeneration in the affected area. Each patient typically received six treatment sessions, administered once weekly during the intervention period.

2.5. Outcome Measures

Clinical data were extracted from patient records at two time points: prior to the initiation of the rPMS treatment protocol and immediately after completion of the six-session intervention. The following validated outcome measures, routinely used in the clinic, were available to assess changes in pain, function, and quality of life:

- **Visual Analog Scale (VAS):** Pain intensity was rated by patients on a 0 - 10 scale, where 0 indicated no pain and 10 indicated unbearable pain [19].
- **Patient-Specific Functional Scale (PSFS):** Each patient identified up to five daily activities most limited by their musculoskeletal condition and rated their ability for each on a 0 - 10 scale, with higher scores indicating less limitation [20].
- **12-Item Short Form Health Survey (SF-12):** This self-reported questionnaire provided the Physical Component Summary (PCS) and Mental Component Summary (MCS) scores, reflecting physical and mental aspects of health-related quality of life [21].
- **Patient Global Impression of Change (PGIC):** Perceived change following treatment was assessed using a modified 6-item PGIC questionnaire covering six domains (overall condition, physical activity, social activity, work-related activity, mood, and pain). Responses ranged from 1 ("very much improved") to 7 ("very much worse") with lower scores indicating greater perceived improvement [22].

To assess clinical relevance, observed changes were compared with published minimal clinically important difference (MCID) thresholds obtained from the available literature for each outcome measure (VAS, PSFS, SF-12) [23]-[26]. Finally, the MCID responder rate (percentage of patients exceeding the respective MCID threshold) was computed to quantify the proportion of clinically meaningful improvements.

In addition to the clinical outcome evaluation, the analysis also explored the feasibility of implementing the double-coil rPMS approach in routine physiotherapy practice. Treating therapists had recorded notes related to the ergonomic aspects of coil positioning and setup feasibility for different joint regions, considering each patient's anatomical characteristics. Any reported difficulties, limitations, or inability to properly position the applicator were systematically extracted from the treatment documentation.

2.6. Sample Size and Statistical Analysis

All statistical analyses were performed using GraphPad Prism version 10 for Win-

dows (GraphPad Software, Inc.). Prior to hypothesis testing, the distribution of each dataset was assessed using the Shapiro-Wilk test for normality. Variables that violated the assumption of normality were analyzed using the non-parametric Wilcoxon signed-rank test, while those with normally distributed residuals were analyzed using a paired t-test. Statistical significance was defined as $p < 0.05$. Given the exploratory nature and clinical heterogeneity of the dataset - which was not limited to a single joint or indication - results were reported as both mean ± standard deviation (SD) and median with interquartile range (IQR) to capture variability in the data.

In addition to conventional significance testing (p-values), effect sizes were calculated to provide a more comprehensive estimate of the magnitude of within-subject changes, considering the small sample size and high inter-individual variability of the cohort. In this exploratory pilot context, effect size estimation was prioritized to support interpretation of the clinical relevance and variability of observed changes rather than to draw definitive efficacy conclusions. For normally distributed outcomes, within-subject standardized effect sizes were expressed as Hedges' g_n (small-sample-corrected Cohen's d), whereas for non-normally distributed outcomes, the rank-biserial correlation (r) was reported. According to conventional benchmarks, effect sizes of 0.2, 0.5, and 0.8 (for g_n) or 0.1, 0.3, and 0.5 (for r) were interpreted as small, medium, and large, respectively. For each outcome, 95% confidence intervals (CI) were calculated for the mean or median change to express the precision of the estimated effects.

Given the retrospective and exploratory nature of this pilot study, no a priori sample size calculation was performed. The present dataset comprised 30 consecutive patients, which was considered appropriate to support exploratory feasibility and variability assessment of the double-coil rPMS protocol in clinical practice.

3. Results

Of the 30 identified patients, 25 completed all six treatment sessions and were included in the primary analysis. Five patients were excluded due to incomplete treatment or missing post-treatment outcome data; none were excluded because of adverse events or treatment intolerance. The average age of the analyzed sample was 48.96 ± 18.02 years, and the group consisted of 19 females and 6 males. Baseline clinical characteristics of the analyzed cohort are summarized in Table 1.

To assess the robustness of the findings from the primary analysis (n = 25), a conservative sensitivity analysis was performed assuming no improvement (0% change from baseline) in patients with missing post-treatment data. Under this worst-case assumption, mean percentage improvements remained clearly positive across all outcome measures, including pain intensity (−54.76%), functional ability (70.38%), and physical and mental components of quality of life (43.36% and 23.22%, respectively), supporting the stability of the main findings.

The feasibility of the double-coil rPMS applicator was confirmed across all anatomical regions, with no cases of setup failure or inability to apply stimulation

due to joint structure or patient discomfort. All patients tolerated the intervention well, and no adverse events or relevant discomfort were recorded that would have interfered with treatment delivery.

Table 1. Baseline clinical characteristics of the analyzed cohort.

Characteristic	N (%)
Treated joint	
Knee	11 (44%)
Shoulder	7 (28%)
Elbow	4 (16%)
Hip	3 (12%)
Primary clinical condition	
Degenerative joint conditions	15 (60%)
Tendinous/periarticular disorders	7 (28%)
Post-traumatic conditions	3 (12%)

All evaluated outcome measures demonstrated statistically significant improvements between baseline and post-treatment assessments, with all comparisons reaching $p < 0.001$ (see Table 2). The largest mean change was observed in the PSFS, where patients reported an average improvement exceeding 80%, reflecting a substantial reduction in activity-related disability following rPMS treatment.

Table 2. Summary of clinical outcome measures analyzed at baseline and after completion of the treatment protocol. Statistical significance was determined using paired *t*-tests for normally distributed data (VAS, PSFS, SF-12 PCS) or the Wilcoxon signed-rank test for non-normally distributed data (SF-12 MCS) at a threshold of $p < 0.05$. Analyses are based on patients who completed the treatment protocol and had complete baseline and post-treatment data (n = 25).

		Baseline	Post-treatment	p (<0.05)
VAS	mean ± SD	5.84 ± 2.15	2 ± 1.61	<0.001
	median (IQR)	6 (3)	2 (2)	
PSFS	mean ± SD	4.86 ± 1.58	7.68 ± 1.35	<0.001
	median (IQR)	5 (2)	7.5 (2)	
SF-12 PCS	mean ± SD	32.46 ± 9.22	46.53 ± 8.56	<0.001
	median (IQR)	28.38 (12.14)	48.33 (10.4)	
SF-12 MCS*	mean ± SD	45.05 ± 10.9	54.83 ± 6.35	<0.001
	median (IQR)	48.36 (20.41)	55.97 (3.15)	

VAS = Visual Analog Scale; PSFS = Patient-Specific Functional Scale; SF-12 PCS = Short Form-12 Physical Component Summary; SF-12 MCS = Short Form-12 Mental Component Summary; IQR = Interquartile Range; SD = Standard Deviation.

Additional analyses summarizing the magnitude and clinical relevance of the observed changes are presented in Table 3. All evaluated outcomes showed large within-subject effect sizes, while the proportion of patients exceeding the MCID approached or surpassed the 70% threshold for most parameters. For the SF-12 MCS, the MCID responder rate reached approximately 60%, consistent with a moderate level of improvement in mental health-related quality of life.

Table 3. Summary of within-subject changes, effect sizes, and clinical significance across outcome measures following double-coil rPMS therapy. Data are presented as mean change ± standard deviation (SD) with 95 % confidence intervals (CI) for normally distributed outcomes (VAS, PSFS, SF-12 PCS) and as median change [interquartile range, IQR] with 95% CI for non-normally distributed data (SF-12 MCS). Effect sizes are expressed as Hedges' g_n for normally distributed variables and rank-biserial correlation (r) for non-normal data. The table also reports percentage change relative to baseline, the corresponding minimal clinically important difference (MCID) threshold, and the proportion of patients who exceeded the MCID. Analyses are based on patients who completed the treatment protocol and had complete baseline and post-treatment data (n = 25).

	Mean Δ ± SD [95 % CI]	%Δ	Effect size	MCID	% ≥ MCID
VAS	−3.84 ± 2.12 [−2.97, −4.71]	−65.71	1.76	≥2 points	84%
PSFS	2.83 ± 1.86 [2.06, 3.6]	84.46	1.47	≥2 points	68%
SF-12 PCS	14.07 ± 10.59 [9.7, 18.44]	52.03	1.29	≥5 points	76%
SF-12 MCS	7.6 (3.5–12.5) [2.6, 12.8]	27.87	0.88	≥5 points	60%

VAS = Visual Analog Scale; PSFS = Patient-Specific Functional Scale; SF-12 PCS = Short Form-12 Physical Component Summary; SF-12 MCS = Short Form-12 Mental Component Summary; IQR = Interquartile Range; SD = Standard Deviation; %Δ = Mean percentage change across the study cohort.

The distribution of individual outcome measures is illustrated in Figure 2 using box-and-whisker plots. The figures clearly depict a reduction in VAS and an increase in PSFS and SF-12 following the intervention.

Individual-level changes in pain intensity relative to the no-change line and the MCID threshold are illustrated in Figure 3.

Subjective global improvement, as assessed by the PGIC score, also indicated robust treatment response. Due to the non-normal distribution of PGIC data (confirmed by the Shapiro-Wilk test), results were reported as median (IQR). The median PGIC score was 2.00 (0.67), corresponding to the "much improved" category. Overall, 23 patients (92%) reported functional improvement on the PGIC scale, whereas 2 patients (8%) perceived no change. This suggests that, across all evaluated domains - including overall condition, physical and social activity, mood, and pain - participants perceived substantial benefit from the intervention. The distribution of individual PGIC scores is illustrated in Figure 4.

Descriptive analyses stratified by treated joint (knee versus other joints) suggested comparable baseline profiles and consistent improvement patterns across outcome measures. Given the limited sample size, stratified analyses were not

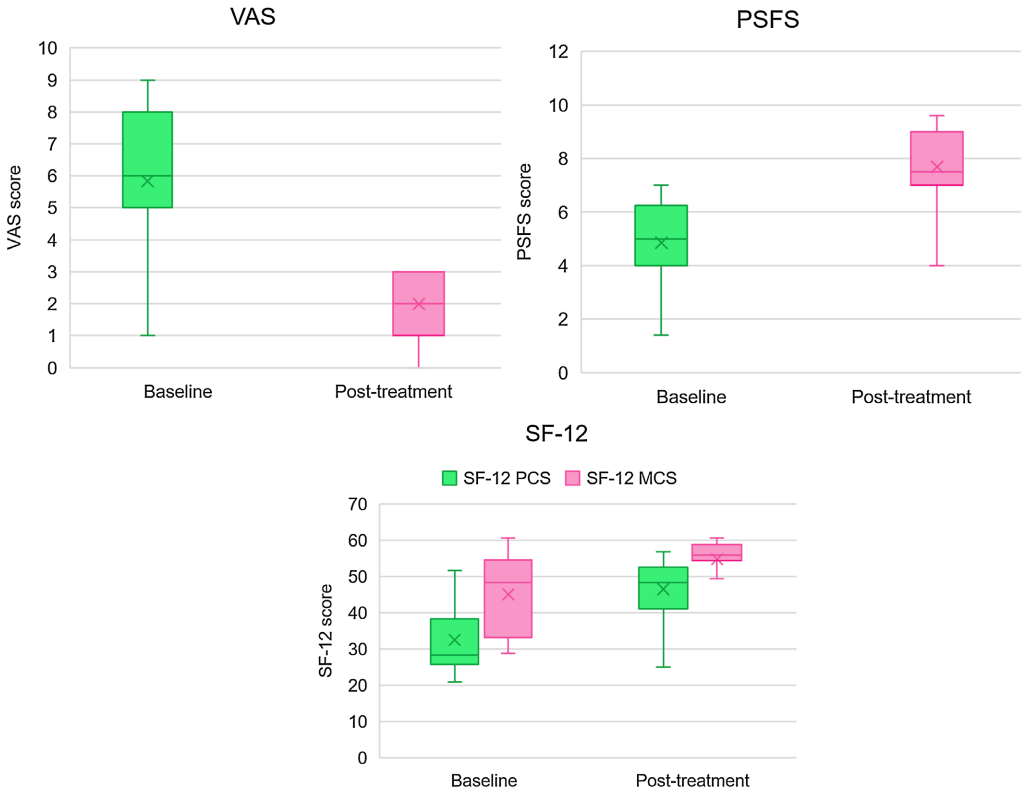

Figure 2. Changes in outcome measures between baseline and post-treatment: pain (VAS) - top, Patient-Specific Functional Scale (PSFS) - middle, and SF-12 physical (PCS) and mental (MCS) scores - bottom. Each plot displays the distribution of scores using a box-and-whisker format, illustrating the change across the study cohort.

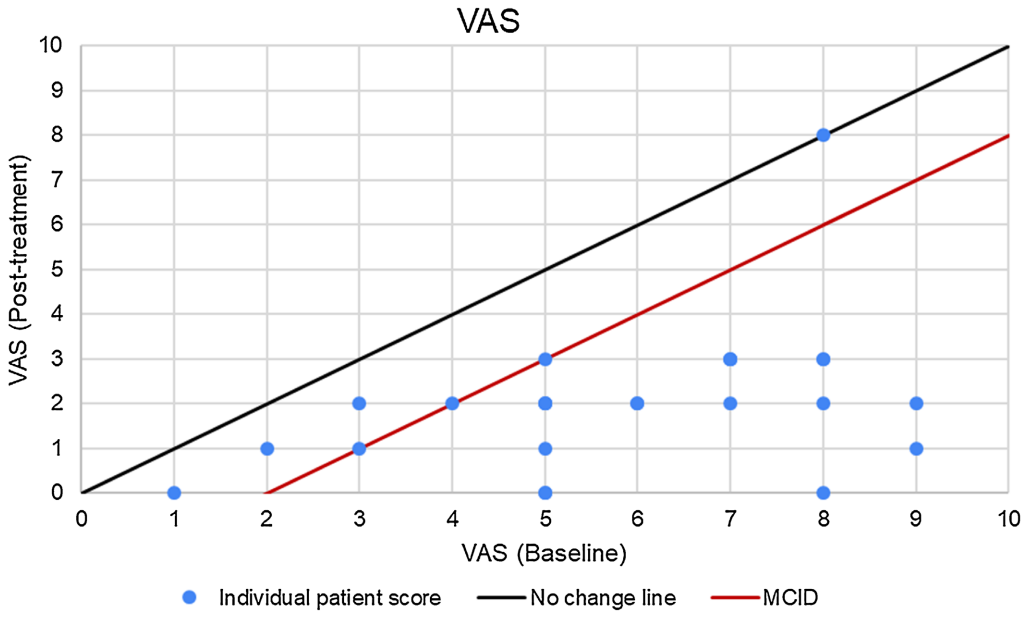

Figure 3. Individual change plot for pain intensity (VAS) showing baseline versus post-treatment scores in patients completing the treatment protocol (n = 25). The black diagonal line represents no change (y = x), and the red line indicates the minimal clinically important difference (MCID, ≥2-point reduction). Each point represents an individual patient. Points located below the black line indicate pain reduction, and points below the red line indicate improvements exceeding the MCID threshold.

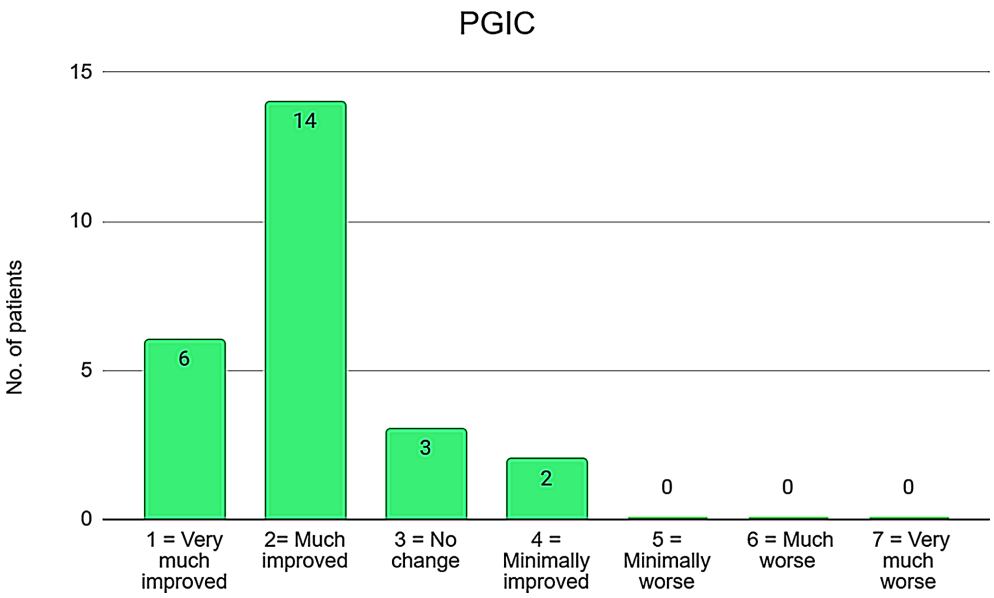

Figure 4. Distribution of Patient Global Impression of Change (PGIC) scores reported after the intervention. The histogram illustrates the frequency of individual ratings across the seven-point PGIC scale.

extended to all individual joint or primary indication subgroups and are presented for descriptive purposes only.

4. Discussion

The present retrospective pilot analysis suggests the feasibility of using a double-coil rPMS applicator for the treatment of large joints and indicates a potential signal of benefit in terms of pain reduction, functional improvement, and enhanced quality of life. The magnitude and clinical relevance of the observed changes were supported by the calculated effect sizes and MCID responder rates. All evaluated outcomes demonstrated large within-subject effect sizes, suggesting clinically relevant changes beyond statistical significance alone. In addition, a majority of patients exceeded the MCID across outcome measures, supporting the clinical relevance of the observed changes.

These findings are broadly consistent with the existing literature on rPMS. However, direct comparisons remain limited due to the heterogeneous nature of the dataset and the variability in protocols and outcome measures used across published trials. For instance, Lee and Nam reported an average 45% reduction in pain following a 20-session intervention in patients with knee OA [15]. In contrast, Kamiue *et al.* observed a complete elimination of pain after just 12 sessions of rPMS in an elderly population [14]. Due to differences in intervention parameters, sample characteristics, and assessment tools across studies, direct comparisons of functional outcomes are not feasible. Therefore, the above comparisons are descriptive only and should not be interpreted as evidence of superiority or equivalence between protocols.

Building on previously published theoretical modeling, the double-coil rPMS

setup used in this study has been hypothesized to offer enhanced stimulation depth and efficiency, particularly for large joints. This added benefit is primarily attributed to the spatial configuration of the two coils, which - when positioned at an angle approaching 90˚ - may be constructive field interaction and energy convergence at depths of approximately 4 - 5 cm. This results in a more effective stimulation of deep musculoskeletal structures compared to standard single-coil configurations, where the magnetic field intensity declines progressively with depth. It has been estimated that, at a depth of 4 cm, the field strength generated by the double-coil configuration could exceed that of the single-coil setup by up to 247% [18]. These modeling findings should be regarded as hypothesis-generating and not as direct explanations of the observed clinical effects.

The analgesic effect of rPMS is believed to arise from multiple, complementary mechanisms. One of the earliest and most widely cited is the gate control theory of pain, which posits that non-nociceptive afferent input from peripheral stimulation can inhibit the transmission of pain signals at the spinal level [27]. However, this mechanism primarily explains short-term pain modulation occurring during active stimulation, rather than the longer-lasting effects observed after treatment completion. Beyond its short-term effects, rPMS may trigger longer-lasting changes by activating proprioceptive pathways and modulating brain activity. This can enhance excitability in the primary motor cortex and related networks, supporting reorganization of motor and sensory functions and contributing to improved movement control and pain relief over time. [28] [29]. In addition to these central mechanisms, peripheral effects also contribute. Rhythmic muscle contractions induced by rPMS may increase local circulation, enhance oxygen delivery, and support tissue recovery [30]. The combination of changes in the brain and local effects in the body may help explain the pain relief and improvements in movement and quality of life.

The improvements observed in pain, function, and quality of life following the rPMS treatment protocol are not unexpected in light of the existing, albeit limited, clinical evidence. Considering the relatively low number of sessions (six), the magnitude of improvement appears notable. Nevertheless, the retrospective single-arm design remains the main limitation of this study and precludes causal inference. Although inclusion was restricted to patients without documented concomitant therapies or medication changes during the intervention period, the observed improvements may still reflect non-specific effects such as placebo responses, regression to the mean, or spontaneous symptom variation. While therapists routinely documented patient-reported co-interventions as part of standard clinical practice, unreported treatments cannot be entirely ruled out. Any residual confounding would likely affect individual cases rather than systematically bias outcomes across the entire cohort.

The absence of a control group, together with the relatively small sample size and clinical heterogeneity of the included patients in terms of treated joints and underlying diagnoses, further limits the generalizability of the findings. However,

this heterogeneity was intentional and appropriate for a pilot feasibility analysis, as it allowed the confirmation that the double-coil applicator can be ergonomically adapted to all commonly treated joint areas. In addition, outcomes were assessed only from baseline to completion of the treatment program, and no follow-up data were collected after the final session. Consequently, it remains unclear whether the observed improvements represent transient post-treatment effects or are sustained over time. Addressing both the durability of treatment effects and the specificity of the intervention will therefore require future prospective studies with an appropriate follow-up period, ideally extending at least one month beyond the final treatment session.

Confirmation of potential added value of the tilted double-coil configuration compared with standard single-coil or fixed figure-8 setups will require prospective randomized studies with sham or active comparator arms. Future studies may benefit from focusing on a specific joint and indication, such as knee OA, which remains one of the most prevalent causes of joint-related disability in the elderly. Demonstrating increased efficacy of the double-coil configuration in this population could offer an important non-invasive alternative to delay surgical intervention or serve as a bridge therapy during long preoperative waiting periods.

Despite its limitations, this study provides initial real-world clinical data supporting the use of an adjustable double-coil rPMS setup for the treatment of large joints. Further prospective and controlled studies are warranted to directly compare this approach with established rPMS protocols and determine its potential added value in musculoskeletal rehabilitation.

5. Conclusions

This retrospective pilot analysis supports the feasibility of a novel double-coil rPMS configuration for the treatment of large joints, including the knee, shoulder, hip, and elbow. Clinically meaningful improvements were observed in pain, functional disability, and health-related quality of life, as reflected by large effect sizes and high MCID responder rates across all evaluated outcomes. These findings should be interpreted as exploratory, and further research is required to assess clinical efficacy and to directly compare this approach to existing single-coil and figure-8 rPMS configurations. Nevertheless, the present results provide initial real-world data that may inform the development and design of future controlled studies investigating innovative neuromodulation strategies for large joint pain.

Conflicts of Interest

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

References

[1] Kaplan, L. D., Burns, B. and Craig, M. (2022) Arthritis. StatPearls Publishing.

[2] Smolen, J.S., Aletaha, D. and McInnes, I.B. (2016) Rheumatoid Arthritis. *The Lancet*, **388**, 2023-2038. https://doi.org/10.1016/s0140-6736(16)30173-8

[3] Mobasheri, A. and Batt, M. (2016) An Update on the Pathophysiology of Osteoarthritis: Integrating New Paradigms with Clinical Insights. *Current Rheumatology Reports*, **18**, Article 45.

[4] Sofat, N., Ejindu, V. and Kiely, P. (2021) What Makes Osteoarthritis Painful? *The Lancet Rheumatology*, **3**, e626-e628.

[5] Safiri, S., Kolahi, A.-A., Smith, E., Hill, C., Bettampadi, D., Mansournia, M. A., *et al.* (2021) Global, Regional, and National Burden of Osteoarthritis in 195 Countries and Territories, 1990-2020: A Systematic Analysis for the Global Burden of Disease Study 2020. *The Lancet Rheumatology*, **3**, e371-e380.

[6] Hunter, D.J. and Bierma-Zeinstra, S. (2019) Osteoarthritis. *The Lancet*, **393**, 1745-1759. https://doi.org/10.1016/s0140-6736(19)30417-9

[7] National Academies of Sciences, Engineering, and Medicine, Health and Medicine Division, Board on Health Care Services, Committee on Identifying Disabling Medical Conditions Likely to Improve with Treatment (2020) Selected Health Conditions and Likelihood of Improvement with Treatment: Musculoskeletal Disorders (Chapter 5). National Academies Press. https://www.ncbi.nlm.nih.gov/books/NBK559512/

[8] Maradit Kremers, H., Larson, D.R., Crowson, C.S., Kremers, W.K., Washington, R.E., Steiner, C.A., *et al.* (2015) Prevalence of Total Hip and Knee Replacement in the United States. *The Journal of Bone and Joint Surgery-American Volume*, **97**, 1386-1397. https://doi.org/10.2106/jbjs.n.01141

[9] Seddigh, S., Lethbridge, L., Theriault, P., Matwin, S. and Dunbar, M.J. (2021) Association between Surgical Wait Time and Hospital Length of Stay in Primary Total Knee and Hip Arthroplasty. *Bone & Joint Open*, **2**, 679-684. https://doi.org/10.1302/2633-1462.28.bjo-2021-0033.r1

[10] Sakai, K., Yasufuku, Y., Kamo, T., Ota, E. and Momosaki, R. (2020) Repetitive Peripheral Magnetic Stimulation for Patients after Stroke. *Stroke*, **51**, e105-e106. https://doi.org/10.1161/strokeaha.120.029373

[11] Kamo, T., Wada, Y., Okamura, M., Sakai, K., Momosaki, R. and Taito, S. (2022) Repetitive Peripheral Magnetic Stimulation for Impairment and Disability in People after Stroke. *Cochrane Database of Systematic Reviews*, No. 9, CD011968. https://doi.org/10.1002/14651858.cd011968.pub4

[12] Kesar, T.M., Perumal, R., Jancosko, A., Reisman, D. S., Rudolph, K.S., Higginson, J. S. and Binder-Macleod, S.A. (2011) Novel Patterns of Functional Electrical Stimulation Have an Immediate Effect on Dorsiflexor Muscle Function during Gait in People Poststroke. *Physical Therapy*, **91**, 554-568.

[13] Fawaz, S.I., Izumi, S., Zaki, A.S., Eldiasty, S.E., Saadawy, A., Saber, H.G.E., *et al.* (2023) Repetitive Peripheral Magnetic Stimulation for Improving Upper Limb Function in Post-Stroke Hemiparesis. *Egyptian Rheumatology and Rehabilitation*, **50**, Article No. 35. https://doi.org/10.1186/s43166-023-00204-x

[14] Kamiue, M., Tsubahara, A., Ito, T. and Koike, Y. (2024) Effects of Repetitive Peripheral Magnetic Stimulation on Knee Joint Extensor Strength in Older Persons Receiving Day Services. *Japanese Journal of Comprehensive Rehabilitation Science*, **15**, 49-57. https://doi.org/10.11336/jjcrs.15.49

[15] Lee, D. and Nam, S. (2021) Effects of Repetitive Peripheral Magnetic Stimulation and Exercise on Pain, Leg Muscle Strength, and WOMAC Index in Knee Osteoarthritis Patients. *Journal of Magnetics*, **26**, 341-346. https://doi.org/10.4283/jmag.2021.26.3.341

[16] Madhuripu, P., Kumar, A., Rajasheker, S. and Venkatesan, P. (2025) Comparison of Repetitive Peripheral Magnetic Stimulation (rPMS) and Sham-Rpms with Supervised

Exercise on Pain and Function in Knee Osteoarthritis Patients: Protocol for Randomized Sham-Controlled Trial. *Journal of Education and Health Promotion*, **14**, Article No. 247. https://doi.org/10.4103/jehp.jehp_1685_24

[17] Baek, J., Park, N., Lee, B., Jee, S., Yang, S. and Kang, S. (2018) Effects of Repetitive Peripheral Magnetic Stimulation over Vastus Lateralis in Patients after Hip Replacement Surgery. *Annals of Rehabilitation Medicine*, **42**, 67-75. https://doi.org/10.5535/arm.2018.42.1.67

[18] Vrbová, B., Malá, J. and Barna, M. (2025) Comparison of Single- and Doublex-Coil Rpms Configurations in Physiotherapy: Perception and Field Distribution in Commonly Treated Areas. *Journal of Orthopaedics and Sports Medicine*, **7**, 351-359. https://doi.org/10.26502/josm.511500214

[19] Boonstra, A.M., Schiphorst Preuper, H.R., Reneman, M.F., Posthumus, J.B. and Stewart, R.E. (2008) Reliability and Validity of the Visual Analogue Scale for Disability in Patients with Chronic Musculoskeletal Pain. *International Journal of Rehabilitation Research*, **31**, 165-169. https://doi.org/10.1097/mrr.0b013e3282fc0f93

[20] Novak, C.B., Anastakis, D.J., Beaton, D.E., Mackinnon, S.E. and Katz, J. (2013) Validity of the Patient Specific Functional Scale in Patients Following Upper Extremity Nerve Injury. *HAND*, **8**, 132-138. https://doi.org/10.1007/s11552-013-9506-9

[21] Luo, X., Lynn George, M., Kakouras, I., Edwards, C.L., Pietrobon, R., Richardson, W., *et al.* (2003) Reliability, Validity, and Responsiveness of the Short Form 12-Item Survey (SF-12) in Patients with Back Pain. *Spine*, **28**, 1739-1745. https://doi.org/10.1097/01.brs.0000083169.58671.96

[22] Hurst, H. and Bolton, J. (2004) Assessing the Clinical Significance of Change Scores Recorded on Subjective Outcome Measures. *Journal of Manipulative and Physiological Therapeutics*, **27**, 26-35. https://doi.org/10.1016/j.jmpt.2003.11.003

[23] Nie, J.W., Hartman, T.J., MacGregor, K.R., Oyetayo, O.O., Zheng, E. and Singh, K. (2023) Establishing Minimum Clinically Important Difference for Patient-Reported Outcome Measures in Patients Undergoing Lateral Lumbar Interbody Fusion. *Acta Neurochirurgica*, **165**, 325-334. https://doi.org/10.1007/s00701-022-05428-y

[24] Abbott, J.H. and Schmitt, J. (2014) Minimum Important Differences for the Patient-Specific Functional Scale, 4 Region-Specific Outcome Measures, and the Numeric Pain Rating Scale. *Journal of Orthopaedic & Sports Physical Therapy*, **44**, 560-564. https://doi.org/10.2519/jospt.2014.5248

[25] Díaz-Arribas, M.J., Fernández-Serrano, M., Royuela, A., Kovacs, F.M., Gallego-Izquierdo, T., Ramos-Sánchez, M., *et al.* (2017) Minimal Clinically Important Difference in Quality of Life for Patients with Low Back Pain. *Spine*, **42**, 1908-1916. https://doi.org/10.1097/brs.0000000000002298

[26] Auffinger, B.M., Lall, R.R., Dahdaleh, N.S., Wong, A.P., Lam, S.K., Koski, T., *et al.* (2013) Measuring Surgical Outcomes in Cervical Spondylotic Myelopathy Patients Undergoing Anterior Cervical Discectomy and Fusion: Assessment of Minimum Clinically Important Difference. *PLOS ONE*, **8**, e67408. https://doi.org/10.1371/journal.pone.0067408

[27] Katz, J. and Rosenbloom, B.N. (2015) The Golden Anniversary of Melzack and Wall's Gate Control Theory of Pain: Celebrating 50 Years of Pain Research and Management. *Pain Research and Management*, **20**, 285-286. https://doi.org/10.1155/2015/865487

[28] Struppler, A., Binkofski, F., Angerer, B., Bernhardt, M., Spiegel, S., Drzezga, A., *et al.* (2007) A Fronto-Parietal Network Is Mediating Improvement of Motor Function Related to Repetitive Peripheral Magnetic Stimulation: A PET-H2O15 Study. *Neu-*

roImage, **36**, T174-T186. https://doi.org/10.1016/j.neuroimage.2007.03.033

[29] Yan, T., Liang, M., Peng, J., Yu, Q., Li, Y., Yang, J., *et al.* (2024) Cortical Mechanisms Underlying Effects of Repetitive Peripheral Magnetic Stimulation on Dynamic and Static Postural Control in Patients with Chronic Non-Specific Low Back Pain: A Double-Blind Randomized Clinical Trial. *Pain and Therapy*, **13**, 953-970. https://doi.org/10.1007/s40122-024-00613-6

[30] Matsuda, T. (2009) Changes in Human Peripheral Blood Flow Obtained by Magnetic Stimulation. *IEEE International Conference on Systems, Man, and Cybernetics*, **6**, 364-369. https://doi.org/10.1109/icsmc.1999.816579