NARRATIVE REVIEW

Bipolar Pulsed Radiofrequency for Pain: Clinical Applications, Mechanistic Rationale and Technical Considerations - A Narrative Review

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ABSTRACT

Pulsed radiofrequency has gained recognition as a minimally neurodestructive modality for the management of diverse chronic pain syndromes. A notable advancement of this technique is bipolar pulsed radiofrequency, which employs two active electrodes to generate a more concentrated and potentially more efficacious electric field compared to its monopolar counterpart. This review presents a comprehensive evaluation of bipolar pulsed radiofrequency as an interventional pain management technique. The biophysical distinctions between bipolar pulsed radiofrequency and monopolar pulsed radiofrequency are delineated, with particular emphasis on the generation of denser and spatially broader electric fields. The proposed mechanisms of action encompassing neuromodulatory effects, anti-inflammatory activity mediated by cytokine suppression, and ultrastructural alterations in neural tissue are constructed from both preclinical and clinical evidence.

An in-depth analysis of clinical applications indicates that bipolar pulsed radiofrequency demonstrates superior or at least comparable efficacy in the treatment of chronic pain conditions, including lumbosacral and cervical radiculopathy, knee osteoarthritis, and postherpetic neuralgia, especially in patients who are refractory to monopolar radiofrequency or conservative therapies. Evidence regarding procedural parameters, including voltage, duration, and inter-electrode distance, highlighting the trend towards high-voltage, extended-duration protocols are consolidated. The safety profile of bipolar pulsed radiofrequency, including its application in patients with cardiac implantable electronic devices, is critically evaluated.

Finally, limitations in the current literature are addressed and future research directions, underscoring the need for standardized treatment protocols and further exploration of potential synergistic applications with orthobiologic therapies are proposed. Collectively, this review seeks to provide pain physicians with a rigorous, evidence-based framework to inform clinical practice and stimulate ongoing investigation in this evolving field.

Keywords: Pulsed Radiofrequency Treatment; Radiofrequency Ablation; Chronic Pain; Pain Management; Neuropathic pain.

Chronic pain constitutes a major global health concern, affecting approximately 20% of the adult population worldwide and imposing a substantial burden on both individuals and healthcare systems[1]. Although pharmacological therapies and conventional interventional approaches, such as epidural steroid injections, remain fundamental components of management, a considerable proportion of patients experience insufficient relief or are not suitable candidates for these treatment modalities[2,3]. This therapeutic gap has encouraged the development of advanced interventional strategies designed to provide targeted, sustained, and safe analgesia.

Radiofrequency (RF) therapy, a minimally invasive technique, has been integral to interventional pain practice for several decades. Initially implemented as continuous radiofrequency to produce thermal neurodestructive lesions, its use was constrained by potential adverse effects, including deafferentation pain and unintended motor nerve injury[4,5]. The introduction of pulsed radiofrequency (PRF) by Sluijter and colleagues in 1998 represented a paradigm shift in the field[6]. By delivering short bursts of high-frequency current followed by silent intervals, pulsed radiofrequency exerts neuromodulatory effects while maintaining tissue temperatures below the neurolytic threshold of 42°C, thereby minimizing structural neural damage[7,8].

Bipolar pulsed radiofrequency (BPRF) represents further technological refinement. In contrast to the monopolar configuration, where current flows between a single active electrode and a large dispersive grounding pad, BPRF utilizes two closely positioned active electrodes. This configuration confines the electrical current to the tissue between the two electrode tips, theoretically generating a dense and spatially extensive electrical field[9 10]. These biophysical characteristics have led to the hypothesis that BPRF may offer enhanced clinical efficacy, particularly for anatomically complex targets or, in patients who have demonstrated suboptimal responses to monopolar pulsed radiofrequency[11,12].

The growing body of evidence indicates that BPRF is not only effective but in some contexts may be potentially superior to monopolar pulsed radiofrequency for a range of chronic pain conditions, including lumbosacral and cervical radiculopathy, as well as chronic joint pain caused by osteoarthritis[13-15].

The present review synthesizes the available literature to provide a comprehensive resource for practicing pain physicians. Specifically, the underlying biophysical principles of bipolar pulsed radiofrequency are examined, its proposed mechanisms of action are evaluated, clinical indications and procedural parameters are analyzed, its safety profile is critically assessed, and future research priorities are outlined. This structured evaluation provides an evidence-based framework for clinical decisions and explores future research directions for this evolving intervention modality.

Biophysical Principles and Proposed Mechanisms of Action of Bipolar Pulsed Radiofrequency

The evolution from monopolar to bipolar pulsed radiofrequency reflects an effort to optimize the distribution and therapeutic impact of the applied electrical field. A clear understanding of the biophysical distinctions between these configurations and their downstream biological effects is essential for appropriate clinical implementation.

Biophysical Advantages of the Bipolar Configuration

In the monopolar pulsed radiofrequency configuration, the electrical field radiates outward from a single active electrode tip toward a distant dispersive grounding pad. Field intensity is maximal at the electrode tip and decreases rapidly with distance[16]. In contrast, bipolar pulsed radiofrequency (BPRF) establishes a circuit between two closely positioned active electrodes placed in parallel. This arrangement confines the current to the tissue between the electrode tips, producing a concentrated, strip-shaped electrical field[17 18].

Computational modeling and ex vivo investigations have clarified the implications of this configuration. Cosman et al. demonstrated that bipolar radiofrequency can generate larger and more geometrically predictable lesions than monopolar techniques[10,17]. Pérez et al. (2014), using computer modeling, confirmed that the electrical and thermal characteristics of bipolar pulsed radiofrequency differ substantially from those of bipolar continuous radiofrequency[16]. Their findings indicated that although the zone of potential irreversible electroporation remains limited to a narrow region adjacent to the electrode tips, the overall electrical field in BPRF is denser than in monopolar pulsed radiofrequency setup[16]. This increased field density is considered a principal factor underlying the enhanced neuromodulatory effects observed with BPRF[10,11].

Inter-electrode distance represents a critical procedural variable. An ex vivo study by Wondra et al. (2024) reported that to maintain lesion confluence, the optimal inter-electrode distance should be <12 mm for 18-gauge probes, <10 mm for 20-gauge probes, and <8 mm for 22-gauge probes[19]. Consistent with these findings, most clinical studies have adopted an inter-electrode distance of <10 mm to ensure a confluent electrical field[11,12].

Mechanisms of Neuromodulation

Although the precise mechanisms of pulsed radiofrequency remain incompletely defined, current evidence supports a multifactorial model incorporating neuromodulation, anti-inflammatory effects, and subtle ultrastructural alterations. Owing to its higher field density, BPRF is hypothesized to potentiate these mechanisms.

ELECTRICAL FIELD-MEDIATED NEUROMODULATION

The prevailing hypothesis proposes that the rapidly oscillating electrical field generated by pulsed radiofrequency induces long-term depression of synaptic transmission, particularly within nociceptive C-fibers, without causing irreversible neural injury[6,20]. This neuromodulatory effect appears to involve alterations in gene expression and neuronal excitability. Experimental studies have demonstrated increased c-Fos expression in the dorsal horn of the spinal cord, following pulsed radiofrequency exposure, suggesting activation of pathways associated with long-term modulation of pain-inhibition pathways[21,22]. Pulsed radiofrequency has also been shown to enhance descending noradrenergic and serotonergic inhibitory pathways[23]. The denser electrical field generated by BPRF may contribute to a more pronounced and sustained neuromodulatory response compared with monopolar pulsed radiofrequency[10,11].

ANTI-INFLAMMATORY AND IMMUNOMODULATORY EFFECTS

Neuroinflammation plays a central role in the persistence of chronic pain. Pulsed radiofrequency appears to exert significant anti-inflammatory effects. In animal models, pulsed radiofrequency applied to the dorsal root ganglion (DRG) has been shown to deactivate microglia in the spinal dorsal horn cells integral to the maintenance of neuropathic pain states[24]. This effect is associated with reduced expression of pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), and IL-6[25,26].

Fang et al. (2019) reported that pulsed radiofrequency applied to the DRG downregulated interferon regulatory factor 8 (IRF8) in the spinal cord and reduced brain-derived neurotrophic factor expression in the nucleus accumbens, providing a potential mechanistic explanation for its beneficial effects on neuropathic pain induced depressive symptoms[27]. Intra-articular pulsed radiofrequency studies have further demonstrated reductions in inflammatory mediators within synovial fluid in osteoarthritic knees, supporting a localized immunomodulatory action[28.] The combination of pulsed radiofrequency with orthobiologic agents, such as platelet-rich plasma (PRP), has been proposed as a synergistic strategy whereby pulsed radiofrequency optimizes the inflammatory environment and may potentialize regenerative effects[29.]

ULTRASTRUCTURAL AND MOLECULAR CHANGES

Although pulsed radiofrequency is considered non-neurodestructive, ultrastructural analyses have identified subtle morphological changes following treatment. Protasoni et al. (2009) observed mitochondrial swelling, dilated endoplasmic reticulum cisternae, and partial myelin delamination in myelinated axons of rat DRGs after pulsed radiofrequency exposure, whereas unmyelinated fibers were largely preserved[30]. Similarly, Erdine et al. (2009) reported microscopic alterations in C- and A-delta fibers[31]. These findings suggest selective modulation of nociceptive fibers by pulsed radiofrequency causing microscopic disruption that interferes with pain transmission without clinically significant neurological deficits.

At the molecular level, pulsed radiofrequency has been associated with increased expression of endogenous opioid precursors and modulation of ion channels, including Nav1.7, which play key roles in nociceptive transmission[32,33]. High-voltage pulsed radiofrequency protocols may further augment these effects by enhancing the expression of brain-derived neurotrophic factor and other neurotrophic factors involved in neural plasticity and pain regulation[27,29].

Clinical Applications and Procedural Parameters

The favorable biophysical profile of BPRF has translated into promising clinical outcomes across multiple chronic pain syndromes. Evidence is most robust in radicular pain and knee osteoarthritis, where BPRF frequently demonstrates superiority over monopolar pulsed radiofrequency, particularly in refractory populations.

LUMBOSACRAL AND CERVICAL RADICULAR PAIN

Radicular pain originating from the lumbar or cervical spine represents a primary indication for BPRF. Pulsed radiofrequency has demonstrated efficacy in radicular pain secondary to disc herniation, particularly in patients who have failed to respond to conservative treatments, epidural steroid injections, and bipolar configurations have shown enhanced outcomes in several studies[34-36].

In a randomized controlled trial, Chang et al. (2017) compared BPRF with monopolar pulsed radiofrequency in 50 patients with chronic lumbosacral radicular pain[11]. The BPRF group exhibited significantly greater reductions in Numeric Rating Scale (NRS) scores at 1, 2, and 3 months post-procedure. At 3 months, ≥50% pain relief was achieved in 76% of the BPRF group versus 48% in the monopolar group ($P = 0.041$) [11]. Lee et al. (2018) evaluated BPRF in patients refractory to monopolar pulsed radiofrequency and reported that 52.2% achieved successful pain relief at 3 months, with sustained NRS reductions[12]. Luo et al. (2022) further demonstrated favorable 6-month outcomes, with the use of BPRF in patients with chronic lumbosacral radicular pain, including in patients with pain duration exceeding two years[37]. Collectively, these findings support BPRF both as a primary intervention and also as a salvage therapy for monopolar pulsed radiofrequency failures.

Comparable results have been observed in cervical radiculopathy. Yang and Chang (2020) reported over 50% pain relief at 3 months in 50% of refractory patients treated with BPRF[14]. A randomized trial by Lee et al. (2022) comparing ultrasound-guided monopolar and bipolar pulsed radiofrequency, found BPRF superior to monopolar pulsed radiofrequency for cervical radicular pain[15].

CHRONIC KNEE PAIN AND OSTEOARTHRITIS

Intra-articular pulsed radiofrequency is an emerging modality for osteoarthritis-related knee pain. Güleç et al. (2017) conducted a randomized trial in 100 patients with grade 2-3 knee osteoarthritis (KOA), demonstrating significantly greater improvements in Visual Analogue Scale (VAS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores with bipolar compared to unipolar pulsed radiofrequency[13]. They reported 84% of patients in the bipolar group achieved ≥50% pain relief versus 50% in the unipolar group in 3 months.

Comparative studies have shown intra-articular bipolar pulsed radiofrequency (IA-bPRF) to be as effective as genicular nerve thermal radiofrequency ablation (G-RFT), with superior outcomes in certain functional subdomains suggesting it is a safe and potent alternative for advanced knee osteoarthritis[38,39]. A network meta-analysis similarly concluded that bipolar radiofrequency ablation yielded superior pain and functional outcomes compared with monopolar approaches in knee osteoarthritis[40].

OTHER NEUROPATHIC AND CHRONIC PAIN CONDITIONS

BPRF has also demonstrated efficacy in postherpetic neuralgia, where high-voltage, long-duration protocols have produced sustained reductions in pain and improvements in quality of life for up to 12 weeks[41]. The use of a bipolar configuration in conjunction with high voltage was thought to maximize the treatment field and neuromodulatory effect. Studies have also shown pulsed radiofrequency to be effective in treating ophthalmic herpetic neuralgia[42-44]. In a comparative study, pulsed radiofrequency was found to be more effective than spinal cord stimulation for the treatment of postherpetic neuralgia[45]. BPRF has been used in the treatment of trigeminal neuralgia[46,47]. BPRF has also been reported as a safe option for treating trigeminal neuralgia in a patient with a cardiac implantable electronic device (CIED), where the confined electrical field of the bipolar configuration may reduce electromagnetic interference risk[48]. Pulsed radiofrequency has also been shown to be effective in treating acute herpetic neuralgia[42,43,49].

OTHER APPLICATIONS

The versatility of BPRF is demonstrated by its application in a wide range of other chronic pain conditions. It has been effectively used for managing headaches, including chronic migraines, by targeting nerves such as the greater occipital nerve[50]. For abdominopelvic pain, BPRF has been applied to thoracic nerves and the ilioinguinal nerves to treat chronic abdominal and thoracic pain syndromes[51,52]. In cases of ischemic pain, such as that seen in diabetic foot ulcers, pulsed radiofrequency has shown potential in improving symptoms[52,53]. Additionally, pulsed radiofrequency has been used to manage sciatic neuropathy and xiphodynia, further highlighting its broad clinical utility[55,56,57].

Procedural Parameters: Voltage, Duration, and Electrode Placement

The optimization of BPRF parameters is an area of active research. There is increasing interest in high-voltage and extended-duration protocols to enhance efficacy.

HIGH VOLTAGE AND LONG DURATION PROTOCOLS

Standard pulsed radiofrequency protocols typically use 45 V. However, several studies suggest that higher voltages may produce a stronger electrical field and better clinical outcomes. High voltages up to 100 V were used for post herpetic neuralgia[41]. High voltages of 100 V have demonstrated enhanced outcomes in failed back surgery syndrome, including reductions in opioid consumption compared to a 45 V protocol[58]. Modern "e-field" technology in some modern generators, automatically adjusts pulse settings to maintain high voltage while limiting tissue temperature to below 42°C[58].

Similarly, treatment duration has been extended in some protocols from the conventional 2-6 minutes to 15 minutes to maximize the neuromodulatory effect[41,58]. However, a recent randomized controlled trial by Kim et al. (2025) found no significant advantage in the primary outcome of leg pain intensity at three months of a 12-minute over a 6-minute application for lumbosacral radicular pain at 3 months, suggesting that longer durations may not uniformly confer additional benefit[59].

Electrode Placement and Inter-Electrode Distance

Studies have shown that pulsed radiofrequency exposure leads to an increase in c-Fos expression in the dorsal horn a marker of neuronal activation that can trigger long-term changes in pain-inhibition pathways[21 22]. Furthermore, pulsed radiofrequency has been shown to enhance descending noradrenergic and serotonergic inhibitory pain pathways[23]. The higher field density of BPRF may lead to a more robust and sustained neuromodulatory effect compared to monopolar pulsed radiofrequency[10 11]. In BPRF, two cannulas are positioned parallel to one another targeting the neural structure under imaging guidance. Maintaining an appropriate Inter-Electrode Distance is critical: distances <5 mm may increase the risk of unintended thermal ablative effects, whereas distances <10 mm are generally used to ensure a confluent electrical field[11,12,16].

For intra-articular applications, Güleç et al. positioned two cannulas medially and laterally to the patellar ligament, with tips approximately 1 cm apart within the joint cavity 13. Precise placement under fluoroscopic or ultrasound guidance remains essential to maximize efficacy and ensure procedural safety.

The application of BPRF varies across different clinical conditions and anatomical targets. A summary of typical parameters from key studies illustrates the evolving protocols, particularly the trend towards high-voltage and long-duration applications for enhanced neuromodulation. Table 1 consolidates these parameters from some studies to provide a practical reference for clinicians.

Table 1: Summary of typical BPRF parameters used in recent clinical studies.

Study (Year)	Pain Condition	Target	Voltage	Frequency	Pulse width	Duration	Temperature
Chang et al. (2017)[11]	Lumbosacral Radicular Pain	Dorsal Root Ganglion	45 V	5 Hz	5 ms	6 min	<42°C
Lee et al. (2018)[12]	Lumbosacral Radicular Pain	Dorsal Root Ganglion	45 V	5 Hz	5 ms	6 min	<42°C
Kim et al. (2025)[39]	Lumbosacral Radicular Pain	Dorsal Root Ganglion	19-21 V	2 Hz	20 ms	6-12 min	42°C
Rufolo et al. (2024)[38]	Failed Back Surgery Syndrome	Dorsal Root Ganglion	45-100 V	2 Hz	20 ms	15 min	42°C
Lee et al. (2022)[15]	Cervical Radicular Pain	Dorsal Root Ganglion	45 V	5 Hz	5 ms	6 min	<42°C
Yang & Chang (2020)[14]	Cervical Radicular Pain	Dorsal Root Ganglion	45 V	5 Hz	5 ms	6 min	<42°C
Güleç et al. (2017)[13]	Knee Osteoarthritis	Intra-articular	45 V	2 Hz	10 ms	10 min	42°C
Yalçın & Salman (2025)[34]	Knee Osteoarthritis	Intra-articular	45 V	2 Hz	20 ms	6 min	42°C
Lin et al. (2023) [49]	Acute Herpetic Neuralgia	Sympathetic Chain	90-100 V	1 Hz	10 ms	15 min	42°C
Wan et al. (2016) [41]	Postherpetic Neuralgia	Dorsal Root Ganglion	70-100 V	2 Hz	20 ms	15 min	42°C

Clinical Decision Support: Optimizing the Application of Bipolar Pulsed Radiofrequency

The selection of bipolar pulsed radiofrequency (BPRF) over monopolar pulsed radiofrequency or alternative interventional modalities necessitates a comprehensive understanding of its relative advantages within specific clinical contexts. This section synthesizes the available evidence to inform patient selection and optimization of technical parameters.

The decision to use BPRF over monopolar pulsed radiofrequency or other interventions requires a nuanced understanding of its advantages and the specific clinical context. This section synthesizes evidence to guide clinicians in patient selection and technical parameter optimization.

Comparative Efficacy and Patient Selection

Current data suggest that BPRF may be preferentially considered in the following scenarios:

- **Refractory Pain Conditions:** Patients with lumbosacral or cervical radicular pain who have failed to achieve satisfactory relief following at least one prior monopolar pulsed radiofrequency procedure or repeated epidural steroid injections represent strong candidates for BPRF. Prospective studies by Lee et al. (2018) and Yang and Chang (2020) demonstrated clinically meaningful pain reduction in such refractory populations[12,14].

- **Anatomically Large or Complex Targets:** In conditions involving larger joint spaces (e.g., knee osteoarthritis) or anatomically diffuse targets such as the sacroiliac joint, the broader and more homogeneous electrical field generated by BPRF may facilitate more comprehensive neuromodulation than a single monopolar electrode[13,60].

- **Maximizing Treatment Efficacy:** Head-to-head randomized trials in lumbosacral and cervical radicular pain have reported higher success rates with BPRF (approximately 76-82%) compared with monopolar pulsed radiofrequency (48-55%)[11,15]. When the primary objective is to optimize the probability of meaningful pain relief, BPRF may therefore be considered as an initial interventional strategy.

Technical Parameter Optimization

Although standardized protocols remain under development, current evidence supports several practical considerations to optimize bipolar pulsed radiofrequency treatment:

- **Inter-Electrode Distance:** To generate a confluent therapeutic electrical field while minimizing unintended thermal effects, an inter-electrode distance of <10 mm is generally recommended. Distances exceeding this threshold may fail to create a continuous lesion strip, whereas distances <5 mm may increase the risk of thermal tissue effects[11,12,16].

- **Voltage:** While conventional pulsed radiofrequency protocols typically employ 45 V, emerging evidence supports the use of high-voltage applications (up to 100 V) in selected refractory conditions such as postherpetic neuralgia and failed back surgery syndrome. High-voltage protocols appear to augment neuromodulatory field strength and have been associated with improved long-term outcomes, including reduced opioid consumption[41,58].

- **Duration:** For most radicular and intra-articular applications, treatment durations of 6-10 minutes appear to balance efficacy and safety [11,13]. Although some protocols have extended application times to 12-15 minutes, a recent randomized controlled trial by Kim et al. (2025) found no statistically significant difference in pain reduction between 6-minute and 12-minute applications ($p = 0.436$), suggesting that prolonged durations may not consistently confer additional benefit[59].

- **Fluid Preinjection:** Preinjection of a sodium chloride containing solution significantly enhances the likelihood of achieving a consistent and continuous lesion between the electrodes, thereby increasing the mean volume of the lesioned tissue, potentially enhancing treatment consistency[61].

Safety Profile and Complications

A significant advantage of pulsed radiofrequency, including bipolar modality, is its favorable safety profile compared to continuous thermal ablation techniques. By maintaining tissue temperatures below the threshold for coagulative necrosis (typically 42°C), pulsed radiofrequency substantially reduces the risk of permanent nerve injury, deafferentation pain, and neuroma formation[8,62].

Across numerous studies encompassing several hundred patients treated with BPRF for various pain conditions, the incidence of serious adverse events has been consistently low[11-14,41]. Reported side effects are typically minor and transient, including temporary puncture-site discomfort, mild ecchymosis, and transient dysesthesia or paresthesia within the treated dermatome[41,63]. A large review of 62 manuscripts on radiofrequency ablation lesions of the dorsal root entry zone complex, which included 3157 cases, reported no permanent serious adverse events resulting in permanent injury and only a 3.58% incidence of minor, self-limited complications like transient site soreness[64].

Utilization in Patients with Cardiac Implantable Electronic Devices

Electromagnetic interference (EMI) remains a theoretical concern during radiofrequency procedures in patients with cardiac implantable electronic devices (CIEDs), such as pacemakers and implantable cardioverter defibrillators (ICDs). Monopolar radiofrequency systems may generate EMI detectable by these devices, potentially leading to inappropriate pacing, inhibition or delivery of shocks[65]. BPRF offers a theoretical and practical safety advantage in this population because the electrical current is confined between two closely spaced electrodes, thereby minimizing the risk of distant EMI[65,66]. A systematic review by Hanna and Abd-Elsayed (2021), evaluating 33 patients with CIEDs undergoing 71 bipolar radiofrequency ablations, reported no device-related adverse events or clinically significant interactions between the radiofrequency and the cardiac implantable electronic devices[65]. This evidence supports the consensus that BPRF, when performed with appropriate precautions (e.g., communication with cardiology, pre- and post-procedure device interrogation, keeping the adequate distance from the CIED), is a safe modality for this high-risk patient group[48,65].

Research Gaps and Future Directions

Despite the growing evidence supporting the use of BPRF, several limitations persist in the existing literature. Many studies are single-center, retrospective, or limited by small sample sizes, thereby restricting external validity[12 38]. Follow-up durations are often limited to 3-6 months, leaving the long-term durability of BPRF-induced analgesia unclear[11,14]. Furthermore, there is significant heterogeneity in procedural parameters such as voltage, duration, pulse width, frequency, and electrode configuration, making it difficult to establish a standardized, evidence-based protocol, a point emphasized in Expert Best Practice Guidelines like those from American Society of Pain and Neuroscience (ASPN)[34]. The lack of sham-controlled trials further limits definitive conclusions regarding efficacy of BPRF, as placebo effects can be significant in interventional pain studies.

Future research should prioritize large-scale, multicenter randomized controlled trials comparing BPRF with monopolar pulsed radiofrequency, sham procedures, and alternative active treatments (e.g., thermal pulsed radiofrequency ablations or corticosteroid injections). Future investigations should incorporate extended follow-up (≥12 months) and standardized outcome measures, including validated pain scales, functional indices, and quality of life surveys to clarify long-term effectiveness[13,39].

Further research is also required to define optimal procedural parameters. Studies comparing different voltages (e.g., standard 45 V vs. high-voltage >60 V) and durations in a randomized fashion would help delineate the dose-response relationships and refine safety margins[58,59]. Additional ex-vivo and clinical studies examining electrode type and inter electrode distance are warranted to optimize field geometry and lesion predictability[19].

Finally, exploring the synergistic potential of BPRF with other modalities represents an exciting frontier. The integration of BPRF with orthobiologics, biological materials used to enhance tissue healing and regeneration, such as platelet-rich plasma (PRP) or mesenchymal stem cells may combine neuromodulatory and tissue regenerative mechanisms, a hypothesis that requires rigorous preclinical and clinical validation[29]. The integration of BPRF with advanced imaging guidance, neuro-navigation, and artificial intelligence-assisted decision support may further enhance procedural precision and patient selection, paving the way for a more personalized approach to interventional pain management[66].

Conclusion

Bipolar pulsed radiofrequency represents a substantive advancement in the field of interventional pain management. By generating a denser and more spatially confined electrical field than its monopolar predecessor, BPRF offers enhanced clinical efficacy across multiple chronic pain conditions, particularly refractory radiculopathy and knee osteoarthritis. Its mechanism of action, though not fully elucidated, appears to be a multifactorial process of neuromodulation, anti-inflammatory activity, and subtle ultrastructural neural modifications. Importantly, BPRF technique demonstrates a strong safety profile, with low complication rates and emerging evidence supporting its safe use in patients with cardiac implantable electronic devices. Although current evidence is promising, the field would benefit from larger, high-quality randomized controlled trials with extended follow-up to establish standardized treatment protocols and strong clinical practice guideline recommendations. For the interventional pain physician, BPRF is a valuable and effective tool that expands the range of therapeutic options, particularly in the management of complex and treatment resistant chronic pain syndromes.

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