Radiofrequency therapies in chronic pain

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Continuous RF (CRF) procedures produce thermal coagulation of target nerves to interrupt pain pathways.

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Radiofrequency (RF) procedures use high-frequency alternating current (in the AM RF range) to interrupt or alter nociceptive pathways at various sites. They are used as a therapeutic tool in a variety of chronic pain syndromes. Two modalities of RF current are used in interventional pain medicine.

Continuous RF (CRF) describes a process whereby RF current is used to produce a thermal lesion in a target nerve, resulting in interruption of nociceptive afferent pathways. Lesions are described according to their site (e.g. cervical, lumbar) and the type of neural structure where the lesion is produced (e.g. cordotomy (spinal cord), rhizotomy (nerve roots), ganglionotomy (ganglia), and neurotomy (peripheral nerves)). Treatment for trigeminal neuralgia may be described as trigeminal RF ganglionotomy.

Pulsed RF (PRF) describes a process whereby short bursts of RF are delivered to a target nerve producing effects on signal transmission to reduce pain. These procedures do not produce a lesion and are not described as such, for example, the treatment of scrotal pain might include pulsed RF therapy of the genitofemoral nerve.

This article will explain the science behind the two techniques and their application in the management of chronic pain.

Basic science

RF current is low-energy, high-frequency (50–500 kHz) alternating current. When it is applied to biological tissues, it causes molecules within the tissues to oscillate thus causing friction between molecules and heat. If the current is applied for sufficient time, enough heat will be generated to cause coagulation, or a thermal lesion, within the target tissues.

The generation of RF current for therapeutic purposes requires an electrical circuit that is similar to that used in monopolar diathermy. One arm of the circuit passes from an RF generator to an indifferent plate of large surface area on the patient’s body. The other arm of the circuit passes from the generator to a needle electrode. When the electrode is at the target site, current passes between the electrode and the indifferent plate. Current is of sufficient density at the uninsulated electrode tip to produce heating. The manner of application of RF current differs between continuous and pulsed RF modalities.

Continuous RF

In CRF, alternating current in the frequency range 100–500 kHz is applied continuously to a target nerve, with the aim of producing a thermal lesion. A needle electrode is placed alongside the nerve using radiographic screening. The needle electrode has an uninsulated ‘active tip’ 2–15 mm in length. The electrode chosen for the procedure depends on the size and anatomy of the target nerve.

Lesions are intended to interrupt conduction of nociceptive signals and therefore ‘block’ pain transmission. The duration of effect is mediated by the length of time taken for coagulated nerves to regenerate. Heat energy is produced transversely along the active tip and not distal to it (Fig. 1); this makes a case for aligning the active tip alongside the target nerve rather than perpendicular to it.

Lesion diameter depends on the size of the electrode—in general, the lesion will spread 1–1.5 times the electrode diameter. The surface temperature of the electrode is monitored. Current passing from the electrode to the tissues produces heat in the tissues; this heats the electrode. Heating of the tissues sufficient to cause coagulation occurs when the electrode temperature reaches 65–75°C. Current must be applied for 60–90 s to achieve thermal equilibrium and an optimal lesion.

Early experimental data suggested that CRF could produce differential lesioning of neurones, with motor fibres having reduced susceptibility. Subsequent studies have shown this to be untrue.

Key points

Radiofrequency (RF) procedures in chronic pain utilize alternating current in the AM RF band to produce effects on pain pathways.

Continuous RF (CRF) procedures produce thermal coagulation of target nerves to interrupt pain pathways.

There is evidence to support the use of CRF neurotomy as a therapy for trigeminal neuralgia, cervicogenic headache, cancer pain, and somatic spinal pain.

Pulsed RF (PRF) procedures alter pain transmission but do not produce a clinically significant neuronal lesion.

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as CRF produces non-selective destruction of nerve fibres, both motor and sensory. This may result in adverse effects if mixed motor and sensory nerves are ablated.

Pulsed RF

In PRF, alternating current is delivered to a target nerve without producing significant heating. Typically, a 50 kHz current is delivered in 20 ms pulses at a frequency of 2 Hz, for a period of 120 s. The relatively long pause between pulses allows for heat dissipation, principally through conduction and convection (venous drainage). Heating is further minimized by limiting electrode-tip temperature to $\leq 42^\circ C$. This results in a temperature in surrounding tissue insufficient to produce neural coagulation.

In contrast to CRF, the greatest current density with PRF is delivered distal to the active tip of the electrode. This allows the electrode to be placed perpendicular to the nerve, potentially resulting in shorter procedure times.

PRF theory maintains that no histological lesion is produced in the target nerve. The mechanism of action of PRF is poorly understood but may involve altered signal transduction in pain pathways. Laboratory studies have demonstrated increased expression of c-Fos, an early activator gene, and activating transcription factor 3 (ATF3), a marker of cellular stress in neurones stimulated by PRF. Expression of c-Fos is non-specific in neuronal tissue, but the changes in ATF3 appear to be restricted to Aδ and C neurones. The role of these markers in the effects of PRF is unclear.3

Clinical science

General considerations

Patient selection and targets for therapy depend on the anatomy and pathophysiology of the underlying pain (Fig. 2). Suitable patients for some RF procedures may be identified on the basis of history and examination alone or by using diagnostic local anaesthetic (LA) block of target nerves. In general, patients undergoing RF procedures should be awake, with sedation avoided where possible. LA is used to anaesthetize the skin before electrode positioning. In CRF, LA is also injected via the needle electrode before lesioning.

General risks common to CRF and PRF relate to practical elements of the procedure such as positioning of the patient and, more specifically, positioning of the needle electrode. Common risks include bleeding and infection and also the possibility that the procedure may have no beneficial effect or, in some cases, make the pain worse. Incorrect placement of the electrode may result in direct trauma to other structures, for example, blood
vessels and other nerves. Additional risks may be incurred with intravascular or intraneural injection of LA.

CRF carries the greater risk of the two modalities because it involves thermal lesioning of nerves. Adverse effects due to this include damage to adjacent nerves (e.g. trochlear and abducens nerves in trigeminal rhizotomy), damage to motor nerves, and deafferentation pain syndromes. PRF carries relatively few complications directly attributable to the RF current. It also does not involve concurrent injection of LA or particulate steroid eliminating the risk of inadvertent intravascular or intraneural injection. It is a potentially more attractive option in some cases.

Specific indications

Trigeminal neuralgia

Percutaneous trigeminal CRF neurotomy is one of the surgical options for patients with trigeminal neuralgia that has not responded to pharmacotherapy. Others include peripheral surgery and open posterior fossa microvascular decompression. The consensus view is that RF neurotomy should be performed in patients of advanced age with significant co-morbidity or in younger patients who do not want to accept the risks associated with posterior fossa surgery. Patients undergo the procedure with a combination of LA and i.v. anaesthesia. A needle electrode is passed, under fluoroscopic guidance, through the foramen ovale to the trigeminal (Gasserian) ganglion that lies close to the cranial opening of the foramen ovale. Anaesthesia is temporarily interrupted, and after ensuring return of cognitive function, sensory testing is performed. The position of the electrode can then be altered such that stimulation results in paraesthesiae only in affected divisions of the trigeminal nerve. Anaesthesia is recommenced and a thermal lesion is performed aiming to produce reduction of pinprick sensation in the affected divisions.

Most patients (≥80%) experience complete relief lasting several years. Approximately one in four patients will have recurrence of pain usually between 2 and 5 yr after operation. Repeating the procedure usually brings about complete relief. Common side-effects are related to damage of the trigeminal nerve, for example, corneal anaesthesia and masseter weakness (up to 20%). Less commonly, diplopia may occur; it is caused by thermal damage to adjacent nerves (trochlear, abducens). Other side-effects are rare.4

PRF has been evaluated in the treatment of trigeminal neuralgia only in a few case reports. Initial results are promising, but follow-up is <2 yr. It must be considered an inferior technique for this indication.

Cervical cordotomy

Patients with intractable unilateral pain due to malignant disease may be considered for anterolateral cervical cordotomy performed percutaneously at high cervical level. It aims to create a lesion in the lateral spinothalamic tract above and contralateral to the site of pain. This reduces pain and temperature sensation but spares touch and proprioception, afferents that are located in dorsal columns. Complications include ipsilateral motor paralysis and respiratory muscle weakness; these are uncommon. It has been largely superseded by advances in pharmacotherapy but it still has a place in the management of terminally ill patients.5

Cervicogenic headache

Cervicogenic headache is a syndrome of chronic hemicranial pain that is referred from structures in the neck. Commonly, the greater occipital nerve (dorsal ramus C2) and the third occipital nerve (dorsal ramus C3) are implicated. Patients may be selected for RF treatment on the basis of diagnostic LA blocks. Third occipital nerve CRF neurotomy has been extensively evaluated; it has good efficacy in this condition.6 There are early data to suggest that PRF of the greater occipital nerve may provide up to 5 month relief.

Fig 3  Z-joint anatomy. (a) Relevant anatomy. NR, nerve root; IAP, inferior articular process; SAP, superior articular process; PR, posterior ramus; MB, medial branch; LB, lateral branch; SP, spinous process; TP, transverse process. Hard outline shows ‘scottie dog’. (b) The oblique X-ray of L4/5 Z-joint with needles in place for CRF neurotomy of L3 and L4 medial branches. Hard outlines show ‘scottie dogs’. Needle electrodes are seen end-on.
Spinal pain
CRF has the most utility for the treatment of spinal pain. The zygo-apophyseal joints (Z or facet joints) are paired synovial joints that form the posterior columns of the spine. They are innervated by the medial branch of the dorsal ramus of the spinal nerve both above and below the joint; the L4/5 Z-joint is innervated by the medial branch of the dorsal ramus of both L3 and L4 (Fig. 3). These joints are sources of somatic spinal pain. Patients suitable for medial branch neurotomy are selected on the basis of a positive response to two diagnostic LA blocks, according to the criteria developed by the International Association for the Study of Pain.7

Up to 60% of patients selected in this way will achieve up to 80% relief of pain for up to 12 months after lumbar medial branch neurotomy. The mean duration of complete pain relief is 400 days for cervical medial branch neurotomy. Analgesia can be reestablished after a repeat procedure. Evidence for thoracic medial branch neurotomy and sacroiliac neurotomy is less clear.

PRF treatments have been evaluated in cervical and lumbar Z-joint pain. Similar analgesia can be achieved compared with CRF but the effects do not last as long.8 Reduced side-effects and the easier procedure make this attractive; it warrants further investigation.

Groin pain and orchialgia
Perhaps, the greatest potential use of PRF will be in the treatment of peripheral nerve entrapment and post-surgical pain when the nerve is already damaged. Any technique causing further nerve damage with CRF seems counterintuitive. PRF has been evaluated as a treatment for groin pain occurring both spontaneously and as a result of inguinal herniorrhaphy. PRF treatments to ilioinguinal and genitofemoral nerves and nerve roots have resulted in complete relief lasting up to 6 months.9

Miscellaneous pain syndromes
CRF and PRF have been applied to dorsal root ganglia and the dorsal root entry zone for a variety of pain syndromes including deafferentation, plexus avulsion, and post-surgical neuropathic pain. CRF carries considerable risks when applied in these areas and there is currently little evidence to support its use. PRF has shown some evidence of benefit in the treatment of spinal radicular pain and post-surgical thoracic pain.10

Conclusion
CRF neurotomy uses high-frequency alternating current to produce a thermal lesion in a target nerve. The electrode must be placed parallel to the target nerve to achieve optimal effect because of the characteristics of heat production around the electrode tip. There is good evidence to support CRF, the treatment of trigeminal neuralgia for patients selected using appropriate criteria. There is moderate evidence to support CRF in the treatment of cervicogenic headache, cervical and lumbar Z-joint pain, and for cervical cordotomy. PRF uses lower frequency alternating current to alter signal transmission in nerves that are not damaged. The electrode can be placed perpendicular to the nerve. There is limited evidence to support PRF; its greatest potential is in the treatment of neuropathic pain syndromes that are not amenable to CRF. PRF has a better side-effect profile; it is technically easier and may result in shorter treatment times. It is potentially attractive as a therapy in patients whose pain does not respond to conventional treatments.

Conflict of interest
None declared.

References

Please see multiple choice questions 1–3.