

Interventional radiofrequency in chronic pain management: Mechanisms, clinical applications and current evidence

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World Journal of Advanced Research and Reviews, 2026, 30(03), 894-901

Publication history: Received on 01 May 2026; revised on 10 June 2026; accepted on 12 June 2026

Article DOI: <https://doi.org/10.30574/wjarr.2026.30.3.1674>

Abstract

Chronic pain represents a major public health challenge, affecting nearly 20% of the world's population and substantially impairing quality of life, physical function and psychosocial well-being. Although pharmacological therapies remain the cornerstone of treatment, their effectiveness may be limited and long-term use is often associated with significant adverse effects. Consequently, interventional pain management has emerged as an essential component of multidisciplinary chronic pain care.

Interventional radiofrequency (RF) is a minimally invasive technique that uses high-frequency electrical current to modulate or interrupt nociceptive transmission within targeted neural structures. Performed under imaging guidance, RF enables precise treatment delivery with a low complication rate.

Several radiofrequency modalities are currently available, including conventional thermal radiofrequency, pulsed radiofrequency, and cooled radiofrequency. These techniques differ in their biological mechanisms, thermal characteristics, and therapeutic objectives. RF has been applied successfully in a wide range of chronic pain conditions, including facet joint syndrome, chronic lumbar radicular pain, sacroiliac joint dysfunction, peripheral neuropathic pain and osteoarthritis-related joint pain, particularly of the knee.

This narrative review aims to summarize the mechanisms of action, technical principles, clinical applications, and current evidence supporting the use of radiofrequency in chronic pain management.

Accumulating evidence supports that RF provides sustained pain relief and functional improvement in appropriately selected patients, making it an important therapeutic option within contemporary pain medicine.

Keywords: Chronic pain; Interventional radiofrequency; Interventional pain management; Neuromodulation; Chronic lower back pain; Knee osteoarthritis; Sacroiliac pain

1 Introduction

Pain is one of the most common reasons for seeking medical care worldwide and remains a leading cause of disability and reduced quality of life. Chronic pain affects nearly 20% of the global population and represents a major public health challenge due to its substantial impact on physical function, psychological well-being and social participation [1]. Unlike acute pain, which serves a protective role, chronic pain persists beyond normal tissue healing and is often sustained by complex mechanisms involving peripheral and central sensitization.

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Conventional pharmacological treatments including analgesics, non-steroidal anti-inflammatory drugs (NSAIDs), and opioids remain the cornerstone of pain management. However, their effectiveness may be limited in some patients, and long-term use is frequently associated with adverse effects and safety concerns, including opioid-related dependence, gastrointestinal toxicity, and increased cardiovascular risk [2]. Furthermore, a significant proportion of patients with refractory chronic pain derive insufficient benefit from pharmacotherapy alone, highlighting the need for alternative or adjunctive strategies [3]. In this context, targeted minimally invasive interventional techniques have gained increasing attention as complementary options within multidisciplinary pain management strategies.

Radiofrequency is an image-guided percutaneous technique that uses high-frequency electrical current (200–500 kHz) to target neural structures involved in pain transmission [4,5]. Depending on the technique employed, RF may induce controlled thermal neurolysis or neuromodulation, resulting in prolonged pain relief while minimizing systemic complications [2].

Several RF modalities are currently available, including conventional thermal radiofrequency, pulsed radiofrequency, and cooled radiofrequency. These techniques are used in a wide range of chronic pain conditions, such as facet joint syndrome, knee osteoarthritis, sacroiliac joint dysfunction, and selected neuropathic pain syndromes.

This narrative review aims to summarize the mechanisms of action of radiofrequency, technical principles, clinical applications, and current evidence supporting its role in the management of chronic pain.

2 Pathophysiology of Chronic Pain

Chronic pain arises from persistent alterations in nociceptive processing involving both peripheral and central nervous systems. Unlike acute pain, which serves as a protective physiological response, chronic pain persists beyond normal tissue healing and is sustained by complex neurobiological mechanisms. Several interconnected processes contribute to pain chronification.

- **Peripheral sensitization:** Following tissue injury or inflammation, peripheral nociceptors become hyperresponsive. This heightened responsiveness results from the influence of inflammatory mediators such as prostaglandins, cytokines, and growth factors. These mediators lower the activation threshold of sensory neurons and increase the transmission of nociceptive signals toward the central nervous system, resulting in enhanced pain sensitivity.
- **Central sensitization:** Persistent nociceptive input induces increased excitability of neurons within the dorsal horn of the spinal cord and higher pain-processing centers. This phenomenon, known as central sensitization, is characterized by amplified neuronal responses, activation of glial cells, and long-term neuroplastic changes that may persist even after the initial tissue injury has resolved [6]. Central sensitization plays a key role in the maintenance of many chronic pain conditions.
- **Dysfunction/Disinhibition of descending modulatory pathways:** Pain perception is normally regulated by descending inhibitory pathways originating from supraspinal structures. In chronic pain, dysfunction of these modulatory systems may reduce endogenous pain inhibition and facilitate the amplification of nociceptive signals, thereby contributing to pain persistence [7].
- **Neuroplastic and molecular changes:** Chronic pain is associated with structural and functional changes at spinal and supraspinal levels. These include synaptic strengthening similar to long-term potentiation, alterations in neurotransmitter expression and maladaptive reorganization of neural networks [6]. These changes contribute to pain persistence and maintenance.

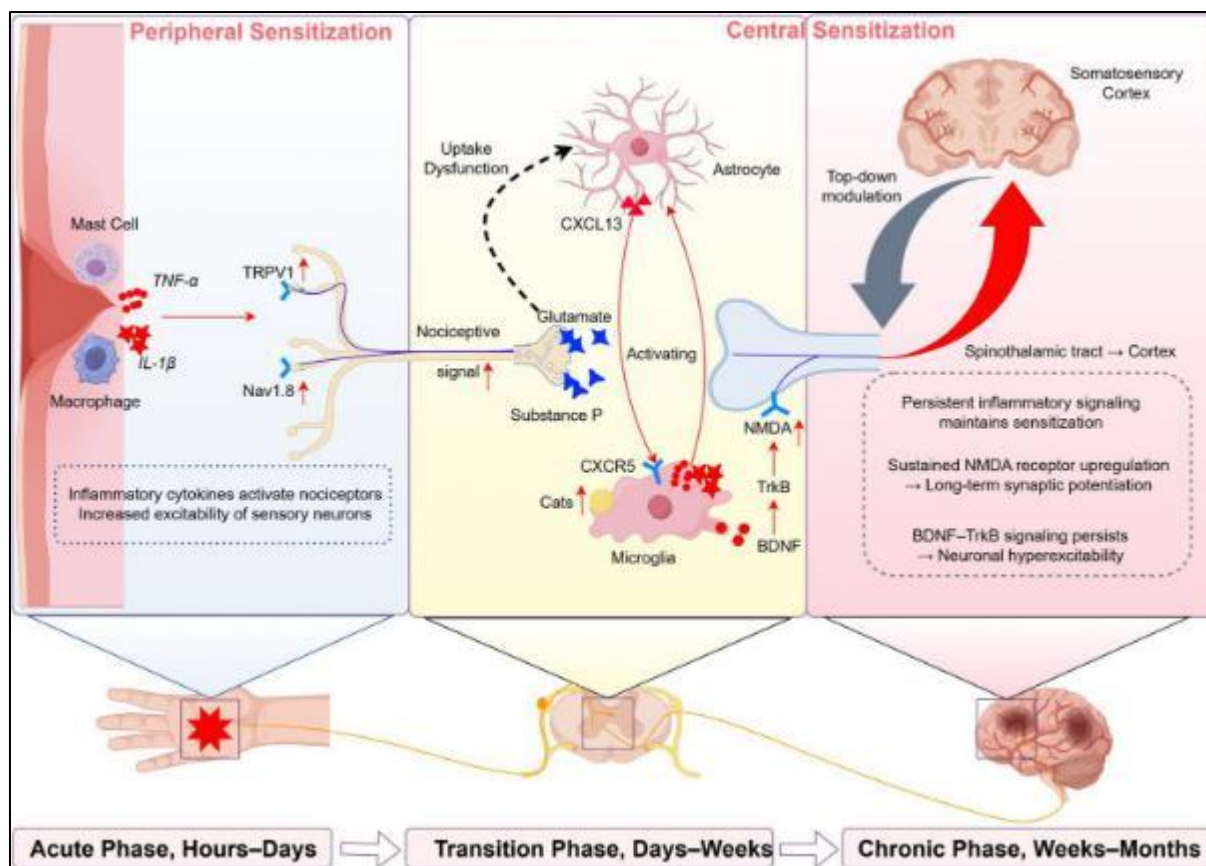


Figure 1 Mechanistic progression of pain chronification: from peripheral sensitization to central maladaptation. The figure illustrates the sequential biological processes involved in the transition from acute to chronic pain, through three overlapping phases: acute (hours to days), transitional (days to weeks) and chronic (weeks to months).
Reproduced from Zhang et al. licensed under CC BY 4.0. [6].

These pathophysiologic processes lead to characteristic clinical manifestations:

- Hyperalgesia: an exaggerated pain response to normally painful stimuli.
- Allodynia: pain elicited by stimuli that are normally non-painful.
- Neuropathic pain: pain caused by lesions or disease affecting the somatosensory nervous system, involving both peripheral and central mechanisms.

3 Principles and Procedure of Interventional Radiofrequency

Interventional radiofrequency is a minimally invasive image-guided procedure performed under sterile conditions, most often in an outpatient setting. Fluoroscopy and/or ultrasound guidance are used to accurately identify and target the neural structure responsible for the pain while minimizing the risk of injury to adjacent tissues [8].

Careful patient selection is essential and should be based on clinical evaluation, imaging findings, and concordance with the suspected pain generator. In selected cases, a diagnostic local anesthetic block may be performed before the procedure to confirm the nociceptive source and predict therapeutic response.

The patient is positioned on the procedural table according to the anatomical region being treated. An insulated needle-electrode with an active tip is then inserted percutaneously toward the target nerve under real-time image guidance. Once the needle is appropriately positioned, sensory (50 Hz) and motor (2 Hz) electrical stimulation are performed to verify correct electrode placement and reduce the risk of injury to adjacent motor structures [5].

After confirmation of correct needle placement, radiofrequency energy is delivered according to the selected modality, including conventional thermal radiofrequency, pulsed radiofrequency, or cooled radiofrequency. Treatment parameters vary depending on the indication and technique employed.

Following the procedure, patients undergo a short period of clinical monitoring before discharge. Radiofrequency is generally well tolerated and complications are uncommon and generally minor. Depending on the indication and technique used, pain relief may develop gradually over several days or weeks and can persist for several months; often resulting in meaningful functional improvement [9].

4 Types of radiofrequency and clinical applications:

Interventional radiofrequency techniques can be broadly categorized into three principal modalities: conventional thermal radiofrequency (CRF), pulsed radiofrequency (PRF), and cooled radiofrequency (C-RF). These techniques differ in their thermal characteristics, mechanisms of action, lesion size and clinical indications.

4.1 Conventional or continuous thermal radiofrequency:

4.1.1 Principle

Conventional thermal radiofrequency (CRF) consists of the delivery of a continuous high-frequency alternating current that generates tissue temperature ranging from 60 to 90°C, resulting in controlled thermal neurolysis through coagulative necrosis of the targeted neural tissue [10].

This thermal lesion interrupts nociceptive transmission by preferentially affecting small pain conducting A δ and C fibers, while largely preserving motor fibers [11].

The resulting lesion is typically ellipsoid and localized around the active tip of the electrode, with its size depending on temperature, exposure time, and electrode characteristics [5].

4.1.2 Clinical applications

4.1.2.1 Spinal facet joint pain

Radiofrequency denervation of the medial branches of the dorsal rami is one of the most extensively studied and best-validated indications for CRF. This technique is widely used in patients with chronic facet-mediated low back pain following a positive diagnostic block [12].

Several randomized controlled clinical trials have demonstrated significant reduction in pain and improvements in function lasting approximately 6 to 12 months, with some patients experiencing longer-lasting benefits [9,12].

4.1.2.2 Sacroiliac joint pain

Thermal radiofrequency targeting the sacral lateral branches may provide effective pain relief in selected patients with chronic sacroiliac joint dysfunction [13]. Several prospective studies have reported clinically meaningful improvements in pain and disability following treatment.

4.2 Pulsed radiofrequency

4.2.1 Principle

Pulsed radiofrequency (PRF) delivers short bursts of electrical current, separated by silent phases to maintain tissue temperature below 42°C and thereby avoiding significant thermal destruction of neural tissue [14].

Unlike conventional thermal radiofrequency, PRF primarily exerts its effects through neuromodulation rather than neuroablation. Proposed mechanisms include alterations in synaptic transmission, modulation of inflammatory mediators, changes in gene expression and effects on neuronal membrane function within nociceptive pathways.

4.2.2 Clinical applications

4.2.2.1 Chronic lumboradiculalgia

PRF applied to the dorsal root ganglion is commonly used in patients with chronic lumboradiculalgia refractory to conservative treatments [15].

Several studies have reported meaningful reduction in radicular pain while preserving nerve integrity, making PRF particularly attractive when destructive techniques are considered undesirable [16].

4.2.2.2 Peripheral neuralgia

Pulsed radiofrequency has been applied successfully in several peripheral neuropathic pain syndromes, including: Arnold's neuralgia, intercostal neuralgia, pudendal neuralgia, post-surgical neuropathic pain [17]. In these settings, its neuromodulatory properties offer the potential for pain relief without permanent neural injury.

Complex regional pain syndrome

PRF applied to peripheral nerves or sympathetic ganglia has shown promising results in selected patients with complex regional pain syndrome (CRPS), although the current evidence remains limited and further studies are required [18].

4.3 Cooled radio frequency:

4.3.1 Principle

Cooled radiofrequency (C-RF) uses an internally cooled through continuous water circulation. Cooling the electrode tip maintains temperatures, generally between 55 and 60 °C, while allowing a broader distribution of energy into the surrounding tissues [19].

As a result, it produces larger and more spherical lesions compared with conventional RF, potentially improving treatment efficacy in anatomical regions characterized by variable nerve distribution [20].

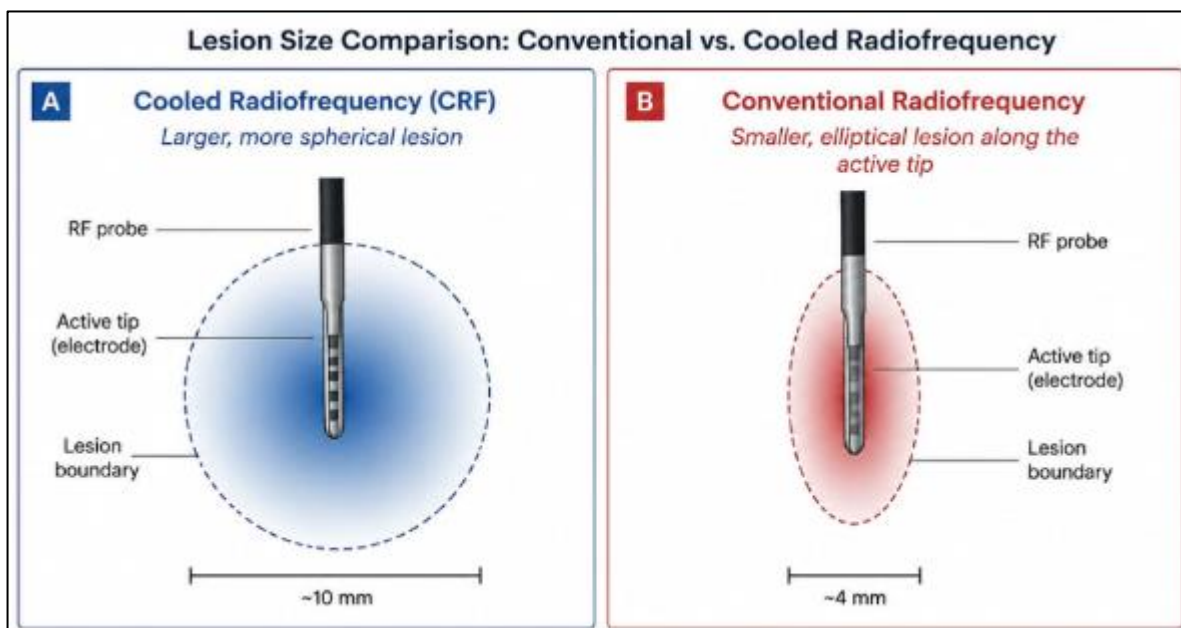


Figure 2 Comparison of lesion size produced by cooled and conventional radiofrequency probes. Cooled RF generates larger and more homogeneous lesions, potentially increasing the likelihood of capturing the targeted neural structures (author-created figure adapted from Cohen et al., 2008)

4.3.2 Clinical applications:

4.3.2.1 Knee Osteoarthritis

Cooled radiofrequency targeting the geniculate nerves has emerged as a valuable treatment option for chronic knee osteoarthritis pain, particularly in patients who are not candidates for prosthetic surgery or who continue to experience pain despite conservative treatment [21].

Clinical studies have shown significant improvements in pain intensity, function and quality of life lasting 6 to 12 months following treatment [22].

4.3.2.2 Sacroiliac joint pain:

Cooled RF is also increasingly used in chronic sacroiliac joint pain, because the larger lesion size may compensate for the anatomical variability of sacral lateral branch innervation [23].

4.3.2.3 Other Peripheral joint pain syndromes

More recently, cooled RF has been applied to chronic hip and shoulder osteoarthritis-related pain, with encouraging early results reported in several clinical studies [24].

Table 1 Characteristics and applications of different types of radio frequency. Table created by the authors

RF technique	Temperature	Nature of effect	Main mechanism	Physiological and typical target	Common clinical applications
Conventional thermal RF (CRF)	60–90 °C	Neurodestructive	Thermocoagulation (Joule effect)	A δ and C fibers; medial branches; sacral lateral branches	Facet joint pain; sacroiliac joint pain
Pulsed RF (PRF)	<42 °C	Non-destructive; neuromodulatory	Electric field and neuromodulation	Nociceptive neurons; dorsal root ganglion; peripheral nerves	Radicular pain; neuropathic pain; selected CRPS cases
Cooled RF (C-RF)	55–60 °C	Extended thermal lesion	Larger thermal lesion without excessive charring at the tip	Diffuse articular nerves; genicular nerves; sacral branches	Knee osteoarthritis; sacroiliac joint pain; hip and shoulder pain

5 Conclusion

Radiofrequency has progressively established itself as a cornerstone technique of interventional pain management, offering a minimally invasive, targeted, and reproducible therapeutic option for a wide spectrum of chronic pain conditions. The availability of different radiofrequency modalities (conventional thermal, pulsed, and cooled radiofrequency) enables clinicians to tailor treatment strategies according to underlying pain mechanisms, the targeted neural structure, and individual patient characteristics.

While conventional thermal radiofrequency is primarily indicated for nociceptive pain of articular or spinal origin, pulsed radiofrequency is preferred in neuropathic pain due to its neuromodulatory effects and preservation of neural integrity. Cooled radiofrequency, on the other hand, enables the creation of larger lesions and may offer advantages in anatomically complex regions, particularly in the management of knee osteoarthritis and sacroiliac joint pain.

Accumulating clinical evidence supports the efficacy and safety of radiofrequency procedures in appropriately selected patients, with the potential to provide sustained pain relief, improve functional outcomes, and reduce reliance on long-term pharmacological therapies. Nevertheless, careful patient selection, accurate image-guided targeting, and a thorough understanding of the underlying pain generator remain essential for optimizing treatment outcomes.

As research continues to expand, further high-quality studies are needed to refine patient selection criteria, compare the long-term effectiveness of the different radiofrequency modalities, and better define their place within comprehensive multidisciplinary chronic pain management strategies.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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