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Upper limb and lower limb radiofrequency treatments in orthopaedics

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- Radiofrequency (RF) is a minimally invasive technique for disrupting or altering nociceptive pathways to treat musculoskeletal neuropathic and nociplastic pain.
- RF has been employed to treat painful shoulder, lateral epicondylitis, knee and hip osteoarthritis, chronic knee pain, Perthes disease, greater trochanteric pain syndrome, plantar fasciitis, and painful stump neuromas; it has also been employed before and after painful total knee arthroplasty and after anterior cruciate ligament reconstruction.
- The benefits of RF include the following:it is safer than surgery; there is no need for general anaesthesia, thereby reducing adverse effects; it alleviates pain for a minimum of 3–4 months; it can be repeatable if necessary; and it improves joint function and minimizes the need for oral pain medication.
- RF is contraindicated for pregnant women; unstable joints (hip, knee, and shoulder); uncontrolled diabetes mellitus; presence of an implanted defibrillator; and chronic joint infection (hip, knee, and shoulder).
- Although adverse events from RF are unusual, potential complications can include infection, bleeding, numbness or dysesthesia, increased pain at the procedural site, deafferentation effect, and Charcot joint neuropathy.
- Although there is a risk of damaging non-targeted neural tissue and other structures, this can be mitigated by performing the technique under imaging guidance (fluoroscopy, ultrasonography, and computed tomography).
- RF appears to be a valuable technique for alleviating chronic pain syndromes; however, firm proof of the technique's efficacy is still required.
- RF is a promising technique for managing chronic musculoskeletal of the limbs pain, particularly when other techniques are futile or not possible.

Keywords
- chronic pain
- management
- radiofrequency

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Introduction

The use of radiofrequency (RF, also known as rhizotomy or neurotomy) for managing chronic pain was first reported in 1931 when Kirschner described the management of trigeminal neuralgia by applying RF to the Gasserian ganglion (1). However, it was not until the 1950s that the first commercial RF generator was developed by Cosman and Arnoff (2). Reports of other RF techniques emerged in 1998, when pulsed RF was created to produce a less 'aggressive' method (3). The precise mechanism of action by which pulsed RF relieves pain remains unclear. A third type of RF, known as 'cooled' RF, began to be used in the mid-1990s (4, 5, 6, 7, 8) and consists of applying cold saline solution to the tip of the RF probe, which generates larger, controlled lesions; however, it was not until 2008 that the first studies describing the use of cooled RF were published (9, 10, 11, 12). Since then, cooled RF has been shown to be helpful for numerous indications (13, 14, 15, 16, 17, 18, 19, 20, 21, 22).

The purpose of this article is to conduct a narrative review of recent literature on the role of RF in treating pain in various orthopaedic conditions in upper and lower limbs, shoulder, elbow, hip, knee and foot, as well as in managing pain in amputation stumps.

For this purpose, a search was performed in PubMed on February 28, 2023, using 'radiofrequency orthopedics' as key words. We found 1086 articles, 65 of which were selected because, in our opinion, they were the most important and were strictly related to the title of this article. The remaining 1021 were therefore excluded. In addition, three chapters from two important books published on the subject were studied, amounting to a total of 68 references. This article is therefore not a systematic literature review but rather a narrative review.

RF mechanism of action

According to Filippiadis *et al.*, energy in the electromagnetic field causes charged particles (ions and polar molecules) to move. This motion is conveyed to the surrounding molecules via friction, thereby transforming electromagnetic energy into kinetic energy at the molecular level, leading to heat production. Heating produces protein coagulation and consequent necrosis (23).

Wave frequency is the main attribute that defines energy. RF energy, in particular, is characterized by a frequency between 3 Hz and 300 GHz. In clinical practice, RF energy is employed as a continuous sinusoidal waveform at a frequency of 400–500 kHz. The RF current passes into tissues via an active electrode tip (which is uninsulated), causing ions such as sodium, chloride, and potassium to oscillate at a frequency of 400–500 kHz. This rapid ionic motion causes friction and consequent heating, with coagulation necrosis as the end result. The created heat is mainly produced in the tissue around the active electrode tip and passes inward (to the cannula lumen) and outward (producing concentric tissue injuries of lower temperature as the distance increases) (23).

RF waves ablate the neural tissue that transmits pain impulses to the brain (24). An RF circuit is formed by an RF generator producing the energy, a needle that is inserted into the patient, and a ground pad that is attached to dissipate the energy while connected to the RF generator. RF energy is applied and transmitted to the patient, which causes the ions in the conducting tissues to oscillate, releasing heat energy at the needle tip but without heating the needle itself. The oscillations of the ions heat the tissue surrounding the needle tip. There is typically a thermocouple at the needle tip to measure the tissue temperature. Heat isotherms are formed around the exposed needle tip secondary to the electrical field. Figure 1 shows the basic components of the RF technique.

Choosing the appropriate location is essential for this technique. RF-induced interactions result in heat generation, which produces coagulation necrosis and tissue destruction, therefore alleviating pain by burning the painful nerve (25). There are three main types of RF: conventional, pulsed, and cooled (26).

Conventional RF

In conventional (continuous or thermal) RF, a high-frequency (500 kHz) current produces a high temperature, causing stimulation and ablation in the target tissue. Most conventional RF systems use high temperatures of 60°C and 90°C for 90–120 s for clinical procedures, temperatures at which tissue destruction occurs, the objective of conventional RF (27, 28). In pain treatment, this heat produces a neurodestructive lesion in the small nerve and alleviates the pain. The RF generator produces coagulation necrosis around the tip of the cannula by generating an alternating current (29). Given that the lesion is round and its long axis is along the cannula tip, the cannula must be parallel to the target nerve (30).

Pulsed RF

Pulsed RF, in contrast, is a non-destructive technique that has been widely used to treat pain due to its minimal tissue damage. A high-frequency current is employed in pulsed RF but in short pulses, applying it to sensory nerves and joints (24). The duration of the pulsed RF current is typically short (20 ms) and has a high-voltage burst (amplitude of 45 V or more), after which there is a silent phase (480 ms) (31). During the pulse, the oscillating frequency is 420 kHz. Discontinuous pulses and a long silent phase between pulses result in heat reduction, keeping the temperature below 42°C (32). Therefore, tissue destruction does not occur, and adverse events such as neuritis, motor dysfunction, and deafferentation pain are less likely (33, 34). Although some mild damage around the pulsed RF electrode has been found, its impact is not clinically substantial and appreciable; overall, pulsed RF appears to be safe.

Cooled RF

Cooled RF resolves some of the problems of its predecessors, has a higher safety profile, and possesses

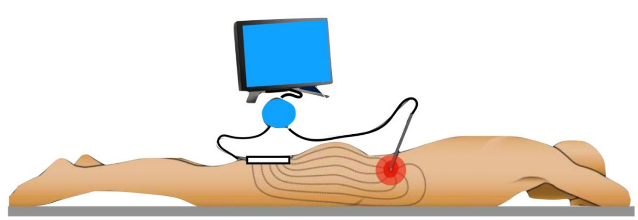

Figure 1
Schematic diagram showing the three basic components of the radiofrequency (RF) technique (RF generator, needle inserted into the patient, and ground pad placed on the patient to dissipate the energy, connected to the RF generator).

long-term effectiveness. The difference between cooled RF and other types of RF (pulsed and conventional) is that it produces a larger local tissue lesion (35).

Larger lesions augment the probability of successful management, particularly if there is physiological variability in the nerve location or complex innervation (such as the knee joint). The reason for the dissimilarity in the magnitude of the lesion is that classical RF probes function at a set temperature of 80°C; higher temperatures produce fast burning of adjacent tissue and not enough energy transfer to other tissues for larger ablation areas. In cooled RF, however, water circulates around the RF probe and diminishes its heat. Thus, these internally cooled probes function at a set 60°C (20°C lower than classical types), bringing the surrounding tissue heat to approximately 80°C. Consequently, this technique causes more energy to be transferred to the tissue. The lesion's magnitude will be larger and deeper, and the pain alleviation will last longer (36). The greatest advantage, however, is that to create a destructive lesion the probe does not need to be placed perpendicular to the target neural tissue.

When RF (thermal or cooled) is performed on neural tissue, nerve ablation is produced, which interferes with axonal continuity. As a result of ablation, the nerve fibres distal to the lesion degenerate, a phenomenon called Wallerian degeneration, which produces a transient interruption in a nerve cell, leading to a nociceptive block (37).

General concepts

In a systematic review and meta-analysis, Fari *et al*. assessed the effectiveness of RF for treating musculoskeletal pain. The authors' conclusion was that RF represents an encouraging technique for managing chronic musculoskeletal pain, particularly when other techniques are futile or not possible (38).

Indications, contraindications, and benefits

RF is recommended for managing pain arising from diverse musculoskeletal sources only if conservative treatment (analgesics, nonsteroidal anti-inflammatory drugs (NSAIDs), weight loss, and physical and rehabilitation medicine) has failed to provide alleviation and the patient is not a candidate for surgery. RF is contraindicated for pregnant women, patients with unstable joints (hip, knee, and shoulder), those with uncontrolled diabetes mellitus, and in the presence of an internal defibrillator, and infection at the target area (hip, knee, and shoulder). RF is a safer alternative to surgery, does not require general anaesthesia (thereby diminishing adverse effects), provides pain relief for a minimum of 3–4 months, can be repeated if needed, improves joint function, and minimizes the need for oral pain medication. Although adverse events from RF are unusual, potential complications can include infection, bleeding, numbness or dysesthesia, increased pain at the procedural site, deafferentation effect, and Charcot joint neuropathy. Although there is a risk of damaging non-targeted neural tissue and other structures, this can be mitigated by performing the technique under imaging guidance (fluoroscopy, ultrasonography, and computed tomography) (39, 40, 41, 42, 43, 44, 45, 46, 47).

Upper limb RF treatments

RF in shoulder osteoarthritis

Tran *et al*. employed image-guided axillary, lateral pectoral, and suprascapular nerve cooled RF as an alternative to managing symptomatically moderate-to-severe glenohumeral osteoarthritis (OA) in individuals who did not respond to other conservative treatments and who were not surgical candidates or who refused surgery (48). The prospective pilot study included 12 individuals experiencing chronic shoulder pain with moderate-to-severe glenohumeral OA. The participants underwent anaesthetic blocks of the axillary, lateral pectoral, and suprascapular nerves to determine candidacy for cooled RF treatment. The appropriate response after anaesthetic block was over 50% immediate pain alleviation. Once the patients were deemed candidates, they underwent cooled RF of the three nerves 2–3 weeks later. Treatment response was assessed by the American Shoulder and Elbow Surgeons (ASES) score and visual analogue scale (VAS) to evaluate pain, stiffness, and functional activities of daily living (ADL). Follow-up scores were collected up to 6 months after cooled RF. In the 12 patients who underwent cooled RF for shoulder OA, the VAS scores improved significantly (from 8.8 to 2.2) a few months after undergoing cooled RF ($P < 0.001$). The participants' total ASES scores significantly improved from 17.2 to 65.7 ($P < 0.0005$), and there were no major adverse events. None of the participants underwent re-treatment or shoulder arthroplasty. Image-guided axillary, lateral pectoral, and suprascapular nerve cooled RF had minimal adverse events and was found to be an promising option for treating chronic shoulder pain and stiffness from glenohumeral OA (48).

Mermekli *et al*. retrospectively assessed the use of ultrasound-guided RF of the suprascapular nerve for treating chronic shoulder pain due to OA (49). The authors used a modified distal and selective ablation technique in the spinoglenoid notch with motor and sensory stimulation, which protected the motor branch of the nerve from ablation. A retrospective study was performed of the patients who underwent ultrasound-guided RF of the suprascapular nerve. During the procedure, the conventional RF electrode was placed in the spinoglenoid notch, at the distal branch of the suprascapular nerve. Motor and sensory stimulations were employed to confirm the position. Ultrasound-guided RF was applied up to three times, at three different points, at least once each time, at 80°C. In total, 127 ultrasound-guided RFs of the suprascapular nerve were performed on 101 individuals with chronic shoulder pain secondary to OA. One hundred and nineteen diagnostic ultrasound-guided suprascapular nerve corticosteroid injections were performed before RF. The mean pre-injection VAS was 8.3, with a post-injection VAS score of 4.4 at 24 h and 4.5 at 2 weeks. The mean pre-RF VAS pain score was 7.7, with a post-RF VAS score of 4.4 at 24 h and 4.5 at 2 weeks. Ultrasound-guided RF of the suprascapular nerve in the spinoglenoid notch was found to be a safe treatment for chronic osteoarthritic shoulder pain, with repeat treatments infrequently needed. The technique was associated with significant improvement in VAS pain scores (49).

Kallas *et al*. claimed that shoulder OA is a significant cause of physical disability and mental distress. Classical nonsurgical treatment alone is frequently unable to entirely relieve the associated chronic articular pain. Furthermore, many individuals are unsuitable for shoulder arthroplasty due to comorbidities and costs. RF of articular sensory nerve fibres can interrupt the transmission of nociceptive signals by neurolysis, thereby producing long-term pain alleviation. Cooled RF uses internally cooled electrodes to create larger ablative areas compared with standard RF. Given the intricate variable innervation of the glenohumeral joint, a larger ablative management area, such as that given by cooled RF, is preferred to capture a greater amount of afferent nociceptive fibres. The targets of cooled RF are the suprascapular, axillary, and lateral pectoral nerve articular sensory branches of the glenohumeral joint. Cooled RF appears to be a promising tool for treating OA-related pain, especially in individuals who cannot undergo shoulder arthroplasty, have long wait times, or have persistent pain after shoulder arthroplasty (50). Figure 2 shows a case of shoulder pain due to OA treated with pulsed RF.

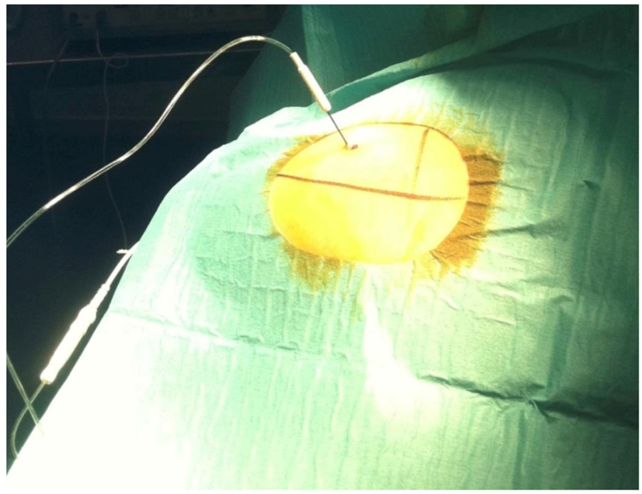

Figure 2
Pulsed radiofrequency in shoulder osteoarthritis.

RF in lateral epicondylitis

In 2016, Oh *et al*. stated that although lateral elbow pain is generally self-limiting, in a minority of people symptoms persist for a long time. When various conservative treatments fail, surgical approach is advised. Surgical denervation of several nerves that innervate the lateral humeral epicondyle could be considered in patients with refractory pain because it denervates the region of pain. The radial nerve can be identified as a target for pulsed RF lesioning in lateral epicondylitis. Oh *et al*. reported on two patients with intractable lateral epicondylitis suffering from elbow pain who did not respond to nonoperative treatments, but in whom the ultrasound-guided pulsed RF neuromodulation of the radial nerve induced symptom improvement. After a successful diagnostic nerve block, RF probe adjustment around the radial nerve was carried out on the lateral aspect of the distal upper arm under ultrasound guidance, and multiple pulsed treatments were applied. A significant reduction in pain was found over the follow-up period of 3 months (51).

In 2018, Hamlin *et al*. compared standard open release (SOR) vs radiofrequency microtenotomy (RFMT) in the treatment of lateral epicondylitis. Both groups showed significant improvements and similar benefit to the patient. The results of the study did not show any benefit of RFMT over the SOR. As a result of the extra expense of RFMT, Hamlin *et al*. recommended SOR as the standard surgical management (52).

In 2022, Viswanathan and Shanker assessed the therapeutic effectiveness and reported long-run outcomes and recurrences in patients treated with RFMT. They presented long-run outcomes with a mean 8-year follow-up in a case series of 19 patients. All patients had a minimum of 6 months (mean 23.25 months and range 6–36 months) of conservative management which included steroid injections prior to being offered RFMT. This was a retrospective case series of 20 elbows (in 19 patients) who underwent RFMT. The majority of patients (65%) were females. The operation was performed in the dominant arm in 55% of patients. Results were analysed by comparing preoperative and postoperative QuickDASH scores (Disabilities of the Arm, Shoulder, and Hand Score) obtained at 1 year and 8 years postoperatively. They found an improvement in QuickDASH scores from a mean of 61.7 preoperatively to 18.9 and 8.5, respectively, at 1 year and 8 years postoperatively. The mean pain component of the QuickDASH scores decreased from 4.8 preoperatively to 2.0 and 1.5, respectively, at 1 year and 8 years postoperatively. More than 83% of the patients had excellent to good functional improvement. RFMT was a dependable modality for managing recalcitrant lateral epicondylitis of the elbow with excellent long-run outcomes (53).

Lower limb RF treatments

RF in knee OA

According to Tran and Gonzalez, degenerative knee OA is a progressive debilitating disease that affects millions of people worldwide. Most patients experience limited range of motion, swelling, and pain. Various treatments can lead to short- and long-term pain alleviation. Short-term pain alleviation commonly involves conservative medical treatments such as analgesics, NSAIDs, weight loss, physical and rehabilitation medicine, and intra-articular injections (e.g. corticosteroids, hyaluronic acid, and platelet-rich plasma). Ultimate long-term pain alleviation treatment involves total knee arthroplasty (TKA). The management algorithm for knee OA also includes treating pain until an individual is suitable for TKA. Moreover, approximately 20% of individuals experience chronic pain following TKA without adverse events such as hardware loosening and infection with limited treatment alternatives. Cooled RF has been shown to be clinically efficacious by interrupting the integrity of deep sensory nerves and therefore interfering with transmission of the pain signal. The analgesic effect after cooled RF has been reported to last up to 2 years (54).

Ghai *et al*. compared ultrasound-guided pulsed RF of the genicular nerve with a genicular nerve block using a local anaesthetic and steroid for the treatment of knee OA pain (55). Thirty individuals with knee OA were randomly assigned to undergo either ultrasound-guided RF of the genicular nerve (RF group) or nerve block with bupivacaine and methylprednisolone acetate (local anaesthetic steroid group). The verbal numeric rating scale (VNRS) and Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) scores were measured before the procedure and at 1, 4, and 12 weeks after the procedure. The VNRS scores diminished significantly in both the groups at 12 weeks and at the other follow-up times compared to baseline. Seventy-three per cent of individuals in the RF group and 66% in the local anaesthetic steroid group achieved efficacious pain relief (≥50% pain decrease) at 12 weeks. A statistically significant improvement in WOMAC scores was observed in both groups at all follow-up times. However, there was no intergroup difference between the VNRS and WOMAC scores. No adverse events were encountered. Both ultrasound-guided RF of the genicular nerve and blocks of the genicular nerve with local anaesthetic and a steroid gave similar pain alleviation without any adverse events. RF of the genicular nerve took much more time and equipment than the genicular nerve block (55).

In a systematic review, Fogarty *et al*. analysed the efficacy of fluoroscopically guided genicular nerve RF for painful knee OA. The primary outcome measure was improvement in pain after 6 months. Secondary outcomes included the Oxford Knee Score (OKS) and WOMAC. Six-month success rates for 50% or greater pain relief following RF ranged from 49% to 74%. When compared with intra-articular steroid injection, the likelihood of success was 4.5 times higher for RF. When RF was compared with hyaluronic acid injection, the likelihood of management success was 1.8 times higher. The group mean OKS and WOMAC scores improved in the individuals experiencing genicular RF compared with intra-articular steroid injection and hyaluronic acid injection. This study showed moderate-quality evidence that fluoroscopically guided genicular RF was effective for relieving pain associated with knee OA at a minimum of 6 months (56).

In a systematic review and meta-analysis of level I and II studies reported in 2022 (grade 2 of evidence), Wu *et al*. assessed various RF treatments for knee OA. The authors' goal was to determine the best modality, target, number of electrodes, and image guidance for improving knee pain and function (47). Twenty-one suitable RCTs (from 2011 to 2021, involving 1818 individuals) with eight RF treatments, six intra-articular injections, NSAIDs, exercise, and placebo were evaluated. Conventional bipolar genicular nerve RF had the greatest net benefit on the VAS at 6 months; cooled monopolar genicular nerve RF had the greatest net benefit on the WOMAC at 6 months. In conventional and pulsed modalities, bipolar RF was associated with a more significant reduction in VAS and WOMAC than monopolar RF. Combining pulsed intra-articular RF and platelet-rich plasma injections had no additional positive effects on VAS or WOMAC at 3 months. RF was efficacious in improving both knee pain and function in individuals with OA, at least in the short term (6 months). Individuals responded better to the cooled modality than to the conventional and pulsed modalities. Bipolar was more efficacious than monopolar for improving pain and function in conventional and pulsed modalities. Fluoroscopy and ultrasound guidance demonstrated no differences in improving pain and function (47).

In 2022, Lyman *et al*. evaluated the long-term results of cooled RF of genicular nerves for chronic knee pain due to OA (46). A prospective, observational extension of an RCT was conducted on adults randomized to cooled RF. The participants were part of a 12-month clinical trial comparing cooled RF of genicular nerves with a single hyaluronic injection for treatment of chronic OA knee pain. The participants then agreed to visits at 18 and 24 months after the procedure and had since not undergone another knee procedure. The participants were assessed for pain using the VNRS, for function using the WOMAC, for subjective benefit using the Global Perceived Effect (GPE) scale, for quality of life (QoL) using the EuroQol-5-Dimensions-5 Level (EQ-5D-5L) questionnaire, and for safety. Of the 57 suitable individuals, 36 enrolled; 32 participants completed the 18-month visit with a mean VNRS score of 2.4, and 22 (69%) reported a ≥50% decrease in pain from baseline (primary endpoint); 27 completed the 24-month visit, with a mean VNRS of 3.4, and 17 (63%) reported a ≥50% pain alleviation. Functional and QoL improvements continued the same way, with mean changes from baseline of 53.5% and 34.9% in WOMAC total scores and 24.8% and 10.7% in EQ-5D-5L index scores, at 18 months and 2 years, respectively. Cooled RF of genicular nerves provided lasting pain alleviation, improved function, and improved QoL extending to 2 years after the procedure, with no significant safety concerns (46).

In 2022, Kaya *et al*. reported the 1-year results of the impact of thermal genicular nerve RF on pain and functional results in individuals with advanced knee OA (57). Forty-nine knees (35 patients) that had undergone thermal RF of the superior medial, superior lateral, and inferior medial branches of the genicular nerve under fluoroscopic guidance were analysed. Twenty-five of the participants were women, and 10 were men, with a mean age of 77.3 years (range 61–92 years). The mean VAS score was 8.4 prior to radiofrequency ablation (RFA), 1.7 immediately after the procedure, 2.4 at 1 month, 3.4 at 6 months, and 4.4 at 12 months ($P < 0.01$). The mean WOMAC score was 69.7 prior to RFA and 36.1 at the final 12-month follow-up ($P < 0.01$). There were no adverse events in any individual during the treatment or follow-up. Nonsurgical thermal genicular nerve RF therapy of knee OA rendered significant results in terms of pain and functionality, with no significant systemic or local complications. According to the authors, the procedure could be considered an alternative to other methods when managing advanced knee OA (57). Figure 3 shows a case of fluoroscopically guided genicular nerve RF for treating chronic knee pain due to OA.

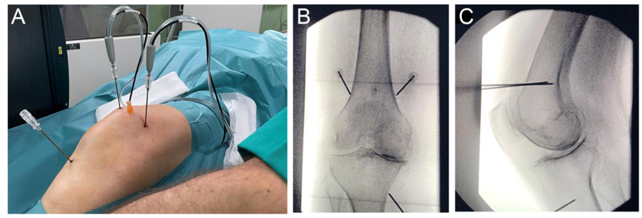

Figure 3
(A–C) Fluoroscopically guided genicular nerve radiofrequency for treating chronic knee pain due to osteoarthritis: (A) clinical view; (B) anteroposterior fluoroscopic view; and (C) lateral fluoroscopic image.

RF in chronic knee pain

Genicular nerve RF is a minimally invasive intervention for individuals with chronic knee pain not responding to conservative treatments. Few investigations have compared treatment results of cooled RF and conventional RF. Wu *et al*. compared the results, including the likelihood of treatment success, between cooled RF and conventional RF in individuals with chronic knee pain (58). The authors analysed a total of 208 propensity score-matched individuals, including 104 who underwent cooled RF and 104 who underwent conventional RF. The primary outcome was likelihood of pain relief following the procedure, defined as a reduction in the VNRS pain score of 2 or more. The secondary outcomes were the decrease in VNRS pain scores, duration of relief, and the likelihood of individuals undergoing TKA within 1 year of treatment. Conventional RF was associated with a higher likelihood of pain relief within 1, 3, and 6 months after the procedure compared with cooled RF. The likelihood of pain relief from conventional RF and cooled RF were 62% and 43% ($P=0.01$) within 1 month, 78% and 55% within 3 months, and 79% and 59% ($P < 0.01$) within 6 months, respectively. Conventional RF was also associated with higher mean VNRS pain score reductions at 1 month after the procedure (−4.71 vs −3.59 ($P=0.02$) from cooled RF). Conventional RF and cooled RF were similar in the pain score decrease at 3, 6, 9, and 12 months after the procedure. Both groups showed similar duration of relief and likelihood of individuals undergoing TKA within 1 year. Both conventional RF and cooled RF efficaciously diminished VNRS pain scores in most individuals with chronic knee pain within the 1-year follow-up. Genicular nerve conventional RF was associated with a higher likelihood of management success and a greater grade of pain relief at 1 month after the procedure compared with cooled RF in propensity score-matched individuals with chronic knee pain (58).

The Retrospective Study on Patients with Chronic Knee Pain Treated with Ultrasound-Guided Radiofrequency of the Genicular Nerves reported by Belba *et al*. was a retrospective single-centre cohort study of individuals treated with ultrasound-guided conventional RF of the genicular nerves for chronic knee pain (59). The outcome parameters were GPE, VNRS for pain, consumption of strong opioids, and safety of management at 6 weeks and cross-sectionally at a variable time point. Management success was defined as GPE ≥50%. Sixty-eight patients were screened, of whom 59 were included (46 diagnosed with postoperative pain and 13 with OA knee pain). Treatment success at 6 weeks was accomplished in 19 (32.2%) of the 59 interventions and was similar in both groups. Seventeen responders were assessed at follow-up. Some 45.1% (8/17) reported the treatment continuing to have a positive impact at the second time point. The mean RF duration of effect was 8.3 months. A safety analysis at 6 weeks and at the second time point demonstrated a good safety profile of the treatment. Conventional RF of the genicular nerves was clinically successful in more than 30% of the individuals refractory to conventional medical treatment. Overall, RF was well tolerated. The mean duration of effect was 8.3 months (59).

RF in TKA

Tran and Gonzalez reported that cooled RF was effective in managing pain in the setting of symptomatic TKA (54). Stake *et al*. compared 2-year postoperative complication rates and rates of prolonged postoperative opioid usage between individuals undergoing TKA after previous genicular nerve RF and those undergoing TKA alone. Individuals who underwent primary TKA after prior genicular nerve RF (RF–TKA) of the ipsilateral knee were identified in national all-payer claims (60). In total, 675 individuals in the genicular nerve RF–TKA group were compared with a control group of 255 351 individuals. The RF–TKA group had a lower likelihood of prolonged postoperative opioid use (P < 0.001). No notable difference was found in the 2-year surgical results between the groups. The RF–TKA group had a lower likelihood of needing blood transfusions and having postoperative anaemia, arrhythmia, and urinary infection compared with the primary TKA control group. Preoperative genicular nerve RF led to a lower rate of prolonged postoperative opioid use in the individuals who underwent TKA, with no increased risk of adverse events. However, future prospective studies are required to validate the conclusions of this database study (60).

RF after anterior cruciate ligament reconstruction

Deviandri *et al*. reported twocases of ultrasound-guided genicular nerve RF for pain control following anterior cruciate ligament reconstruction (ACLR). At postoperative days 1, 3, and 7, the mean VAS was lower after performing the procedure (from 8 to 5, 2, and 1, respectively). The mean EQ-5D-5L improved from 0.48 to 0.52, 0.56, and 0.66, respectively. Genicular nerve RF appeared to be an appropriate and safe technique for treating postoperative pain after ACLR and could improve the postoperative rehabilitation programme (61).

RF in hip OA

RF of the obturator and femoral nerve articular sensory branches has shown promising results in the management of hip OA-related pain, especially in individuals who cannot undergo, have long wait times until, or have persistent pain following total hip arthroplasty (THA) (50). In 2022, Tran *et al*. established the effectiveness of cooled RF in managing hip pain from OA at 6 months after treatment in individuals whose conservative treatments failed and were not surgical candidates due to comorbidities or unwillingness to undergo THA through targeting of the obturator and femoral nerve branches. The authors analysed 11 individuals experiencing persistent chronic hip pain in the setting of advanced OA (62). The participants initially underwent anaesthetic blocks of the obturator and femoral nerve branches to determine cooled RF candidacy. After appropriate response to the anaesthetic blocks (>50% immediate pain alleviation), the participants underwent the procedures 2–3 weeks later. Treatment response was assessed using clinically validated questionnaires and VAS to evaluate the effect on pain intensity, stiffness, and functional ADL. Follow-up outcome scores were collected up to 6 months after the cooled RF was administered. The mean patient age was 61.4 years, and eight of the patients were men and three were women. The mean total hip disability and OA outcome score significantly ameliorated from baseline at 17 to 52.9 at a mean of 6.2 months following RF (P < 0.0001), with significant improvement in the mean pain score from 16.1 to 53.4 (P < 0.0001) and mean stiffness score from 15.0 to 53.6 (P < 0.0001). No major adverse events were observed. No participant required re-treatment, surgery, or other intervention. Image-guided obturator and femoral nerve cooled RF was efficacious and safe for managing chronic hip pain/stiffness in the setting of advanced OA (62).

RF in Perthes disease

Tee *et al*. claimed that Perthes disease is a rare paediatric condition involving idiopathic avascular necrosis of the femoral head, leading to degenerative hip joint disease. Although THA is considered the definitive surgical choice for managing degenerative hip disease, alternative pain relief methods are available (particularly for young individuals) to delay THA. One technique for reducing pain for 18–24 months is cooled RF. The authors published the first case report describing the successful use of cooled RF in the nonsurgical treatment of Perthes disease-related osteoarthritic hip pain in a man in his 40s. Cooled RF led to a reported subjective improvement in pain of 60–70%, with a documented objective improvement in the OKS from 18 to 40 within 6 weeks of the procedure (63).

RF in greater trochanter pain syndrome

Abd-Elsayed *et al*. indicated that greater trochanter pain syndrome was a frequent source of lateral hip pain. Corticosteroid injections are frequently employed as nonsurgical interventions; however, they are not effective for all individuals. The authors described two cases of cooled RF for treating greater trochanteric pain syndrome. The trochanteric branch of the femoral nerve was identified as providing sensory innervation to the greater trochanter and its surrounding structures. The authors identified fluoroscopic targets to block the nerve and perform cooled RF. The technique provides a possible steroid-sparing interventional treatment based on reproducible fluoroscopic reference points (64). Figure 4 shows fluoroscopically guided conventional RF for the treatment of greater trochanter pain syndrome.

RF in plantar fasciitis

According to Koh *et al*., plantar fasciitis is the most frequent source of plantar heel pain. Although most cases are self-limiting, recalcitrant conditions can be debilitating, substantially diminishing the patient's QoL. There are numerous surgical techniques for managing recalcitrant plantar fasciitis with little consensus on the best practice. The authors evaluated the effectiveness of RF with and without gastrocnemius release on the surgical management of recalcitrant plantar fasciitis (65). They analysed 128 individuals with recalcitrant plantar fasciitis and tight gastrocnemius treated surgically. The presence of tight gastrocnemius was clinically determined by a positive Silfverskiold test. Group A ($n=73$) consisted of individuals who underwent RF alone; group B ($n=55$) consisted of individuals who underwent RF and endoscopic gastrocnemius recession. The primary outcome measure was the VAS score. Secondary outcome measures were the American Orthopaedic Foot & Ankle Society (AOFAS) hindfoot score; the physical component summary (PCS) and mental component summary (MCS) of the 36-Item Short Form Health Survey; overall evaluation of improvement, expectation fulfilment, and satisfaction; and percentages of adverse events. Both groups reported significant improvement in VAS, AOFAS, and PCS scores postoperatively at 6 months and 2 years. Group B (RF with gastrocnemius recession) was associated with better VAS at 6 months (3 vs 1.7, $P < 0.05$) and 2 years (1.9 vs 0.8, $P < 0.05$) postoperatively compared with group A (RF without gastrocnemius recession). At 2 years postoperatively, no differences were observed in AOFAS, PCS, and MCS scores, expectation fulfilment, or overall satisfaction. No wound complications were found in either group. One individual (group B) had continuous pain consistent with tarsal tunnel syndrome. In this retrospective cohort comparative study with level 3 of evidence, treatment of recalcitrant plantar fasciitis with RF alone was associated with slightly inferior outcomes than RF combined with endoscopic gastrocnemius recession in terms of pain relief with no increase in complication rates. However, at 2 years, no significant difference in other outcome measures were found (65).

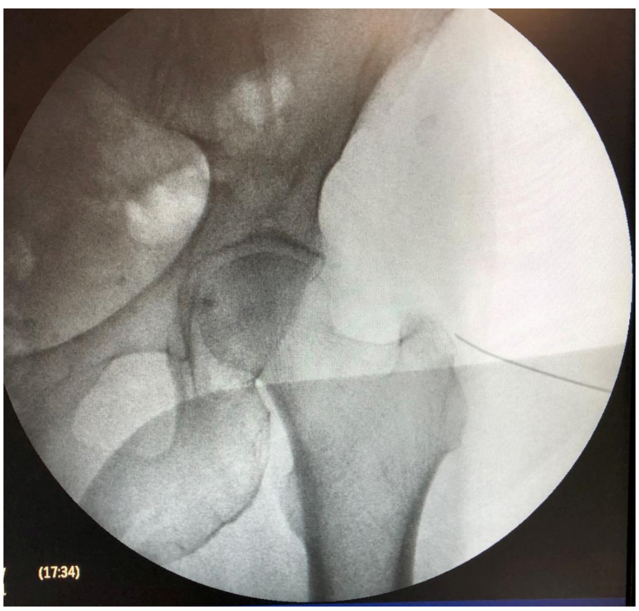

Figure 4
Fluoroscopically guided conventional radiofrequency (RF) for greater trochanter pain syndrome.

Kurtoglu *et al*. retrospectively assessed 261 patients with plantar fasciitis (378 feet) treated with RF (66). All of the patients had plantar heel pain for at least 6 months. Based on their body mass index (BMI), the enrolled individuals were divided into obese (BMI $\geq$30 kg/m^2) and non-obese (BMI <30 kg/m^2) groups. The BNS Radiofrequency Lesion Generator was employed during a single session. The VAS and AOFAS scores of all the participants were assessed before RF, in the first month after the procedure, and during the final follow-up (8–24 months). There was a statistically significant difference between the pre-procedure and post-procedure VAS scores ($P < 0.001$); however, there was no statistically significant difference between the VAS scores in the first month post-procedure and during the final follow-up. There was a statistically significant difference between the pre-procedure and post-procedure AOFAS scores ($P < 0.001$); however, there was no statistically significant difference between the AOFAS scores in the first month post-procedure and during the final follow-up. The authors claimed that RF can be used as an alternative to surgical procedures for treating plantar fasciitis due to its safety and efficaciousness. The advantages of RF are that patients can rapidly return to work and resume weight-bearing activities (66).

Thor *et al*. performed an evidence-based systematic review and meta-analysis (level 2 of evidence) of the results of RFMT for managing plantar fasciitis (67), identifying 11 relevant articles evaluating the effectiveness of plantar fascia RFMT. The studies were then assigned to a level of evidence (I–IV). Each study was reviewed to provide a degree of recommendation (A–C, I) according to the Wright classification in support of or against the procedure. A meta-analysis was performed for seven of the studies that measured AOFAS scores. Based on the results of this study, there was fair (grade B) evidence to support plantar fascia RFMT. There was a statistically significant mean increase of 40.9 in the AOFAS scores after the procedure and fair (grade B) evidence to advise RF microtenotomy for plantar fasciitis. The authors indicated that there was a need for more high-quality level I RCTs with validated outcome measures to permit for stronger recommendations to be made (67).

RF in painful stump neuromas of the upper and lower limbs

Pu *et al*. analysed the immediate and long-term effects of ultrasonography-guided RFA on postamputation pain. Eighteen patients with painful peripheral neuromas were treated with ultrasonography-guided RF (68). Of the 17 patients with residual limb pain, 14 (82.4%) had successful results. Nine (69.2%) of the 13 individuals with phantom limb pain also had successful results. There were no significant associations between symptom alleviation and sex, age, or pain duration. There were no severe adverse events. Ultrasonography-guided RF for painful stump neuromas effectively alleviated stump pain and phantom limb pain in amputees with postamputation pain (1-year follow-up) (68).

Conclusions

RF is a minimally invasive technique used to disrupt or alter nociceptive pathways for treating musculoskeletal pain. Encouraging results have been reported in shoulder OA using RF of suprascapular, axillary, and lateral pectoral nerve articular sensory branches of the glenohumeral joint, as well as in painful knee OA; chronic knee pain, before and after painful TKA; and after ACLR using RF of the genicular nerve. Promising results have also been reported in hip OA and Perthes disease by means of RF of the obturator and femoral nerve articular sensory branches, as well as in greater trochanteric pain syndrome by means of RF of the trochanteric branch of the femoral nerve. Satisfactory results have also been observed in plantar fasciitis by means of plantar fascia RFMT. RF has also been employed for treating coccydynia, and ultrasonography-guided RF has been employed for treating painful stump neuromas. RF appears a valuable technique for alleviating chronic pain syndromes of the limbs, even if, to date, firm proof is still required on the efficacy of this technique. RF represents an encouraging technique for managing chronic musculoskeletal pain of the limbs, particularly when other techniques are futile or not possible.

ICMJE conflict of interest statement
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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