Chapter 6

Application of Radiofrequency in Pain Management

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Additional information is available at the end of the chapter

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Abstract

The application of radiofrequency is a treatment for many clinical conditions such as trigeminal neuralgia, complex regional pain syndrome, chronic postsurgical pain, cancer pain, hyperhidrosis and facet joint pain requiring ablation of different nerve locations. In this procedure, a constant high-frequency, high-temperature electrical current is applied to target tissue. Sluijter has achieved significant pain relief using radiofrequency current at a temperature below 42°C that produced strong electromagnetic field with no thermal lesion and referred as pulsed radiofrequency. The use of pulsed radiofrequency is a non-neurodestructive and therefore less painful technique, and it serves as an alternative method to continuous radiofrequency. Many studies have demonstrated favorable outcomes with pulsed radiofrequency compared to continuous radiofrequency.

This chapter suggests the use of continuous and pulsed radiofrequency with a minimally invasive procedure for patients with chronic pain as an alternative to surgical treatment and it might be an additional option among nonsurgical treatment methods.

Keywords: pain, treatment, pulsed radiofrequency, minimally invasive surgical procedures, continuous

1. Introduction

The application of radiofrequency (RF) electrical signals to neural tissue with an RF lesion generator and RF electrodes inserted into the tissue is common to treat pain [1] and other diseases such as atrial fibrillation [2], malignant liver tumors [3], intermediate and large bone tumors [4] and varicose veins [5]. The basis of this method is to generate enough RF heating power in the tissue to raise the temperature above 45–50°C which is referred as the “lethal temperature”, as the tissue exposed to these temperatures for 20 s or more are known to be destroyed by the heat [1].

The earliest RF lesion generators and electrodes were built by Cosman et al. in the early 1950s. They used continuous-wave RF with 0.1–1 mHz frequency and therefore referred as continuous RF lesioning [6, 7]. The basic principles and properties such as shape and size of heat lesions caused by for different electrode geometries and temperatures are well described today [8].

Recently, another RF method is especially used for pain treatment in which short pulses of RF signals are applied to the neural tissue through the RF electrode. This method is referred as pulsed RF lesioning [9].

While continuous RF used power sources with 0.1–1 mHz frequency range to produce RF heat lesion, pulsed RF signals have pulse durations ranging from 10 to 30 ms, and pulse repetition rates ranging from 1 to 8 Hz (pulses per second) [1]. Pulsed RF which produces a lesion to nerve tissue by transmission of high-voltage current through thermocouple probe has been used as a non- or minimally neurodestructive technique alternative to heat lesions because the average tissue temperature rise is less than continuous RF with the same voltage [1, 10–14]. Sluijter has achieved significant pain relief using radiofrequency current at a temperature below 42°C that produced strong electromagnetic field with no thermal lesion [9–11].

The objective of this book chapter is to explain the physics, operating principles, the mechanism of action, contraindications, complications and evaluation of efficacy of pulsed RF and continuous RF therapies in chronic pain management, in addition discussion of examples of clinical procedures.

2. The physics and operating principles of radiofrequency

RF lesioning is based on the principle of a very-high-frequency current passage down a 27G thermocouple probe which is inserted through a special 22G fully insulated cannula except for its tip. The current passes down the thermocouple probe and heats the surrounding tissues to a temperature controlled by the operator. The location of the nerve is achieved by a stimulating current with the thermocouple probe, and with a destructive current a circumscribed lesion is created. The lesion is shaped like a match with a diameter of about 2–4 mm [1, 11, 12].

The cannula, placed close to the targeted nerve to be lesioned, is usually confirmed under X-ray. Then, stylet of cannula is removed and replaced by the thermocouple probe. The operator initially attempts to seek the nerve by low-voltage stimulation at a frequency of 50 Hz, aiming the strongest sensory stimulation at the lowest possible voltage. The cannula needs to be within 3 mm of the nerve in order to create an adequate lesion and a maximum stimulation level of around 0.6 V would indicate this. The operator should always ensure that the cannula is not dangerously close to any motor nerve when trying to lesion a sensory nerve [1, 10–12].

When the operator is satisfied that the needle is in a safe place, a radiofrequency current (about 300–500 kHz) is passed through the thermocouple probe. The current heats up the surrounding tissues and produces a lesion in the targeted nerve. At a temperature of below 44–50°C, no permanent neurological damage will occur; thus, for practical purposes, when we mention lesion size, we mean the volume of tissue within the 44–50°C. In all cell types, the heating of tissue above 44–50°C for several minutes will indeed result in cell death [1, 10–12].

In order to eliminate any possibility of a heat lesion being produced, Sluijter suggested a radiofrequency technique which uses a temperature of no greater than 42°C and which utilises the strong electric field generated by the passage of the radiofrequency current to achieve pain relief [12]. In order to apply an electric field to the tissues, without raising the tip temperature above 42°C, the radiofrequency current can be applied in a pulsed fashion. The "silent" period between pulses allows for the dissipation of heat produced during the active cycle [12]. Cosman and Sluijter have modified the standard lesion generator to deliver radiofrequency current bursts of 45 V at a repetition rate of 2 Hz with each burst 20 ms long; the rest period is therefore 480 msec. This is defined as pulsed RF [10–12, 15, 16].

The resistance to the current flow can be measured and it is useful in certain procedures since it indicates the position of the needle tip. The impedans will be 400 Ω in extradural tissues and measuring a 200 will warn operator that the tip is passed to the cerebrospinal fluid (CSF) and a 800 Ω impedans will indicate when the tip enters CSF during percutaneuous cordotomy. Similarly, during procedures with intervertebral disc, an impedans is very high and it falls below 200 Ω while nucleus pulposus impedans of nucleus pulposus is reached [1, 10–12].

3. Mechanism of action of radiofrequency

Continuous RF lesioning involves the passage of a very high frequency which causes destruction by heat. It is simple and clear. Efficacy of pulsed RF has been clinically documented and has been used for chronic pain conditions for the last 20 years, but its mechanism of action is not fully understood [10–14]. It has been suggested to alter gene expression in neurons, by means of neuromodulation [1, 11, 17–23]. Stimulation of serotonergic and noradrenergic systems and induction of descending pathways have also been proposed [22]. There is no clinical evidence of any nerve damage with pulsed RF [11, 12, 19, 22, 23]. Higuchi et al. have presented experimental evidence that pulsed RF applied to the rat cervical dorsal root ganglion causes upregulation of the immediate early gene c-fos immunoreactivity in the laminae I & II of the dorsal horn [18]. Hamann et al. applied pulsed RF to the sciatic nerve or the L5 dorsal root ganglion in the rat. They studied the expression of activating transmission factor 3 (ATF3), an early intermediate gene expressed in response to cell stress. They also reported a trend downregulation of CGRP expression [24]. Hamann et al., pointing out the lack of laboratory evidence for this phenomenon, felt that this may be due to changes induced in the function of the Schwann cells [24]. Electric fields have demonstrated effects on immune modulation, as there are studies that show proinflammatory cytokines, such as interleukin (IL)-1b, TNF-alpha and IL-6, are attenuated by electric fields [25]. Upregulation of adenosine A2A receptor density has also been observed in human neutrophils treated with generated electric fields, and this appeared to be associated with inhibition of the catabolic cytokines, such as TNF-alpha, IL-6 and IL-8 [26].

In an animal study evaluating the histologic effects of continuous RF at 67°C and pulsed RF applied adjacent to rabbit dorsal root ganglia (DRG), Erdine et al. found mitochondrial degeneration and a loss of nuclear membrane integrity in the continuous, but not in the pulsed group [27]. Another histopathologic study, comparing the effects of continuous RF and pulsed RF delivered at 42°C on the rat DRG and sciatic nerve, showed no structural changes aside from transient endoneurial edema and collagen deposition [28]. In addition, Hagiwara et al. more recently demonstrated that pulsed RF may actually enhance the descending noradrenergic and serotonergic inhibitory pathways, which are intimately involved in the modulation of neuropathic pain [22]. Pulsed RF may be useful and continuous RF is contraindicated, e.g., in neuropathic pain and it is safe in locations where continuous RF may be potentially hazardous, e.g., DRG lesioning. It is virtually painless as no heat is generated [10–12].

Sluijter describes four phases in a pulsed RF treatment procedure:

a. *A stunning phase, which provides immediate relief.*

b. *A phase of post procedure discomfort, which may last for up to 3 weeks.*

c. *A phase of beneficial clinical effect, which has a variable duration.*

d. *A phase of recurrence of pain, we are still in the early days but many cases record 4–24 months of relief* [11, 12].

4. Contraindications of radiofrequency

Gauci does not recommend the use of both continuous and pulsed RF in patients with psychological overlay, drug dependency and total body pain [12]. Continuous RF treatment is also contraindicated in all nerve that carries motor fibers [1, 10–13].

Pulsed RF therapy seems ineffective in some diseases and would be contraindicated. Whereas according to some studies, pulsed RF appears to be ineffective in our opinion; one of the reasons for this is the insufficient “pulsed RF dose” applied. For example, in a study the anti-allodynic effects of pulsed RF was significantly greater when pulsed RF exposure was increased from 2 to 6 min [29]. Therefore, there also exist unresolved questions regarding the effective “pulsed RF dose” based on voltage settings and duration of pulsed RF treatment, which require further clinical studies in order to confirm.

5. Complications of radiofrequency

The high temperature applied with continuous RF is neurodestructive and is usually characterized by a period of discomfort, including hypoanesthesia and a neuritis-like reaction [1, 10–14]. Sometimes pain may potentially worsen due to nerve regeneration and may lead to neuroma formation. Other complications such as hematoma, numbness, transitory diplopia, meningitis, Horner’s syndrome and urinary retention may occur [12–14, 16, 17, 19, 30, 31].

In the publication of Cahana et al., it is stated that there is documentation of more than 1200 patients who have been treated with pulsed RF and no neurological complication was reported [23]. In a recent clinical study on patients with premature ejaculation, pulsed RF was performed to dorsal nerves of penis and no functional disorder that indicates a nerve lesion was determined [19]. We have not observed such a complication in our clinical experience.

6. Procedure for application of radiofrequency

The applications of continuous and pulsed RF in our department were made in operating room. Before procedure, prothrombin time and platelet counts were checked. Following a peripheral IV route, the patients were monitorized with ECG, oxygen saturation and non-invasive arterial blood pressure and sedated with 0.02 mg/kg IV midazolam. Following subcutaneous local anesthetic infiltration, a RF lesion generator was used for continuous and pulsed RF thermal ablation. A 22-gauge, 5–15 cm, RF cannula with a 2–10 mm active-pinned tip (with matching electrode) is advanced to the target tissue. The electrode of the RF device is placed on the cannula, and the impedance is seen to be between 200–400 Ω. In order to check the position of the cannula neurophysiologically, paresthesia is observed with 50 Hz sensory stimulation at 0.3–0.5 V and lack of motor contraction with 2 Hz motor stimulation at 0.9–1.5 V. After this neurophysiological testing, continuous RF thermal coagulation is applied at 60–80°C for 60–120 s. Pulsed RF thermal coagulation is applied at 42°C for 120–600 s. Following thermal coagulation, 2 ml of 2% lidocaine is applied through the cannula. All patients are monitored for potential complications following 2 h after the procedure. Patients were discharged home on the same day.

7. Applications of radiofrequency treatment

a. Radiofrequency facet joint denervation

- *Cervical facet joint denervation* [12, 32–35]

  Target: Medial branch of the cervical posterior primary ramus

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5 cm length, 2–4 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Supine and the X-ray tube "looks" at the side opposite to that being treated (C2–C5), prone (C6–C7)

  View: Lateral-oblique view of the cervical spine (C2–C5), postero-anterior-oblique view of the cervical spine (C6–C7)

Treatment modality: Continuous RF (80°C for 60 s), pulsed RF (42°C for 120–360 s)

- *Thoracic facet joint denervation* [12, 32, 34, 35]

  Target: Medial branch of the thoracic posterior primary ramus

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5–10 cm length, 2–4 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior view of the thoracic spine

  Treatment modality: Continuous RF (80–85°C for 60 s), pulsed RF (42°C for 120–360 s)

- *Lumbar facet joint denervation* [12, 32, 34–36]

  Target: Medial branch of the lumbar posterior primary ramus (eye of the Scottie dog, L1–L4), the junction between the superior articular process and the upper surface of the lateral part of the sacrum (L5), just lateral to the sacral foramen (S1–S3)

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 10–15 cm length, 5 mm active-pinned tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior-oblique view of the lumbar spine (tunnel vision)

  Treatment modality: Continuous RF (85°C for 60 s), pulsed RF (42°C for 180–360 s)

b. Radiofrequency dorsal root ganglion

- *Cervical DRG pulsed RF/continuous RF* [12, 34, 35, 37]

  Target: Typical cervical DRG (C3–C6)

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5–10 cm length, 2 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Supine and the X-ray tube "looks" at the side opposite to that being treated (C1–C6), prone (C7–C8)

  View: Lateral-oblique view of the cervical spine (C2–C5), postero-anterior-oblique view of the cervical spine (C6–C7)

  Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (65°C for 60 s) (do not carry out C1–C2)

  Attention: The vertebral artery may lie in needle path. Careful! (C1–C2)

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- *Thoracic DRG pulsed RF/continuous RF* [12, 34, 38–40]

  Information: Effective in the treatment of chronic thoracic postherpetic neuralgia and chronic postsurgical thoracic pain

  Target: Thoracic DRG

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 10 cm length, 2 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior-oblique view of the thoracic spine, angle your beam slightly cranially (T1–6), angle your beam slightly caudally (T7–12)

  Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (67°C for 60 s)

  Attention: Pneumothorax! Careful!

- *Lumbar DRG pulsed RF/continuous RF* [12, 27, 41–43]

  Information: Effective in the treatment of chronic post-amputation stump pain and complex regional pain syndrome

  Target: Lumbar DRG

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 10–15 cm length, 2 mm active-pinned tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior-oblique view of the lumbar spine (no double end plate) (chin of the dog)

  Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (50–65°C for 60 s)

c. Radiofrequency sympathetic nervous system

- *Sphenopalatine ganglion pulsed RF/continuous RF* [12, 44–47]

  Information: Effective in the treatment of posttraumatic headache, chronic face and head pain and cluster headaches

  Target: Pterygopalatine fossa, pterygomaxillary fissure

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5 cm length, 2 mm active-pinned tip (with matching electrode) of the RF, the grounding line

  Patient position: Supine and the X-ray tube "looks" at opposite to the treated side

  View: Lateral-oblique X-ray view of skull to show pterygomaxillary fissure

Treatment modality: Pulsed RF (42°C for 120–240 s), continuous RF (60–90°C for 60–90 s)

- *Superior cervical ganglion pulsed RF/continuous RF* [12, 48]

  Information: Effective in the treatment of tinnitus and atypical face pain

  Target: The superior cervical sympathetic ganglion is formed by the coalescence of the upper four cervical sympathetic ganglia. It is situated at the level of C3, postero-medial to the carotid sheath and to the internal jugular vein

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5–10 cm length, 2 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Lateral-oblique X-ray view of the cervical spine

  Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (70–75°C for 60 s)

- *Stellate ganglion pulsed RF/continuous RF* [12, 49–51]

  Information: Effective in the treatment of complex regional pain syndrome and posttraumatic stress disorder

  Target: It is situated at the level of C7

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5–10 cm length, 2 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Supine, prevent patient swallowing during procedure!

  View: Antero-posterior X-ray view of the cervical spine

  Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (70–75°C for 60 s)

  Attention: Ask the patient to phonate (recurrent laryngeal nerve!), Horner's syndrome!

- *Thoracic sympathetic ganglion pulsed RF/continuous RF* [12, 52–54]

  Information: Effective in the treatment of complex regional pain syndrome, palmar hyperhidrosis and compensatory hyperhidrosis of the trunk

  Target: It is situated at the levels of T4, T2, T3 and T6

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 5–10 cm length, 2 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior X-ray view of the thoracic spine

Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (75–80°C for 60–90 s)

Attention: Pneumothorax!

- *Splanchnic nerve pulsed RF/continuous RF* [12, 55–58]

  Information: Effective in the treatment of chronic abdominal pain, chronic pancreatitis and cancer pain

  Target: It is situated at the level of T11 at the costovertebral angle (about 4 cm from the midline)

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 15 cm length, 2–5 mm active-curved tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior X-ray view of the thoracic spine

  Treatment modality: Pulsed RF (42°C for 120 s), continuous RF (75–80°C for 60–90 s)

  Attention: Pneumothorax!

- *Lumbar sympathetic ganglion continuous RF/pulsed RF* [12, 59–61]

  Information: Effective in the treatment of complex regional pain syndrome, plantar hyperhidrosis, chronic pelvic and perineal pain and cancer pain

  Target: It is situated at the level of L4, L2 and L3

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 15 cm length, 2–5 mm active-pinned tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior-oblique and lateral X-ray view of the lumbar spine (no double end plate)

  Treatment modality: Continuous RF (80°C for 90 s), pulsed RF (42°C for 120–300 s)

d. Miscellaneous procedures

- *Trigeminal ganglion continuous RF/pulsed RF* [12, 62–64]

  Information: Effective in the trigeminal neuralgia treatment of combined pulsed and continuous radiofrequency

  Target: Foramen ovale

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 10 cm length, 2–5 mm active-pinned tip (with matching electrode) of the RF, the grounding line

Patient position: Supine

View: X-ray beam in an antero-posterior axis over the head, move the axis of the intensifier caudo-cranially so that the X-ray beam makes an angle of 45°, next, 45–50° between the sagittal and the vertical planes. Lateral control (Clivus must be seen!)

Treatment modality: Continuous RF (60°C for 60 s, followed by; 65°C for 60 s, followed by; 70°C for 60 s, followed by; 75°C for 60 s, and next, 80°C for 60 s), pulsed RF (42°C for 120–240 s)

Attention: The procedure is very painful (Sedoanalgesia may be required!), CSF may be seen (If so, position is correct). Exhibit eye movements or facial contractions may be seen (If so, position is incorrect), blood may be seen (If so, position is incorrect), contractions of the masseter muscles can be seen (If so, position is incorrect), corneal reflex should be protected!

- *Intradiscal RF/pulsed RF* [12, 65, 66]

  Target: Posterior anulus tear

  Required equipment: Mobile C-arm fluoroscopic X-ray systems, RF lesion generator, the cannula (a 22-gauge, 15 cm length, 2–5 mm active-pinned tip (with matching electrode) of the RF, the grounding line

  Patient position: Prone

  View: Postero-anterior-oblique view of the lumbar spine (no double end plate)

  Treatment modality: Continuous RF (50°C for 120 s, followed by; 55°C for 120 s, followed by; 60°C for 120 s, and next; 65°C for 240 s), pulsed RF (42°C for 120–900 s)

  Attention: Monitor external temperature of disc, never exceeds 44°C

- *Occipital nerve pulsed RF* [12, 67, 68]

  Information: Effective in the treatment of occipital neuralgia, migraine and cervicogenic headaches

  Target: Greater occipital nerve (C2), lesser occipital nerve (C3)

  Required equipment: RF lesion generator, the cannula (a 22-gauge, 5 cm length, 4 mm active-pinned tip (with matching electrode) of the RF, the grounding line, ultrasonography

  Patient position: The sitting position

  View: Occipital artery can be viewed with ultrasonography

  Treatment modality: Pulsed RF (42°C for 180–600 s)

  Attention: Temperature not to exceed 42°C

- *Suprascapular nerve pulsed RF* [12, 69–71]

  Information: Effective in the treatment of adhesive capsulitis, chronic shoulder pain

  Target: Suprascapular notch

  Required equipment: RF lesion generator, the cannula (a 22-gauge, 10 cm length, 5 mm active-pinned tip (with matching electrode) of the RF, the grounding line, ultrasonography

  Patient position: The sitting position

  View: Suprascapular artery can be viewed with ultrasonography

  Treatment modality: Pulsed RF (42°C for 180–600 s)

  Attention: Temperature not to exceed 42°C, Be careful about pneumothorax!

- *Percutaneous cervical cordotomy* [12, 72–74]

  Information: Indicated for unilateral pain due to malignant disease, when the pain is not responsive to drug therapy or other less invasive methods of treatment. The patient cannot be sedated

  Target: C1/C2 intervertebral space, lateral spinothalamic tract

  Required equipment: RF lesion generator, the cannula (a 22-gauge, 5–10 cm length, 2 mm active-pinned tip (with matching electrode) of the RF (Cordotomy kit!), the grounding line, computerized tomography

  Patient position: Supine

  View: Lateral view of cervical spine

  Treatment modality: Continuous RF (75°C for 60 s, followed by; 75°C for 60 s, followed by; 75°C for 60 s, and next; 75°C for 60 s)

  Attention: Working on the side opposite to the pain! Protect motor fibers!

Also, pulsed RF are reported in the literature that it can be used in treatment of *Morton's neuroma* [13], *coccygodynia* [14], *pudendal neuralgia* [75], *vaginismus* [76], *carpal tunnel syndrome* [77], *chronic hip pain* [78], *post herniorrhaphy pain* [79], *chronic inguinal neuralgia* [80], *plantar heel pain* [81], *osteoarthritis* [82], *intra-articular pain* [83], *plantar fascitis pain* [84], *tarsal tunnel syndrome* [85], *myofascial pain syndrome* [86], *postamputation phantom pain* [87], *meralgia paresthetica* [88], *lingual neuralgia* [89] and *chronic testicular pain* [90].

This chapter suggests the use of continuous and pulsed RF with a minimally invasive procedure for patients with chronic pain as an alternative to surgical treatment and it might be an additional option among non-surgical treatment methods. On the other hand, further randomized prospective controlled studies in patients with chronic pain are needed to fully evaluate the effectiveness of continuous and pulsed RF.

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