Essentials of Radiofrequency Ablation of the Spine and Joints

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Nomen Azeem
Editors

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ISBN 978-3-030-78031-9 ISBN 978-3-030-78032-6 (eBook)
https://doi.org/10.1007/978-3-030-78032-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To my family, friends and medical team who have given me support and love to continue to push the field forward, To the United States of America the land of the free, and To my God who has blessed me beyond my greatest dreams.

Timothy R. Deer, MD President and CEO, The Spine and Nerve Center of The Virginias Clinical Professor of Anesthesiology and Pain Medicine WVU School of Medicine Chairman, American Society of Pain and Neuroscience Past President, INS President Emeritus, WVSIPP Past Chairman, ASA, Committee on Pain Medicine Multi-Finisher, Ironman World Championship, Kona, Multi-Finisher, Leadville 100 mile Trail Run Finisher, Ironman 70.3 World Championship, Mooloolaba, Australia Male Champion, Keys 50 mile Ultra Marathon, 2017 Male Grand Master Champion, Seaside 1/2 Marathon 2020 Multi-Finisher, Boston Marathon Finisher, Badwater 135 Ultramarathon Malama Ambassador, Ironman Foundation Co Founder, IRONAID

I would like to thank God for blessing me with the life that has been bestowed upon me and surrounding me with love and support always.

To Rida, my wonderful wife and partner in all things, the one that I adore. Thank you for your love and steadfast support, kindness, and generosity. You have been and will continue to be my inspiration.

To my loving children, thank you Sofia and Aydin for being so wonderful and patient during the times that "daddy is doing doctor stuff." It is a joy to see you growing into such kind, honest, and beautiful people, I cherish every moment.

To my parents, thank you for leaving everything that you knew behind to provide a better opportunity for me. I pray that I have made you proud and will continue to do my best to honor your sacrifices.

To Tim Deer, my friend and mentor over the years. It has been both humbling and an honor to work alongside you for this text and numerous other projects. I will always appreciate the advice that you have shared,

the opportunities that you have provided, and your vision for the future of our space.

Lastly, to my patients, to whom I have dedicated this book and much effort to try to improve their quality of life by continuing to learn, teach, and advocate for the most effective treatments to provide long-term relief.

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Foreword

Hippocrates (460–377BC) is said to have used temperature, including cold and heat, as analgesic for controlling pain. Over the subsequent centuries, physicians froze nerves during surgery, or used cautery and heat to ablate nerves, all in an effort to control pain in both acute and chronic settings. While those who have studied the history of medicine suggest that many of the therapies physicians used before the 1950s were actually placebos, the early use of temperature was most definitely an effective strategy with a strong biologic basis. However, early on, it was difficult to harness temperature in a reliable fashion, which led to complications and great variability in outcome. Unfortunately, a lack of understanding of how the nervous system regenerates itself also led to complications that today would be considered avoidable. More importantly, early on, in the chronic pain world, physicians were inadequately trained on how to use temperature techniques to optimize patient care. Fast forwarding to the 1940s, radiofrequency ablation procedures, using direct current, were placed into clinical practice, effectively solving the problem of wildly different and uncontrolled lesions. While lesion size and temperature were difficult to control with early iterations, RF techniques developed by Cosman and Arana and subsequently many others introduced strategies to make the therapies more uniform, and thus much safer.

If RF techniques have been around for so long, why does this text so needed now? The truth is, while the foundation of what we have required to treat our patients has been around for decades, the field was not ready for the tools created for us by forward-thinking engineers. Moreover, both the science of radiofrequency and the clinical science of pain medicine needed advancement as well.

Pain medicine today is not what it was in the 1950s, 1960s, or 1970s. Pain medicine as a field has been rapidly evolving, expanding our knowledge base and scope of practice from decade to decade. As recently as 30 years ago, the specialty of pain medicine was still in in its infancy with a relatively low level of sophistication. Over the past 30 years, a variety of developments helped advance our field. Board certification in pain medicine validated the uniqueness of what we do and highlighted the importance of treating pain as its own discipline. Pain specialists trained in the complex field of "*diagnosis* and management of pain problems." Training programs

expanded to train a critical mass of physicians, who developed a deep understanding of pain. Pain physicians focused solely on patients with pain and offered office-based practices. They developed surgical skills, developed a wide variety tools for a wide variety of complex problems. No longer would one treatment be applied to all problems of chronic pain.

As the field of pain medicine developed, there became a broad recognition that pain frequently has a biologic basis, and that targeted therapies based on an accurate diagnosis had an important role in the management of complex problems. There seemed to be a movement pushing the field forward. In 2000, Bill Clinton signed into law as the decade of pain control concepts such as the fifth vital sign, and patients' bill of rights seemed to validate pain as an important concern. Unfortunately, one key problem arose, we as a field under-emphasized the importance of making a specific and accurate diagnosis, necessary for optimal treatment strategies. Over time, however, we recognized that all back pain was not the same, and that a patient may have many pain generators, and the expert pain physician needs to tease out the various pain generators, and frequently apply tools for each specific pathology. No longer can the care of the patient end with a failed epidural. More definitive procedures need to be entertained. No longer can insurer deny outright RF procedures as not medically necessary or experimental. Radiofrequency procedures are now firmly within the standard of care, being performed by leading international physicians. In addition, we have migrated away from complex spinal surgery, looking for minimally invasive procedures.

Simultaneously, the science of how RF interacts with the nervous system has likewise developed. Alterations in the mRNA of the nervous system, protein production by the DRG and concepts of pulsing the nervous system, low temperature, high temperature, and time of lesion have all been exhaustively studied. In addition, effects on cancer and identification of new targets have all contributed to our current understanding of how to optimize RF therapy. Randomized controlled trials comparing radiofrequency procedures that validated the role of RF procedures in carefully selected patients have now validated the clinical utility.

There have been several advances in the field of pain care that have really altered the direction of our specialty. First, we have recognized the importance of treating pain, understood that systemic medications are not a panacea, developed strong skill sets in establishing a diagnosis with both a renewed interest in clinical medicine, as well as advanced imaging techniques that have facilitated our diagnosis.

The entire field of pain care has exploded, with advanced technologies improving efficacy. Regenerative medicine has harnessed the power of stem cells and our body's ability to heal itself. Ultrasound has improved our ability to make a diagnosis and offer site-specific therapeutic interventions. Neuromodulation has harnessed the power of electricity in helping the electrochemical system we call our nervous system. And finally, our ability to make an accurate diagnosis has led to a rebirth of site-specific ablations with radiofrequency techniques.

While there is much to learn about how RF procedures help with pain, RF techniques have come of age. Deer and Azeem in conjunction among other clinical leaders in the field have done a great service in helping physicians understand the

intricacies of RF techniques, when they are to be used, why they should be used, and how to avoid complications. Radiofrequency procedures offer highly effective, site specific therapeutic interventions. These therapies are non-drug (and thus non opioid) and cost effective, and can be performed with a very favorable benefit-to-risk profile. This text will provide the expert and novice alike the foundations of what is needed to accurately diagnose and treat patients with chronic pain, expanding your tools in your toolbox.

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Part I
Foundations of RFA

Chapter 1
History and Development of Radiofrequency Ablation for Chronic Pain

Jonathan M. Hagedorn, Stanley Golovac, Timothy R. Deer, and Nomen Azeem

The use of radiofrequency ablation (RFA) also known as rhizotomy or neurotomy for the treatment of chronic pain was first described in 1931 when Kirschner described treatment of trigeminal neuralgia through radiofrequency to the gasserian ganglion [1]. Surprisingly, it wasn't until the 1950s that the first commercial RFA generator became available from Cosman and Arnoff [2]. In the mid-1960s, RFA of the anterolateral spinal cord was described by Rosomoff et al. for the treatment of intractable malignant and non-malignant pain [3]. The first dorsal root RFA was described in 1974 [4]. The first described application of RFA for lumbar facetogenic pain occurred in 1975 by Shealy [5]. He published multiple related papers between 1974 and 1976 on the topic [6–8]. This led to a number of other physicians describing the use of RFA for the treatment of low back pain between 1976 and 1980 [9–15]. In 1978, Tew et al. published their work targeting the three branches of the trigeminal nerve for the treatment of trigeminal neuralgia [16]. Around that same time, Nashold described the use of radiofrequency to create dorsal root entry zone (DREZ) lesions for the treatment of deafferentation pain [17, 18].

A significant amount of research was performed in the early 1980s regarding the specific anatomical structures related to low back pain generation and the use of RFA for its treatment [19]. In 1980, Bogduk and Long described a new technique

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_1

driven by anatomical studies of the medial branches of the lumbar dorsal rami with the goal of placing the electrodes parallel to the nerves [20]. A year later, Sluijter and Mehta published refined techniques for RFA lesioning for cervical, thoracic, lumbar, and sacral pain syndromes that allowed precise needle placement and performance of the procedure under local anesthesia [21]. Sluijter would go on to describe treatment of discogenic and vertebral body pain with RFA through lesioning of the gray ramus communicans [22]. Along with Van Kleef, he would later describe a separate radiofrequency technique for treatment of discogenic pain by ablating the sinuvertebral nerves intradiscally [23].

The percutaneous radiofrequency lumbar sympathectomy was pioneered by Khanta in 1989 [24]. In 1990, Sluijter described radiofrequency sympatholysis of the cervicothoracic junction for the treatment of sympathetically mediated pain syndromes of the head, face, neck, shoulder, and upper extremities [25]. Radiofrequency ablation for thoracic radicular pain was developed by Stolker et al. and Van Kleef et al. in the mid-1990s [26–28]. Both teams described radiofrequency lesions at the dorsal root ganglion for thoracic segmental pain that avoided puncture of the parietal pleura and potential pneumothorax development. Surprisingly, it wasn't until 1996 that data was published regarding the efficacy of cervical RFA for facetogenic pain [29]. The randomized, controlled trial by Lord et al. described the use of radiofrequency ablation for cervical facet pain compared to a similarly performed sham procedure.

Description of alternative RFA methods began in 1998 when pulsed radiofrequency was developed to produce a less destructive, equally efficacious technique [30]. The exact mechanism of action of pulsed RFA remains unclear. Cooled radiofrequency ablation for indications outside of pain medicine began in the mid-1990s [31–35]. It wasn't until 2008 that the first studies describing the use of cooled RFA were published [36–39]. In both manuscripts, cooled RFA was used to treat sacroiliac joint pain. Since then, the use of cooled RFA has been proven beneficial for multiple indications [40–50].

Radiofrequency treatments of chronic pain have evolved over the past 90 years. For the treatment of chronic intractable pain in patients who have failed conservative therapies, it is a specialized intervention that may provide relief. Recently, interest has been growing in the development of new and innovative applications, so it's likely that even more patients may benefit in the future.

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Chapter 2
Mechanism of Action of Radiofrequency Ablation

Farzan Vahedifard, Mark Malinowski, and Krishnan Chakravarthy

Why Knowing the Mechanism of Radiofrequency Is Important?

- Patient: Doctor! How do these RF waves help relieve my pain?
- Doctor: Well, sometimes it destroys your nerves, and most of the time, it doesn't!
- Patient: So, how does it calm my pain?
- Doctor: "What does not kill you, makes you stronger!"

Radiofrequency (RF) waves are commonly utilized for pain relief in patients. RF ablation, or rhizotomy, is a minimally invasive procedure in pain management. RF waves ablate the damaged nerves or modulate them, to stop the transmission of pain [1]. Understanding the underlying mechanism of RF (ablation- non-ablation) can assist physicians to enhance their pain management practice and also better inform their patients.

Since RF ablation involves an electrical device, electrodes, and frequencies in RF, we need to understand how they affect the patient's pain in order to enhance and optimize pain treatment. This basic mechanism helps us prevent unnecessary damage or ablation to the nerves, to decrease complications. By knowing the mechanism

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_2

of electromagnetic stimulation more precisely, we can better perform the patient selection for RF, which improves the pain management outcome [2].

This knowledge also helps us design clinical trials in pain management via RF and combination therapies (different types of RF, RF adjunct therapy, etc.). Since we have limitations in designing pain management trials, and the ablation is sometimes irreversible, the design of complex pain studies based on RF's primary mechanism is immensely valuable.

Although several studies have been performed on RF ablation, there is no general overview of different aspects of RF ablation in the literature. Accordingly, this chapter aims to provide a comprehensive review of various aspects of RF ablation, including the underlying phenomena, fundamental mechanisms, and areas of need for future studies.

Before explaining the specific effects of RF in pain relief, we must first describe the neurological basis of nerve injury, the physics of RF, and then the physiology of pain.

Review of the Neurological Base of Nerve Injury

The nervous system is divided into peripheral and central systems, and neurons are its building blocks. Each neuron is comprised of a dendrite (receptor), a cell body (containing the nucleus), and an axon that leads to axonal terminals. The axon is surrounded by myelin, a lipoprotein, which speeds up impulse transmission along the axon. "Ranvier nodes," located at intervals of the myelin membrane and along the axon, increase nerve conduction velocity (Fig. 2.1).

In addition to neurons, other supporting cells, such as microglia, oligodendroglia, and Schwann cells, play specific roles in the nervous system. Microglia is a cellular macrophage that becomes more activated in response to injury. Myelin is

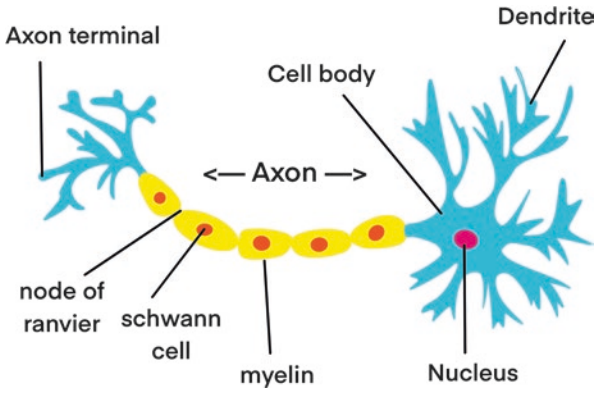

Fig. 2.1 Structure of a neuron

made by Schwann cells in the PNS and by oligodendrocytes in the CNS. Schwann cell myelinate each axon separately and plays a vital role in neuron regeneration.

Nerve fibers are divided according to their size as well as whether or not they have myelin [3]:

1. A-alpha fibers: The largest nerve fiber, with 6–15 microns in diameter. They are myelinated, transmitting sense of touch, vibration, and position.
2. A-delta fibers: small, with a size of 3–5 microns in diameter, transmitting the sense of cold and pain.
3. C fibers: small, with a size of 0.5–2 microns, transmitting the sense of warmth and pain.

There are various nerve terminals with particular usage, including free nerve endings, Meissner's Corpuscles, Pacinian Corpuscles, and Merkel's disks. Pain terminals mainly contain C and A-delta.

In addition to axons and myelin, there are various membranes within the structure of a peripheral nerve [4]. These structures are in order from smallest to largest as follows (Fig. 2.2):

1. Endoneurium: surrounds myelinated axons and groups of unmyelinated axons.
2. Perineurium: surrounds the fascicles (a set of axons)
3. Epineurium: the outermost layer that surrounds the nerve trunk

Nerve damage has a different prognosis depending on the injury's location and can cause sensory damage or weakness. According to the Seddon classification described for the degree of damage to peripheral nerves, these injuries listed below range from mild to severe [5] (Fig. 2.3):

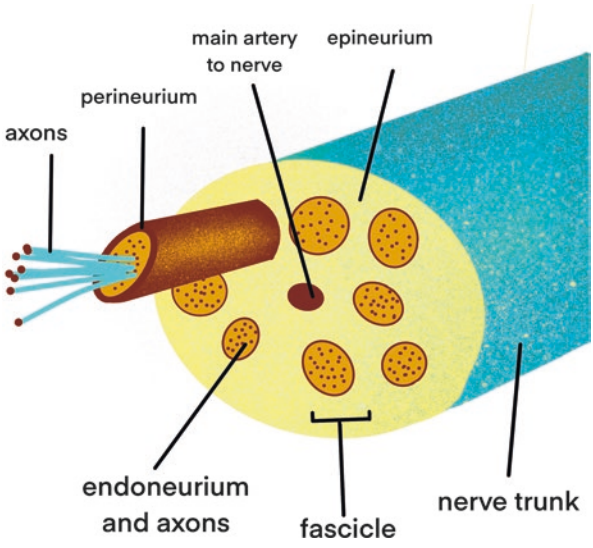

Fig. 2.2 Membranes of individual spinal nerve

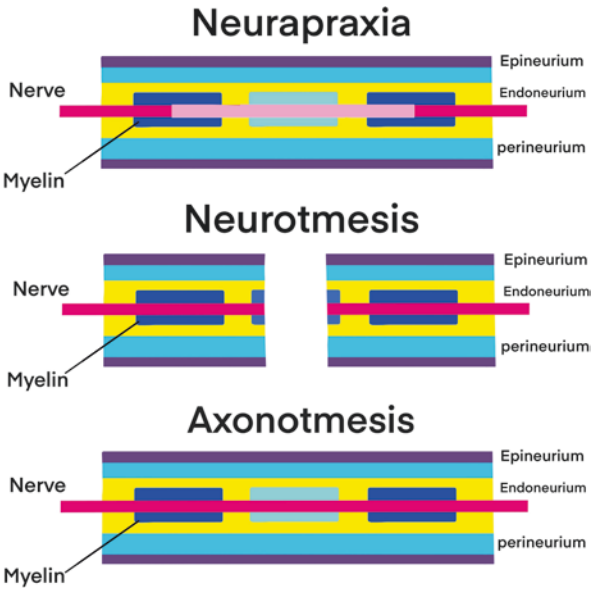

Fig. 2.3 Seddon classification for PNI. (Modified from Neurology of Boards and Beyond, Jason Ryan, 2019)

1. Neurapraxia: The mildest damage, which is a focal demyelination, and the axon is temporarily nonfunctional, but without structural damage. The distal axon to damage is intact, and its continuity is maintained. Wallerian degeneration (degeneration of a nerve's distal aspects after the injury to the cell body or proximal portion of the axon, anterograde or orthograde degeneration) did not occur, and recovery was excellent (about 3–6 months). Examples of neurapraxia are "Saturday night radial nerve palsy" and "leg-crossing peroneal nerve palsy."
2. Axonotmesis: Grade 2 damage, where both myelin and axons are damaged, but the endoneurium and perineurium remain intact. Complete peripheral degeneration occurs, but the sheath and its supporting connective tissues are spared. Fragmentation of the axon and its myelin sheath can be observed.
3. Neurotmesis: Cutting, third-degree damage, which is a complete neural separation. The epineurium and most connective tissue are lost.

There is another classification for nerve damage by Sunderland that was done to better understand spontaneous regeneration [6]. Sunderland divided the axonotmesis into three subcategories: second, third, and fourth degrees of peripheral nerve injury (PNI).

– Second-degree PNI: Axonal discontinuity occurs, but the endoneurium, fascicular arrangement, and perineurium remain intact.
– Third-degree PNI: Myelin, axon, and endoneurium are disrupted, but fascicular arrangement and perineurium remain intact.
– Fourth-degree PNI: Only the epineurium remains intact.

Physics of Radiofrequency

Electromagnetic (EM) spectrums are a continuous spectrum of frequencies. These waves are made up of a combination of electric and magnetic fields oriented at 90 ° to each other.

This spectrum includes radio waves, infrared radiation, the visible spectrum, ultraviolet radiation, x-rays, and gamma-rays in the increasing order of frequency. Radio waves are at the beginning of this spectrum and include a range of 3 Hz to 300 GHz.

All EM waves (including RF) have the same physics, but their effects on the target tissue vary depending on their frequency and type of tissue. This difference can be used to design several therapeutic frequencies in distinct target tissues (nerves, joints, intervertebral disc).

Overall, we need a circuit to apply RF ablation (Fig. 2.4). In this circuit, the RF electrode acts as a cathode, and the pads attached to the patient's body act as an anode. The current as applied by the RF generator is transmitted from the cathode to the anode. The patient's tissue is the therapeutic target, and subsequently, tissue conductivity in this circuit is crucial for energy transfer and ablation zone determination.

We have a high-energy influx around the electrode's tip due to its small cross section, and this energy is minimized as we move toward the pads. Therefore, most tissue damage has occurred around the cathode, and it is vital to select the appropriate location for the target.

In general, RF-induced interactions lead to heat production, which causes coagulation necrosis and tissue destruction, thereby relieving pain or burning the painful nerve [8]. Nevertheless, a few practical points in the RF mechanism are essential:

1. Physics point of view: The RF electrode does not generate heat. The alternating EM field generated by the electrode creates an intense agitation in the adjusting

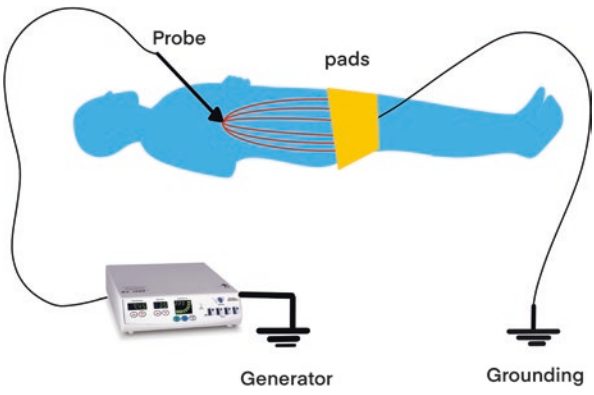

Fig. 2.4 Circuit of RF. (Modified from Hong et al. [7])

molecules directly adjacent to the cathode. The molecules' vibration also moves the next adjacent molecules in the direction of the applied RF current. Frictional energy lost in these molecules causes an increase in temperature and, consequently, coagulation necrosis in the tissue.

2. The farther away from the RF cathode and the energy source, the less heat is generated in the molecules, and subsequently less tissue necrosis occurs (Fig. 2.5). Goldberg [9] formulates the amount of thermal lesion created by RF:

$$\begin{aligned}\text{Development of a thermal lesion} &= \text{induced coagulation necrosis} \\ &= \left(\text{energy deposited} * \text{local tissue interactions}\right) \\ &\quad - \text{heat loss.}\end{aligned}$$

3. In general, mammalian tissue is sensitive to heat. If heat is applied in a shorter time and with more intensity, more damage will be done. At 55 degrees, tissue destruction occurs in these tissues within 2 seconds, and at 100 degrees, evaporation and instantaneous death occur. At temperatures above 105 degrees, we will see boiling, evaporation, and carbonization.

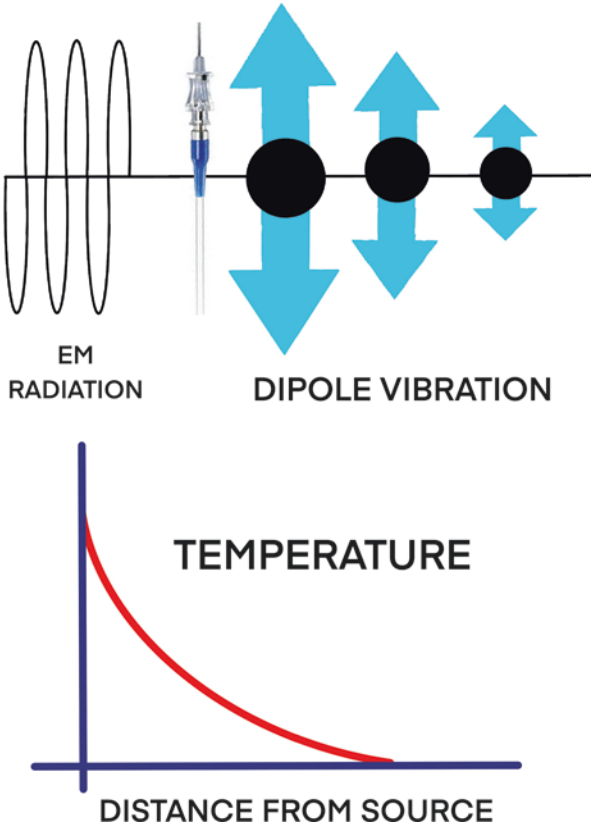

Fig. 2.5 RF cathode and its energy source. (Modified from Hong et al. [7])

If too much heat is applied to a tissue in a short time, it desiccates (becomes charred). Figure 2.5 shows the time needed for tissue death at various temperatures. Since the tissue adjacent to the electrode acts as the primary source of heat generation and transfer, it becomes a sleeve around the cathode and cannot transfer the generated energy if desiccated. This causes the ablation zone to become smaller, which is not desirable for treatment.

Therefore, in order to achieve a confident ablation zone, we must give the appropriate frequency at the desired time (e.g., raise each of the temperatures to 50–100 degrees, in 4–6 minutes).

Different Applications of Radiofrequency

There are several types of RF (thermal, pulsed, cooled), which will be discussed in more detail in the next chapter. However, in order to better understand the mechanism of action of RF types, we will give a brief explanation on how they work.

Thermal

In thermal (or conventional, continuous) RFA, a high-frequency current (500 kHz), creating a high temperature, leads to stimulation and ablation in the target tissue. Most CRFs use high temperatures of 60 C and 90 C for 90–120 seconds in clinical procedures, and we know that tissue destruction occurs at this temperature, which is the purpose of CRF [10, 11]. The severity of the lesion caused by CRF depends on the tissue temperature, the size of the electrode, and the length of time within which the procedure is performed.

In pain management, this heat causes a neurodestructive lesion in the small nerve and relieves the pain. The RF generator causes coagulation necrosis around the tip of the cannula by creating an alternating current [7]. The lesion is spherical, and its long axis is along the cannula tip. For this reason, the cannula must be parallel to the target nerve. Because the lesion is severely reduced by distance from the tip of the cannula [12], the lesions created by CRF are well circumscribed than other ablations (such as chemical neurolysis).

Pulsed

Pulsed RF, unlike CRF, is a nondestructive method that has been used extensively in pain management due to its minimizing nerve damage. Current in PRF is applied as high frequency but in short pulses, to the sensory nerve, joint, DRG, disc, etc. PRF pulses are given for a longer duration than continuous RFA, in repetitive intervals [1].

This generated electric field modulates pain signal, gene expression, and other relieving effects.

The PRF current is usually short (20 ms) and has a high-voltage burst (amplitude 45v), and then a silent phase (480 ms) occurs [13]. During the pulse, the oscillating frequency is 420 kHz. Intermittent pulses and long silent phase between pulses lead to heat reduction and keep the temperature below 42 degrees [14]. Consequently, tissue destruction does not occur, and complications such as neuritis, motor dysfunction, and deafferentation pain will be decreased [15, 16]. Although some mild damage around the PRF electrode has recently been reported, its effect is not clinically significant and detectable, and overall, PRF appears to be safe.

Cryoablation

Cooled radiofrequency ablation (CRFA) is a newer type of RFA that solves some of the problems of its predecessors, has a higher safety profile, and possesses long-term efficiency.

The difference between CRFA and other types of RFA (pulsed and thermal) is that it creates a larger local neuronal lesion [17]. Larger lesions increase the likelihood of successful treatment, especially if we have physiological variability of nerve location or complex innervation (like the knee).

But what is the mechanism of this difference in the size of the lesion? Traditional RFA probes operate at a set temperature of 80 degrees, and as described earlier, higher temperatures cause rapid burning of adjacent tissue and insufficient energy transfer to other tissues for larger ablation zones. However, in cooled RFA, water circulates about the RF probe and reduces its heat. Therefore, these internally cooled probes operate at 60 degrees set (20 degrees lower than traditional types), bringing the surrounding tissue heat to about 60 degrees. So, it causes more energy to be transferred in peripheral. The size of the lesion will be larger and deeper, and the pain relief will last longer [18].

Mechanism of Action of Radiofrequency

In this section, we describe the analgesic effects of different types of RF. It is noteworthy that despite numerous clinical studies on the effectiveness of RF types in pain management, the mechanism of action is still not generally agreed upon. This is especially true in the pulsed type.

Since the mechanisms proposed for RF in the treatment of pain are varied, we classified them based on the distinct factors for a better explanation. We also introduced the relevant gap of knowledge at the end of each section for further research.

Ablation Mechanism of Radiofrequency

Various chemical and physical methods (including thermal and electromagnetic) for ablation and resection/removal of innervation exist. In the thermal type, RF and cooled RF act mostly through the ablation mechanism, unlike pulsed RF, which leaves no damage or its destruction is negligible [1].

Nerve ablation disrupts axonal continuity. As a consequence of ablation, the distal nerve fibers to the lesion degenerate, a phenomenon called Wallerian degeneration. Wallerian degeneration causes a temporary interruption in a nerve cell, which causes a nociceptive block [19].

This nerve ablation only causes sensory or sympathetic degeneration, leaving no motor damage. According to the Sunderland classification, neural ablation causes third degree of peripheral nerve injury (PNI). In this type of injury, the axons, myelin, and endoneurium are damaged, but the rest of the neuron layers remain intact.

Nerve Regeneration and Pain Recurrence

Wallerian degeneration does not entirely interrupt the nerve cell, and it leaves the Schwann cell spared. Therefore, these Schwann cells allow the regeneration of axons in peripheral nerves. This nerve regeneration is suitable for patients with nerve damage, but in nerve ablation that we do in pain management, it is not desirable and causes the recurrence of pain that requires further procedures.

Nerve repair can begin very quickly after injury (30 minutes after). Its three main mechanisms are:

1. Remyelination
2. Sprout from the remaining healthy axons as lateral branches (especially in cases where less than 20% of the axons are damaged)
3. Regeneration (especially in cases where more than 90% of axons are damaged) [20].

Schwann cells play a consequential role in nerve regeneration. They increase the synthesis of surface cell adhesion molecules (CAM) and prepare the basement membrane to regenerate. The NGF (nerve growth factor) receptors are increased on Schwann cells, causing sprouts and regeneration of axons [1].

Non-ablative Mechanisms of Radiofrequency

As mentioned, pulsed RF works in ways other than ablation. It has been shown that pain relief effect in thermal and pulsed RF in DRF stimulation is similar, without pulsed leaving a destructive lesion. Such studies have shown that the effect of pulsed RF is independent of the development of destructive lesions.

Table 2.1 described the non-ablative mechanism of RF.

Electromagnetic Fields

Most studies on the analgesic effect of PRF have focused on its neuromodulatory effect from its electromagnetic field [21]. PRF alters ynaptic transmission as well as neuron-specific gene expression thereby creating an alternating electrical field. The electromagnetic field created in PRF is a rapid electrical pulsation and has its intended biological effect on the target and the nerve [8, 22]. A popular theory for the mechanism of action of PRF is that it is a low electric field phenomenon that can induce long-term depression of synaptic transmission [23, 24].

Electromagnetic stimulation creates an electrical disruption for the transmission of sensory transitions, probably similar to the mechanism proposed in gate control theory [25]. This electric field disrupts the transmission of impulses in small, unmyelinated neurons, without destroying them. Interestingly, larger myelin-protected neurons remain unaffected.

Although pulsed-RF and continuous-RF follow basic physical principles, they differ in the space, time, and strength of the field that they create. PRF creates a stronger electric field than CRF, although the temperature generated and its destructive effect are far less. Tissue change by a strong electric field creates a more specific effect than heat energy. This electric field causes changes in tissue and charged molecular structures, causing them to distort, dislocate, and move [26].

Disrupt and Modulate Pain Signal Transmission Via Nerve Fibers

The electric field created by PRF around the sensory nerves can reduce the conduction of pain signals through the nerve fibers. PRF enhances various descending noradrenergic and serotonergic inhibitory pathways and performs its pain modulation [27]. In addition, electron microscopic studies show minor damage to the axonal microfilaments and the microtubules of pain-transmitting fibers after PRF. These changes were selectively observed, especially in smaller principal sensory neural fibers C and Ad, and less in larger non-pain-related sensory fibers, such as Aβ fibers [28]. The ultimate goal is to provide pain relief by selectively blocking the fibers that carry nociceptive signals from the joint or painful site.

For example, PRF can have several different analgesic effects [29]:

1. Directly activate DRG or spinal cord cells
2. Minimize microglial activity
3. Enhancement of endogenous opioids, which inhibit the incoming nociceptive signal
4. Inhibit the retrograde transport of neurotrophins in the posterior horn

The above items, as well as more theories, will be discussed later.

Table 2.1 Non-ablative mechanism of RF

Types of mechanism	Mechanism of action of RF
1. Electromagnetic fields	Neuromodulatory effect
2. Modulate pain signal transmission	Reduces the conduction of pain signals through the nerve fibers
3. Microglia activation	Morphological change + change in releasing various cytokines and chemokines involved in pain signaling
4. Gene expression	Alternation of gene expression involved in pain
5. C-Fos (an immediate-early gene used as an indirect marker of neuronal activity)	Alters C fiber transmission associated with greater c-Fos expression in the dorsal horn
6. MET-encephalin (an endogenous opioids)	Increases the amount of M-ENK in the spinal cord to regulate nociceptive pain
7. TNF-α, IL-6, IL-1	Alter immune cells Reduce the expression of proinflammatory cytokines Relieve neuropathic pain by attenuating neuroinflammation
8. Calcitonin gene-related peptide (a neuropeptide)	Breaks the pain cycle by inhibiting CGRP expression, changes in the nociception transduction pathway
9. Activating translation factor 3 (a marker of cellular stress, increases in neurons and glial cells after axotomy)	Extension of PRF exposure times did not increase the antiallodynic effect but could also have neurolytic effects
10. Neurotransmitter: BDNF, PI3K, and p-ERK (released in the spinal cord in a microglia-dependent manner, developing chronic pain and pain sensitization)	PRF to DRG can reduce neuropathic pain by suppressing microglia and downregulated levels of them
11. Excitatory amino acids released in the spinal cord (in a microglia-dependent manner, developing chronic pain and pain sensitization)	Reduce inflammatory pain with spinal dorsal horn modulation; suppress EAAs-citrulline release and alter glutamate receptor
12. Regenerative mechanism	The electrical stimulation can increase chondrocyte proliferation and matrix synthesis; increase DNA synthesis and increase GAG proliferation and synthesis in human cartilage
13. IGF-2 (a protein involved in prenatal growth and development)	This effect of immediate PRF is achieved through the downregulation of IGF 2
14. Cellular and histological changes in RA	PRF: Changes in mitochondrial membranes and appearance, disorganized microfilaments and microtubules CRF: Changes such as mitochondrial degeneration and loss of nuclear membrane integrity

Microglia Activation

Microglia are macrophages of the central nervous system, which respond to pathological stimuli or anything disruptive of homeostasis [30]. After the damage to the nervous system, microglia are among the first cells to become activated and will remain so for several weeks. They switch to the active state with a series of cellular and molecular changes. These changes include morphological hypertrophy, proliferation, upregulated various genes, and increased expression of microglia characteristic markers, such as ionized calcium-binding adapter molecule 1 (Iba1) [31]. Considerable evidence has confirmed the critical role of spinal microglia in neuropathic pain. Behavioral pain responses are seen with a glial response at the dorsal horn [32].

By releasing various cytokines and chemokines involved in pain signaling, microglia play a substantial role in the development of chronic neuropathic pain, pain hypersensitization, and long-persistent pain [33]: Therefore, the downregulation of microglia can prevent the progression of chronic neuropathic pain. For example, intrathecal injection of microglia inhibitors has shown a significant impact on analgesic efficacy [34].

It has been reported that PRF application to DRG in rats with lumbar disc herniation may reduce microglia activity in the dorsal spinal horn [35]. Furthermore, the PRF application on DRG of rat models with neuropathic pain showed that the established mechanical hypersensitivity was relieved and the microglial activity in the spinal dorsal horn was strongly attenuated [36].

Mechanical allodynia and thermal hyperalgesia improved up to 14 days after a single PRF stimulation, associated with a significant reduction in Iba1 expression. PRF can suppress microglial activity, thereby creating nociceptive relief [37].

Gene Expression

One of the mechanisms of pulsed RF in pain management is its neuromodulatory effect, primarily through the alternation of gene expression, which will be described in the following items.

C-Fos

Neurophysiological studies have shown that PRF alters pain signaling at nerve synapses and induces electroporation [24]. RF-induced electromagnetic field alters C fiber transmission associated with greater c-Fos expression in the dorsal horn [38]. The c-Fos is an immediate-early gene used as an indirect marker of neuronal activity. C-Fos is most often expressed when neurons fire an action potential [39].

Increased expression of c-Fos has been suggested to activate some pain inhibitory mechanisms.

The formation and expression of c-Fos in the lamina during PRF treatment is one of its neuromodulation effects [23, 40]. In the study of Higuchi et al., pulsed RF was given to rat cervical DRG at 38 °C. Subsequently, c-Fos immunoreactivity in the superficial lamina [1 and 2] in the dorsal horn increased [41]. The formation of the c-Fos gene leads to the proliferation of a second messenger RNA and the production of a substance called pre-pro-dynorphin. The pre-pro-dynorphin belongs to the group of endogenous opioids and can increase endorphin production [42].

In confirmation of the above, it has been proven that antinociceptive effects are also applied in pulsed RF by enhancing pain inhibitory pathways. These pathways include the serotonergic, noradrenergic, and endogenous opioid pathways.

For more research: In most studies (such as Higuchi), elevated c-Fos was seen only in the pulsed-RF-treated group, not in animals treated with continued RF [41]; however, in some studies, this increase in c-Fos was seen in both CRF and PRF [43]. So, proving that this effect is only limited to pulsed RF or can be seen in continuous RF requires further study. In more recent studies, the causal relationship between the therapeutic effect of PRF and the increase in c-Fos has been questioned. More molecular evidence and more controlled studies are needed to prove this.

M-ENK

MET-encephalin is a peptide and neurotransmitter found in spinal cord neurons. M-ENK belongs to the endogenous opioid group, and its intravascular injection has not shown analgesic effects in either humans or rats [44]. It has generally been suggested that endogenous M-ENK expression is one of the mechanisms of the analgesic effect of RPF, similar to what occurs in spinal cord stimulation.

Various experiments in neuropathic pain have shown the analgesic effect of RPF on mechanical hypersensitivity, one of which is through the internal opioid pathways. A study in which PRF was applied to DRG revealed that the level of M-ENK in the dorsal horn of spinal cord was significantly elevated, indicating the effect of PRF on the CNS. At the same time, the mechanical threshold value in these rats had increased. This coincidence indicated that the application of PRF to the DRG reduces mechanical hypersensitivity, and it does so by modulating M-ENK expression in the dorsal horn in the spinal cord.

So, PRF could activate the endogenous analgesia system through nerve conduction in the spinal cord. This process increases the amount of M-ENK in the spinal cord to regulate nociceptive pain through synaptic mechanisms [45].

By the interaction of encephalin and opioid receptors on the cell surface, intracellular signal pathways are activated, an action which results in several conclusions: [1] Opioid receptors and membrane binding inhibitory channel are activated, and [2] opioid receptors connect to ion channels such as mu, delta, and kappa, which eventually inhibit neuronal excitability.

TNF-α, IL-6, IL-1

One of the mechanisms of PRF neuromodulation is by reducing the expression of proinflammatory cytokines, such as TNF-α, IL-6, and IL-1. Proinflammatory cytokines are increased after nerve damage. For example, TNF-α has been shown to play a role as a pain modulation factor in the development and maintenance of neuropathic pain. TNF-α levels in the glial cell and nerve cell body also increase after chronic constriction injury (CCI)-induced neuropathic pain [46].

The properties of nerve roots in neuropathy are also closely related to cytokines such as TNF-α and COX-2. TNF-α induces the production of inflammatory neuropeptides (such as inflammatory neuropeptides) or increases their release from the dorsal horn [47].

The electric field generated in PRF, with its immunomodulatory effect, can alter immune cells and normalize the production of inflammatory cytokines [48]. In one study, 7 days after PRF stimulation on the spinal cord and sciatic nerve, the TNF-α immunoreactivity was decreased; additionally, mechanical allodynia and thermal hyperalgesia were improved. This study showed that PRF could relieve neuropathic pain by attenuating neuroinflammation at the molecular level [49].

It has also been shown that electric field therapy can induce the upregulation of adenosine A2A receptor density in human neutrophils. This upregulation appears to be associated with inhibition of catabolic cytokines such as TNF-α, IL-6, and IL-8 [49, 50]. The PRF electromagnetic field modulates and relieves pain neuroinflammatory conditions in two general ways:

1. Decreased expression of proinflammatory cytokine genes, such as TNF-α, IL-6, and IL-1
2. Increased expression of anti-inflammatory cytokine genes, such as GABAB-R1, Na/K ATPase, and 5-HT3r [2].

For future studies, it is suggested that the mechanism of injury-induced gene expression of neuroinflammatory conditions be investigated.

Calcitonin Gene-Related Peptide

One of the recently described ways for the analgesic effect of PRF is modulation in the expression of calcitonin gene-related peptide (CGRP) in the pain transmission pathway. CGRP is a 37-amino acid neuropeptide found in humans and rats [51]. CRGP plays a crucial role in transmitting synaptic pain information and uses two second-messenger pathways: protein-kinase-A along and protein-kinase-C. CGRP is also effective in creating and maintaining allodynia and hyperpathia [52].

CGRP is mainly synthesized in DRG, where primary sensory neurons are projected into the spinal dorsal horn. When peripheral nerve damage occurs, the spinal dorsal horn begins to release substances such as CGRP and P substance, which

leads to the activation of glial cells; subsequently, several pain regulators are released, such as TNF-α, IL-6, and nerve growth factors involved in central sensitization [53].

It is suggested that PRF treatment can break this cycle by inhibiting CGRP expression, and this is one of the analgesic mechanisms of PRG. There is no definite consensus on CGRP changes in the nociception transduction pathway in neuropathic models; however, in most studies, after peripheral nerve injury, there is an increase in CGRP in the DRG, spinal cord, and its accumulation at the site of nerve injury [54, 55].

Because many DRG neurons begin to express CGRP after nerve damage, which is important in creating and maintaining pain behaviors, we can relieve pain by taking action against CGRP. In this regard, a new study has shown a decrease in expression CGRP in DRG after PRF application on the damaged sciatic nerve. In the study, after sciatic nerve ligation in rats, hyperalgesia and allodynia appeared, and CRGP mRNA and CRGP content in DRG increased. After PRF stimulation on DRG, ELISA, and RT-qPCR, studies showed that the proportion of CGRP-positive neurons in the DRG were reduced. This study showed that PRF could inhibit the transcription and translation of CGRP in the rat's DRG, and this reduction in CGRP can alleviate pain behavior [52].

For further research: It is suggested that the role of the CGRP mechanism in post-PRF pain relief be investigated. The relationship between CGRP, pain behaviors, and PRF should be investigated in more follow-up studies.

ATF 3 (Is the Extended PRF Efficient?)

Activating translation factor 3 (ATF3) is a marker of cellular stress in various tissues. ATF 3 is used as a sensitive marker in neuronal response to injury, as well as in the neuropathy [56]. ATF 3 also increases in neurons and glial cells after axotomy. It is not expressed in healthy DRGs, but it is seen in axotomized DRG neurons [28]. As mentioned earlier, PRF is a nondestructive method and exerts its clinical effects through neuromodulation. Nevertheless, PRF application leads to ultrastructural changes in DRF cells as well as in sensory nociceptive axons. One of these changes is that by applying PRF to DRG, the amount of ATF 3 is upregulated. It is noteworthy that the increase was found only in small-diameter C and A-δ nociceptive fibers.

The story of ATF 3 is a bit different from the other markers mentioned earlier. So far, we have studied the mechanisms of pain relief after PRF. But in this section, we will answer these questions: according to molecular evidence and especially the amount of ATF3, does PRF application for a longer time provide more pain relief? If we stimulate the PRF for a longer time (e.g., 12 minutes), do we necessarily get a better therapeutic response than when we stimulate the PRF for a shorter time (e.g., 6 minutes)? Probably not!

A similar study was performed about extended PRF exposure times on mechanical allodynia in rats. First, an SNL nerve injury was created, and then PRF was

applied to the DRG, after which antiallodynic effects were seen. Interestingly, the antiallodynic effects at 12-min PRF were not significantly different from 6-min PRF. On the other hand, the expression of ATF3 mRNA, as a marker for cell damage, was much higher in the 12-minute PRF than even the group without PRF treatment!

It was found that the amount of ATF3 mRNA was related to the PRF exposure time. Thus, the expression of ATF 3 in the naive group was very low, which indicates their intact neurons; however, the level of ATF3 mRNA in the sham group, PRF 6 minutes and PRF 12 minutes, was much higher. Finally, it was suggested that the extension of PRF exposure times did not increase the antiallodynic effect, but could also have neurolytic effects [57].

For further research: It is suggested that the optimum conditions for PRF treatment be determined, based on the molecular evidence and the mechanism of action of PRF. Also, further investigation of the side effects of PRF at the molecular level is suggested.

Neurotransmitter (BDNF, PI3K, and p-ERK)

In this section, we review three factors that are effective in the analgesic effect of PRF. These three substances, called neurotrophins, play their role as pain mediators/modulators:

1. Brain-derived neurotrophic factor (BDNF)
2. Phosphatidylinositol 3-kinase (PI3K)
3. Phosphorylated extracellular signal-regulated kinase (p-ERK) [58].

By applying PRF to DRG in rats with neuropathic pain, the levels of these three substances (BDNF, PI3K, and p-ERK) are suppressed in the spinal cord.

Brain-derived neurotrophic factor (BDNF) is a secretory protein from the neurotrophin family. Neurotrophins are effective in the survival, growth, and differentiation of new neurons and synapses; however, after nerve damage, they have a devastating effect on the spinal cord. BDNF is associated with microglial neurons and is an important signaling molecule. It is involved in nociceptive processing in the spinal cord and pain processes in the peripheral and CNS. Nociceptor-derived BDNF is effective in inflammatory pain, and microglial-derived BDNF is effective in neuropathic pain [59].

Increased BDNF expression was found in the spinal cord after SNI. Enhanced BDNF was shown to induce nociceptive hypersensitivity, and inhibition of BDNF signal improved allodynia in rats with SNI. As Liu et al. reported, BDNF is effective in colitis-induced spinal central sensitization, and PI3K can mediate BDNF function in the spinal cord. PI3K can also enable p-ERK via second messengers' pathways [60]. PI3K is a lipid kinase that acts as a membrane-embedded second messenger. The role of PI3K in refractory pain has been demonstrated. For example,

plantar incision activates PI3K in the microglia, but inhibition of PI3K relieves pain-induced pain behaviors [61]. PI3K signaling has also been seen in bone cancer pain and also after SNI injury. PI3K-specific small-interfering RNA rat pain inhibited pain behaviors in bone cancer pain [62]. In that study, PI3K levels also increased after SNI injury.

ERK signaling pathway in microglia is involved in modulating different types of pain, and its inhibition can relieve pain. In microglia, ERK activity occurs after nerve damage, and inhibition of ERK can stop the spread of neuropathic pain. The p-ERK level was significantly upregulated after SNI. It was generally confirmed that microglia, BDNF, PI3K, and p-ERK are involved in developing chronic pain and pain sensitization. These substances are released in the spinal cord in a microglia-dependent manner.Since the application of PRF to DRG in rats with neuropathic pain reduces microglial activity, the studies concluded that PRF could regulate the release of BDNF, PI3K, and p-ERK in the spinal cord and subsequently reduce pain. After PRF application to ipsilateral DRG of the rats, mechanical allodynia and thermal hyperalgesia were reversed. In practice, this theory proved that the amount of these three substances decreased simultaneously after 6 minutes of PRF treatment for SNI.Therefore, it has been suggested that the application of PRF to DRG can reduce neuropathic pain by suppressing microglia and downregulated levels of BDNF, PI3K, and p-ERK in the spinal cord via microglia-dependent manner [37].

Excitatory Amino Acids (EAAs)

Another mechanism proposed for the analgesic effect of PRF is through inhibition of excitatory amino acids. Excitatory amino acids (EAAs) are essential neurotransmitters of the central and peripheral nervous systems, involved in modulating peripheral inflammation and the transmission of peripheral pain in the spinal cord [63]. Glutamate and aspartate are among the EEAs. The activation of glutamate receptors is involved in central hypersensitivity [64].

Inhibitory amino acids, including glycine and g-aminobutyric acid, also act to counteract the effects of EAAs, for example, by inhibiting nociceptive input and modulating the level of pain transmission [65]. The role of EEA, citrulline (a marker for nitric oxide synthesis), and glycine in thermal and tactile after peripheral inflammation, has been demonstrated [66].

It has been shown that applying PRF to DRG reduces mechanical allodynia, spinal EAAs (glutamate and aspartate), and citrulline concentration. PRF was able to reduce experimentally induced inflammatory pain with spinal dorsal horn modulation, suppress EAAs-citrulline release, and alter glutamate receptor activity [67].

Overall, given that some PRF target tissues do not have nerve tissue (such as intra-articular PRF), neurophysiological theories alone cannot suffice to find the analgesic mechanism of PRF, making the role of novel mechanisms, such as EAA, more critical.

Regenerative Mechanism

Another mechanism proposed for PRF, especially in the intra-articular type, is the cartilage-protective or regenerative mechanism. Laboratory studies show that electrical stimulation can increase chondrocyte proliferation and matrix synthesis [68]. A study by Fini et al. suggested that pulsed electric fields have several effects, including an anabolic effect on chondrocytes, catabolic cytokine blockage, and inhibition of inflammatory processes in osteoarthritis [69]. These studies need further investigation in vivo.

A review article in 2019 examines the effects of electromagnetic fields on cartilage. In vivo, research has shown that EM can protect the chondrocyte form, increase DNA synthesis, and increase GAG proliferation and synthesis in human cartilage. In vivo studies have also shown that the EM field can improve osteoarthritis, increase PG synthesis, and counteract catabolic activity [70].

Overall, it has been shown that EM stimulation can preserve articular cartilage morphology, improve joint mobility, and reduce joint pain.

For further studies: Research on the mechanism of action of PRF may need to be more focused on other cell lines, such as the joint, cartilage, and bone. It should also not be limited to the pathways of pain transmission.

IGF-2

Insulin-like growth factor 2 (IGF2) is a protein involved in prenatal growth and development and the growth and proliferation of various tissue cells [71]. The role of IGF 2 in pain has not been confirmed but is being investigated as a new target in nerve injury-induced pathological pain [72].

PRF, which is applied immediately after nerve injury, has been shown to have a more significant inhibitory effect of mechanical allodynia than delayed PRF (14 days after injury). This effect of immediate PRF is achieved through the down-regulation of IGF 2 and reduction of phosphorylation of ERK1/2. This reduction is mainly in microglial cells in the spinal dorsal horn [73].

Therefore, further study to determine the time to optimize RF using IGF 2 is recommended.

Cellular and Histological Changes in RA

In an animal study, by applying continuous RF at 67 °C to DRG, changes such as mitochondrial degeneration and the loss of nuclear membrane integrity were observed. These changes were not seen in PRF [74]. In another study, which performed continuous RF and PRF at 42 °C, no significant structural changes were seen except for transient endoneural edema and collagen deposition [75].

The research on axonal ultrastructural changes after PRF has shown changes in mitochondrial membranes and appearance, as well as disorganized microfilaments and microtubules [76]. Another similar study in PRF for 120 seconds showed just separation in myelin configuration in damaged myelinated axons [15]. These histological changes in PRF are probably due to the high transmembrane potentials generated and the tissue being exposed to electrical current.

In general, by calculating the electric field generated, and in vitro studies, PRF has been shown to cause definite tissue changes. These changes can also relieve neuropathic pain in animal models in vivo [23]. In addition to the histological and ultrastructural axonal findings that occur after the PRF application, there is a convincing biochemical basis for PRF mechanisms, which has been described in earlier sections.

Concluding Remarks

In this chapter, with a review of the principles of nerve damage and the physics of RF types, we described the various mechanisms of action proposed for RF. The two main mechanisms of RF are ablation and creation of the electromagnetic field. These therapeutic effects were mediated by neuronal modulation in pain signal transmission via nerve fibers, changes in gene expression, and changes in cytokines and neurotransmitters. The direct and indirect effects of RF on nerve fibers, microglia, and chondrocytes were also discussed.

In the decades since the application of RF in pain management, much research has focused on determining the outcome of RF in various areas, rather than finding its mechanism of action. Many advances have been made in basic science and pain-related translation research. It is clear that using this new knowledge window has enabled novel researches to determine the accurate mechanism of action of RF easier and more possible. We can do a more optimized patient selection, approach selection, and pain management via these findings. For these goals, in addition to the research questions posed in each section, longitudinal studies with longer follow-up, as well as closer contact of pain physician with pain scientists and researchers, are recommended.

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Chapter 3
Types of Radiofrequency Ablation-Pulsed Radiofrequency Ablation

Jackie Weisbein, Michael Esposito, Timothy R. Deer, and Nomen Azeem

What Is Pulsed RFA

Continuous radiofrequency (CRF) ablation has been utilized in the treatment of chronic pain since 1974. While its use is varied, there are concerns regarding the risk of motor nerve injury and pain associated with deafferentation. Pulsed radiofrequency (PRF) emerged as a way to treat pain generators without the destructive effects associated with CRF.

In 1995, Armenian biophysicist Professor Sinerik Ayrapetyan, Ph.D postulated that PRF effects might be a manifestation of magnetic field exposure at a conference in Austria. For the 6 months following this conference, a group worked diligently to determine a method to pulse the output of the radiofrequency generator, an idea proposed by Menno E. Sluijter, M.D., Ph.D. After discussing this with Eric R. Cosman, Ph.D., the two with William Rittman, M.S. devised an PRF waveform that would be able to be utilized by the Radionics RFG-3C RF Lesion Generator. A small patient series in 1996 demonstrated results that indicated they might be working in the right direction. The first published data on PRF was published in The Pain

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_3

Clinic in 1998 by Sluijter, Cosman, Rittman, and van Kleef. It was hypothesized that the energy from PRF was one that affected the electrical field, but unlike CRF, there was no tissue thermocoagulation and thus less tissue injury due to application of short pulses of RF signals.

Biophysics of Pulsed RFA

Thermocoagulation in CRF uses alternating current to create ohmic heating at temperatures between 60° and 80 ° C resulting in both neuroablation and protein coagulation. Conversely, PRF alternates short bursts of current and a "silent" phase which allows for heat elimination. This can effect changes in nociception while keeping the tissue temperature below 42 ° C.

Most commercially available RF generators are able to provide pulse frequency ranges of 1–10 Hz with short high voltage durations lasting from 5 to 50 milliseconds. One of the most commonly utilized sequences is a pulse of 50 kHz current frequency of 2 Hz. During the interval between the bursts, the heat is able to dissipate because the duration of the burst is a smaller percentage of time. Thus, larger RF voltages can be used without risk to surrounding tissue. A common sequence of PRF is a 2 Hz frequency with a pulse width of 20 ms for a treatment of 2 minutes produces a power deposition 4/100 of that during continuous RF for the same voltage. Experiments demonstrate, however, that heat spikes do occur about the tip of the needle with temperatures ranging between 45°C and 50°C. Work in the dorsal root ganglia of rat and rabbits has proven that there is only transient endoneurial edema compared to the Wallerian degeneration seen with standard CRF.

While the complete mechanism of action of PRF is not understood, research continues in the space. Although there is believed to be some degree of changes that develop with regard to neural markers and transmission of synapses, the effect of PRF causes some degree of destruction around the electrode; however, the degree of impact is questionable. What is known is that PRF is able to produce a stronger electrical field than CRF. In contrast to CRF, however, in PRF, the electric field drops rapidly as it moves away from the tip of the probe, and thus the local target tissues are not subjected to the degree of damage that is seen in CRF. The low or moderate electric fields may induce changes in the transmembrane potentials. The resultant changes in transmembrane potentials occurring at low temperatures can result in a number of possible side effects, including disruption of ion channels, resting, and threshold potential alterations. This can theoretically result in long-term depression of synaptic transmission at the spinal cord.

The development of the pain state is through the protein form of c-Fos, FOS, which leads to the expression of dynorphin. The dynorphin protein has implications in the development of the pain state. There have been differing opinions regarding

the activation of c-Fos. Richebe et al. feel that there is a lack of evidence. However, Higuchi et al. performed PRF at 42° C for 8 minutes to rat cervical DRG, and there was a resultant increase in c-Fos immunoreactivity.

While the exact mechanism of PRF is unclear, the proposed mechanisms are the induction of long-term depression of synaptic potentials which modulate c-fiber transmission. This in turn decreases/inhibits ERK activation. These signal changes in the spinal/dorsal horn processing of nociceptive signals are noted as well as a decrease in inflammatory mediators. This supports PRF as a treatment intervention indicated for therapy for chronic neuropathic pain.

Comparison to Conventional Thermal RFA

Bogduk compared conventional and pulsed RF in a position paper in 2006 [1]. Many of the comparisons still hold true. There are more data adding to the support of pulsed RF as an efficacious treatment modality; however, these data are limited. There is a robust biologic foundation for thermal radiofrequency ablation. A radiofrequency current is applied to heat tissue, resulting in an objective and verifiable pathologic tissue lesion. There is also strong evidence of outcomes with conventional thermal RFA. Pain relief [2], restoration of function, and resolution of psychological distress [3] have been demonstrated and in placebo-controlled trials. Pain relief from properly executed conventional thermal RFA can be significant, and the duration of relief can last beyond a year. Although pain may recur as the peripheral nerve regenerates, relief can be achieved once again by repeating the radiofrequency ablation. What is clearly evident from the literature is that pulsed RF does not produce a lesion [4]. Therefore, pulsed RF cannot be characterized as a procedure resulting in nerve destruction, and thus, pulsed RF is clearly a different procedure from thermal RF. The differences between thermal RF and pulsed RF are as follows:

"Pulsed radiofrequency is not equivalent to thermal radiofrequency. It is not a substitute for thermal radiofrequency in conditions for which thermal radiofrequency has an established and proven efficacy. There is no evidence that pulsed radiofrequency replicates the efficacy of thermal radiofrequency. The available data indicate that pulsed radiofrequency is markedly inferior in these instances." [5] Some examples comparing conventional and pulse RF will be discussed in the following section.

Pulsed RF has some advantages:

1. Pulsed RF is technically simpler than thermal RF. Placement of the needles can be done in the same manner as needles are used for diagnostic blocks. The needle/probe combination does not need to be positioned as laboriously and as meticulously as is vital for thermal RF. Close to the target is "good enough." This also allows for pulsed RF to be a faster procedure than thermal RF.
2. Pulsed RF potentially has a lower risk profile (Table 3.1). Since pulsed RF does not cause a destructive thermal lesion, complications that are otherwise associated

Table 3.1 Comparison of advantages and disadvantages of conventional vs. pulsed RF

	Advantages	Disadvantages
Thermal/ conventional	Longer-lasting pain reliefCovered by most insurance carriers	Increased procedural painDestruction of motor nerves with improper placementRisk of deafferentation pain
Pulsed	Less neurodestructiveLess pain with procedureMinimized tissue destruction and tissue overheatingLess risk of deafferentation pain	Shorter duration of reliefProcedure may need to be repeated more frequentlyHigher cost to patient if not covered by insurance

with thermal lesions are likely to be reduced (less pain, no motor dysfunction). Furthermore, as no injection of local anesthetic or (particulate) steroid is needed, pulsed RF treatment also purports avoidance of potential complications associated with intravascular or intraneural injections of these substances and their sequela.

In summary, conventional thermal RF and pulsed RF differ in mechanism and effect:

- Thermal RF produces a tissue lesion; pulsed RF does not.
- Thermal RF ablation has proven efficacy; pulsed RF efficacy is limited based on the neural target and available primary literature.
- Using pulsed RF instead of thermal RF in situations where the thermal RF is indicated denies the patient the benefit of a proven procedure in favor of one with less robust efficacy and durability.

Specific Comparisons of Conventional RF and Pulsed RF Based on Neural Target

There are a few studies that have examined the comparative efficacy of conventional thermal RF and pulsed RF based on neural target/pain generator and/or pain syndrome. Kroll et al. examined the comparative efficacy of conventional versus pulsed RF in the treatment of lumbar facet syndrome [6]. Conventional RF was superior to pulsed in that those treated with conventional RF obtained more durable relief.

With respect to the treatment of cervicogenic headache, Grandhi et al. performed a systematic review of both conventional and pulsed RF [7]. This systematic review demonstrated that conventional RF and pulsed RF provide a very limited benefit in the management of cervicogenic headache. At present, there is no high-quality RCT and/or strong non-RCTs to support the use of these modalities, despite several case reports which have demonstrated benefit.

Salgado-Lopez et al. examined the efficacy of pulsed and conventional RF of the sphenopalatine ganglion for the treatment of refractory chronic cluster headache [8]. No difference was observed between conventional and pulsed RF.

A couple of studies examined the efficacy of pulsed and conventional RF of the sphenopalatine ganglion for the treatment of trigeminal neuralgia. The first, by Erdine et al., found that conventional RF was better than pulsed in the treatment of idiopathic trigeminal neuralgia [9]. The second, by Kim et al., also found that conventional RF was better than pulsed RF in the treatment of dental procedure-related trigeminal neuralgia [10].

The treatment of knee pain with conventional RF and pulsed RF has been studied. Gupta et al. performed a systematic review on the comparative effectiveness of cooled versus pulsed RF [11]. A that time, the meta-analysis could not favor one treatment over the other. Subsequently, Hong et al. undertook a systematic review and performed a meta-analysis of 12 RCTs evaluating different types of RF treatment for knee pain and function [12]. Conventional RF was shown to be superior to pulsed RF.

Finally, Usmani et al. examined the use of conventional versus pulsed RF of the ganglion impar in the treatment of chronic perineal pain [13]. In this study, conventional RF was demonstrated to be superior to pulsed RF.

Chronic Pain Targets

As with conventional thermal RF, there are a multitude of pain generators that have been targeted with pulsed RF for the treatment of pain. Some of these targets are more ideal for pulsed RF as compared to thermal RF due to the fact that no tissue destruction occurs with pulsed RF, namely, nerves with mixed sensory and motor components. Thus, pulsed RF offers a potential treatment for these pain generators/conduits resulting in pain relief without the sequela of nerve destruction. However, most literature is limited to case reports and series, and therefore data are limited to support durable efficacy. The following table (Table 3.2) lists by category different targets for which pulsed has been applied.

Other Indications for Pulsed RFA

There have been other reported indications for pulsed RF outside of the treatment of pain. Some of these will be mentioned here, but they are beyond the scope of this text (Table 3.3).

Table 3.2 Pulsed RF targets

Treatment of spinal pain
Facet joints [14, 15]
Sacroiliac joint [16]
Coccyx [17, 18]
Intradiscal [19]
Treatment of radicular pain
Cervical DRG [20]
Lumbar DRG [21–23]
Thoracic DRG/intercostal [24]
Treatment of joint pain
Shoulder [25]
Hip joint [26]
Knee joint [27, 28]
Foot and ankle [29, 30]
Treatment of head and neck pain
Trigeminal [31, 32]
Glossopharyngeal [33]
Treatment of headache pain
Occipital [34]
Atlantoaxial joint [35]
C2 DRG [36]
Sphenopalatine [37–39]
Treatment of pelvic pain
Pudendal [40–42]
Ganglion impar [43]
Other [44, 45]
Peripheral nerves [46]
Anterior cutaneous nerve (abdominal) [47]
Brachial plexus [48]
Ilioinguinal/iliohypogastric [49]
Lateral femoral cutaneous [50, 51]
Lumbar sympathetic chain [52]
Median [53]
Neuromas (phantom pain, stump pain) [54, 55, 56]
Splanchnic nerves [57]
Stellate ganglion [58]

Table 3.3 Other indications for pulsed RFA

Arrhythmias [59]
BPH [60]
Chronic pancreatitis [61]
Hyperhidrosis [62]
Premature ejaculation [63]
Treatment of tumors (liver)/tumor invasion of nerves [64]

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Chapter 4
Types of Radiofrequency Ablation-Cooled Radiofrequency Ablation

Timothy Davis, Ajay Antony, Nomen Azeem, and Timothy R. Deer

Introduction

Radiofrequency ablation (RFA) is a minimally invasive technique designed to treat musculoskeletal disorders such as chronic low back, shoulder, and arthritic joint pain [1]. Aside from chronic pain, there is sufficient literature to show its clinical application in a multitude of diseases including, but not limited to, cancer, cardiac arrhythmia, trigeminal neuralgia, and pain originating from the spine.

The term radiofrequency is derived from the electromagnetic spectrum containing a distribution of electromagnetic radiation ranging in wavelength and frequency. Radio waves, utilized in radiofrequency ablation procedures, are defined as having the lowest frequency and highest wavelength. RFA harnesses radio waves to induce necrosis in target tissue or nerves via ionic heating. The resulting ablated lesions disrupt pain signals transmitted by the target sensory nerve [2].

Similar to conventional radiofrequency, cooled radiofrequency ablation (CRFA) also utilizes radio waves and ionic heating for tissue ablation. However, the CRFA approach uses water-cooled technology to cool the electrode tip to a temperature lower than that seen in conventional RFA. Promising developments and treatment results have shown that CRFA allows for larger lesion sizes by minimizing chances of tissue charring and crater formation [2].

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Mechanism of Cooled RFA

Consistent results of conventional RFA require precise needle placement extremely close to the nerve—within 1 to 2 mm. This is due to the small size and variable location of sensory nerves, the lack of visualization of the targeted structures, and the limited effective radius of the lesion. Therefore, standard radiofrequency technology is limited in size and shape of the lesion [3]. Cooled radiofrequency ablation was developed to address limitations of lesion field seen in conventional radiofrequency [2]. Tissue desiccation is seen as ablation temperatures approach 100 °C, and insulating properties prevent heat radiofrequency waves from reaching further target tissue [4]. The temperature at which this insulating nature of charred tissue results in an impedance of electrical conductivity is referred to as the "electrode interface disruption temperature" or EIDT [4]. The premise of CRFA is to ablate a greater volume of tissue by increasing the electrical output of the probe while keeping the temperature of the tip below the EIDT to prevent charring [4].

Conventional RFA needles vary between 2.5 mm and 10 mm in length and 16G and 22G in diameter, while CRFA needles range from 4.5 mm to 5.5 mm in length and are typically 17G in diameter [4]. The CRFA needle also has a hollow exterior casing by which a coolant is continuously circulated to modulate temperature at the tip of the probe [2] to around 60 °C [5]. The cooling of the tip during ablation averts direct charring of the surrounding tissue by preventing fast coagulation and increased insulation [5], thus inducing more efficient heat transfer beyond the tip's most proximal region [1]. This consequently alters the overall size, shape, and projections of the ablated lesion, as compared to conventional RF [5].

The cooled electrode probe is able to maintain a lower steady temperature of 60 °C at the tip over a longer period of time, allowing further heat transmission and producing greater lesion volume. CRFA can create a volume five times larger than conventional RF and project a lesion 45% or greater beyond the probe tip [4, 6–14].

This greater ablation volume increases the likelihood of reproducible procedure success and longer-lasting pain relief [15]. In a study comparing lesion volume and shape of conventional versus cooled RFA, results indicated that a lesion obtained with CRFA at a tip temperature of 60 DC and duration of 150 seconds is significantly larger than lesions obtained using conventional monopolar probes. When using a 17 G diameter tip at the aforementioned conditions, the average lesion volume of CRFA was 595mm^3 after ten experiments [1]. In comparison, a monopolar 16 G diameter probe produced a mean volume of 360mm^3. It is noteworthy that the length of the active tip of a CRFA probe is 4 mm, yet the lesion volume is much larger than what would be expected for its monopolar equivalent. Although results corroborate the claims of CRFA producing a larger lesion field, all experiments were performed ex vivo; therefore, results may not be reproducible when used in clinical practice [1].

The shape of the lesion volume seen with CRFA is also spherical rather than the conventional elliptical shape. Because of its spherical projection, the CRFA probe may be placed perpendicularly adjacent to the nerve of interest as opposed to

limited parallel placement required with conventional RFA due to its production of narrow elliptical burn [15].

Chronic Pain Applications of CRFA

Sacroiliac Joint Pain

CRFA has been shown to provide durable pain relief for several conditions in the spine. The most robust evidence exists for CRFA of the lateral branches innervating the sacroiliac (SI) joint. Sacroiliac joint pain is common and accounts for up to 30% of all complaints of low back pain [16].

The anatomy of the diarthrodial sacroiliac joint is complex due to the separate innervations of the anterior and posterior portions. The anterior portion is innervated by the sacral plexus, while the posterior innervation is derived from the L4 to S1 nerve roots with contribution from the superior gluteal nerve [17]. This posterior innervation can be a target for therapeutic denervation at the L4 medial branch nerve, L5 dorsal ramus, and the lateral branches of S1 to S3. Because of the variability in lateral branch anatomical location, the size and shape of CRFA lesioning have been an area of interest and study for SI joint pain.

There are a number of case series that report success using cooled radiofrequency ablative therapy at the sacroiliac joint. In 2008, Kapural et al. reported results of improved VAS scores with decreased opioid usage in 27 patients within an initial case series. A number of retrospective cohorts have since shown similar success. A randomized controlled trial published in 2008 by Cohen et al. compared results of CRFA lesioning against placebo denervation (n = 28). Results indicated that a majority of patients received significant pain relief and functional improvement at 6 months [18]. A second randomized controlled trial (n = 51) published in 2016 by Patel et al. found an average NRS decrease of 2.7 and 2.5 at 12 months in the treatment group and the crossover group, respectively. Secondary functional assessments were also favorable [19]. In a 2018 meta-analysis of 240 patients that received CRF for SI joint pain across 7 studies, results showed an overall significant reduction in pain, as indicated by NRS (3.81 at 95% CI) and VAS (3.78 at 95% CI). Disability and perceived effect by ODI and GPE were also favorable [20].

Several studies have compared various methods of neurotomy at the sacroiliac joint. This often centers around potential differences in efficacy as well as availability of equipment at a particular practice location. In a 2013 report, Cheng et al. did not find a significant difference in reducing pain between these two methods among 88 patients [21]. A comparison was also performed between cooled radiofrequency and a specialized probe designed for posterior radiofrequency lesioning. These results indicated that cooled radiofrequency provided more durable analgesia and disability relief [22]. Further studies are needed to better elucidate the efficacy of CRFA techniques for different regions of the SI joint.

Complications from CRFA of the sacroiliac joints are rare and may include localized post-procedural pain or bruising. An incident of neuropathic pain at the site has been reported, but severe complications are exceedingly rare [23].

Discogenic Pain

Cooled radiofrequency technology has been applied not only to the denervation of joints but also to the intervertebral discs. Intradiscal biacuplasty is a RF technique that generates a lesion using cooled, bipolar radiofrequency probes inside the posterior annulus fibrosis of the disc. It was first described in 2007 as a modification of conventional intradiscal radiofrequency annuloplasty [24]. Histological changes and temperature distribution within the spinal elements have been studied as well, citing temperatures greater than 45 °C in the posterior annulus are required for neuroablation without damage to surrounding neural structures [25, 26].

Several studies treating discogenic pain with biacuplasty have been reported. In a pilot study, Kapural et al. reported average VAS reductions in 13 patients from 7 cm to 4 cm. Seven of the 13 patients had greater than 50% pain relief, and there were no complications or serious adverse events reported [27]. Another study comparing intradiscal biacuplasty against sham treatment showed clinically significant improvements in both pain (as seen by an average decrease of 2.9 in NRS) and physical function (as seen by 22 in SF-36) in 22 of the 27 subjects in the treatment group at 12 months. Of the 30 patients originally in the sham group, 24 crossed over and reported similar results [28].

Intradiscal biacuplasty has been compared against conservative medical management as well. Desai et al. reported the treatment provided clinically meaningful and statistically significant pain reduction at 12 months in a crossover study. 55% of those receiving biacuplasty in addition to medical management were considered responders with a mean VAS reduction of 2.2 cm at 12 months [29]. An overall systematic review of all thermal annular procedures conducted in 2017 showed level I evidence for percutaneous biacuplasty being effective in successfully treating refractory discogenic pain and even recommended its consideration as a first-line treatment [30].

Facet Joint Pain

Medial branch nerves (MBN) supplying zygapophyseal facet joints are also a common target for thermal denervation. Although facetogenic pain is more commonly treated with conventional MBN lesioning techniques, early studies of cooled RFA treatment offer potential alternatives for thermal ablation. Studies have reported varying degrees of success dependent on proximity to the nerve and size of the RF cannula [31].

An early case series followed patients with lumbar facet syndrome treated with CRFA. Of the nine patients that continued in the study, six had a repeated CRFA procedure. At 3 years, 33% of patients reported ≥50% improvement of pain and 78% reported functional improvement [32]. In a larger randomized prospective trial ($n = 43$), patients with lumbar facet joint pain and positive diagnostic medial branch block were treated with either conventional or cooled RFA. Both groups saw a success rate of 50% with no statistically significant difference between either modalities at 6 months [33]. Though CRFA has been shown to provide pain relief for facet pain, more large-scale comparative studies are needed to better determine conclusive evidence of CRFA for lumbar facet joint-related pain.

Though there is evidence that RFA of branch medial nerves provides relief for cervical and lumbar facet joint pain, evidence is limited for use in treating thoracic facet joint pain. Medial branch nerves of the thoracic spine differ anatomically from that of the lumbar spine, with more than 1 nerve per level and nerves dispersed in the superior and lateral aspect of the thoracic transverse processes. This limits the ability of conventional RFA in lesioning all of the medial branches per vertebral level. In the first retrospective study ($n = 23$) evaluating 40 cooled RFA procedures for patients diagnosed with thoracic facet joint-related pain, they found that improvement in average pain level was 20.72%, 53%, and 37.58% during the 4–8 weeks', 2–6 months', and 6–12 months' period, respectively [34]. Further comparative studies of different RFA modalities for thoracic facet joint-related pain may offer more conclusive evidence of CRFA efficacy.

Knee Pain

Thermal ablation of the sensory nerves innervating the knee is the most common use of water-cooled radiofrequency technology. Terminal sensory branches of the saphenous and femoral, termed superomedial, anteromedial, and superolateral genicular nerves are effective targets for therapeutic ablation. This has been reported as a safe and effective therapy in treating osteoarthritic knee pain as well as pain in the setting of prior total knee arthroplasty [15]. By producing a larger and spherical lesion, CRFA may provide a better option than conventional radiofrequency for this application due to the variable paths and anatomical locations of these nerves.

Emerging evidence indicates efficacy of cooled radiofrequency ablation for knee pain treatment. A 2017 review examined two prospective trials, one retrospective cohort study, and five case reports or series with encouraging evidence supporting safe and effective use of CRFA for knee pain [5]. In a 2019 multicenter crossover study comparing the safety and efficacy of CRFA to corticosteroid injection treatment for knee osteoarthritis (OA) pain, Davis et al. found that 74.1% of subjects treated with CRFA reported at least 50% of pain remission at 6 months, compared to 16.2% of subjects in the IAS-treated group [35]. At 12 months post-intervention, they found that 65% of the originally treated CRFA group sustained a pain reduction of ≥50%. These results demonstrate that analgesia following CRFA for knee

OA pain could provide long-lasting relief and could rescue patients who experience intolerable discomfort following intra-articular steroid injections [36]. Improved function, pain relief, and perceived positive effects were further observed at 24 months post-procedure [37]. Another recent study followed a similar premise and found that CRFA demonstrated sustained knee pain relief for at least 12 months for both the treatment cohort and the crossover cohort that initially received a hyaluronic acid injection [38].

Cooled radiofrequency ablation is an emerging procedure with encouraging results for chronic pain management. Additional long-term clinical trials and comparative studies are necessary to further determine efficacy and longevity of pain relief from CRFA treatment.

Other Applications of Cooled RFA Outside of Chronic Pain

Though advancements of water-cooled radiofrequency usage in treatment of chronic pain are fairly recent, cooled radiofrequency ablation methods have long been used as minimally invasive treatment modalities for tumors and electrophysiological cardiac arrhythmias.

CRFA is a well-established and commonly used procedure for the treatment of hepatocellular carcinoma (HCC) and liver metastases. A study was conducted among 30 patients with HCC who were treated with a cooled-tip 10 mm electrode RFA over the course of three years. They found that 13.3% of lesions showed local progression, with results suggesting that cooled-tip RFA is indicated in hypovascular HCC nodules of lesion diameters <10 mm [39]. A recent 10-year cohort study of subjects with HCC found that 99.4% of tumor ablation procedures showed complete ablation, with a 5- and 10-year survival rate of 60.2% and 27.3%, respectively. With approximately only 20% of HCC patients eligible for resection, CRFA offers an alternative treatment for those who do not have the option of resection and who would better tolerate a minimally invasive procedure [40].

CRFA is also an emerging treatment modality for lung malignancies in patients who are not candidates for surgical resection. A study examining the safety and feasibility of bronchoscopy-guided CRFA as a treatment therapy for inoperable non-small-cell lung cancer (NSCLC) followed 20 patients who had received a total of 28 CRFA procedures. Koizumi et al. found that the median progression-free survival rate was 35 months (95% CI) and a 5-year overall survival rate was 61.5% (95% CI). Three patients required hospitalization due to ablation-related adverse events. With consideration of natural disease progression on a limited sample size, results indicate that CT-guided bronchoscopy CRFA offers a safe and effective treatment option for disease local control in patients with inoperable stage I NSCLC [41].

Many studies have sought to apply cooled RFA treatments toward other tumor growths. In a study assessing efficacy and safety of CRFA in benign thyroid nodules, 276 ablated lesions were examined following ablation with straight-type

modified internally cooled electrodes. They found that the average volume reduction in benign thyroid nodules at 12, 24, 36, 48, and 60 months' follow-up was 80.3%, 84.3%, 89.2%, 91.9%, and 95.3%, respectively, with significant improvements in symptoms [42]. Another study using finite-element method (FEM) models and ex vivo procedures found that cooled-tip RF breast ablation produced better temperature ablation and duration than multiprobe RF, thus inducing more consistent necrosis volume in the breast tumor tissue. However, further in vivo studies of cooled-tip RF breast ablation would better determine feasibility and safety of this method for treatment of breast malignancies [43].

Moreover, cooled-tip catheter ablation has been shown to be effective in treating and managing ventricular arrhythmias. Active cooling of the catheter tip with a closed-loop or open-irrigated electrode has been found to prevent overheating temperatures of the tip-myocardium interface, consequently allowing prolonged delivery of current over a larger lesion volume. These open- and closed-loop irrigated catheters were also found to deliver current in the coronary sinus as well as achieve ablation of atrial fibrillation and left-sided ventricular tachycardia [44]. In a Thermocool VT Ablation Trial, researchers found that in 321 patients with recurrent episodes of VT induced by myocardial infarction, open-irrigated catheter tip ablation acutely eliminated inducible VT in 49% of patients, and 53% of patients were VT-free at 6 months post-ablation [45]. Other developments of flexible-tip and cooled catheters have been shown to produce increased lesion sizes with lower incidence of charring and enhanced cardiac ablation safety [46].

Although cooled-tip tumor ablation and catheter ablation have been shown to treat certain malignancies and reduce recurrence rates in VT or tumor progression, these populations of patients are still at risk for adverse effects and recurrence, warranting further study of treatment longevity and durability.

Reimbursement and Challenges

The billing and coding of CRFA can be ambiguous as of the time of this publication. As stated above, multiple areas in the body may be targeted with CRFA. Regarding ICD-10 codes for facet joint, sacroiliac joint, knee, hip, and shoulder, the authors recommend referring to the 2020 ICD-10 codes available at the Center for Medicare and Medicaid Services website, www.cms.gov.

The following CPT codes may be used according to diagnosis: For SIJ CRFA, the CPT 64625 can be used; for genicular RFA, the CPT code 64624 can be used; for hip and shoulder CRFA, the CPT 64640 can be used with 64,650–59 or XS for second and third nerves as appropriate. Additionally, the authors recommend using the 2020 American Medical Association (AMA) CPT book and viewing the above CMS website regarding particular CPT coding including modifiers.

Specifically, regarding facet joint pain, there is potential debate regarding interpretation of the methods of facet denervation. As of January 1, 2016, the AMA guidelines for facet denervation dictate that the CPT codes including 64,633

(cervical/thoracic first nerve), 64,634 (cervical/thoracic second and third nerves), 64,635 (lumbar first nerve), and 64,636 (lumbar second and third nerves) should not be used for facet denervation for low-grade thermal energy of <80 degrees Celsius. According to this, Medicare would not pay for non-thermal facet RFA. However, the following argument is posed: When using COOLIEF for CRFA, although the CRFA temp on the generator displays 60 degrees Celsius, the radiofrequency energy produces thermal energy which heats the tissue up to greater than 80 degrees Celsius. Thus, COOLIEF affirms that their CRFA technology is not considered non-thermal. References [4, 6–14] provide scientific evidence of this and may be used to appeal potential denials.

Disclaimer: The authors of this chapter do not claim to provide billing advice. At the time of publication, the above parameters were applicable; however, these are subject to change. It is recommended to consult reimbursement specialists and payers' policies regarding specific billing and coding inquiries.

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Chapter 5
Monopolar Versus Bipolar Radiofrequency Ablation

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The use of alternating current (AC) radiofrequency waveforms to deliver suprathera-peutic targeted thermal neurolysis is a well-established technique across many surgical specialties to treat a variety of painful disorders, cardiopulmonary conditions, tumors, and dermatologic conditions. The two most frequently utilized methods of radiofrequency ablations are in the form of monopolar RFA (MRFA) and bipolar RFA (BRFA) techniques. With advancements in RF generators, there is now a major economic advantage of using one machine for both modalities.

MRFA has been the standard in interventional pain management with different methods being studied to compare efficacy as well as safety of radiofrequency ablation for the treatment of chronic pain. MRFA uses oscillating high-frequency current that passes from a single electrode through targeted tissue and then dispersed to a grounding pad and applied on the body a distance away to complete the circuit. The lesion is induced by the electromagnetic field around the tip of a single electrode causing protein denaturation, coagulation, and electrodessication [1].

In contrast, bipolar RFA (BRFA) uses two closely placed electrodes within the tissue, creating the electromagnetic field around these contacts and eliminating need for a grounding pad. The size of lesion produced with MRFA and BRFA depends on the parameters of each configuration. The variables that affect lesion size include needle gauge, active tip length, temperature, and time period of ablation [2]. When these variables are constant, the lesion size created using MRFA is smaller and more egg shaped than the larger more brick shape of BRFA. This assumes adequate

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_5

electrode configuration as typically BRFA requires the interventionalist to place two electrodes in parallel with a common distance of 10 mm or less. Cosman et al. demonstrate the different size lesions comparing MRFA and BRFA ex vivo in bovine liver tissue [2].

Increasing the size of the lesion has advantages and disadvantages despite which method is used. When anatomical variation exists, a larger lesion size may increase the likelihood of denervation of the appropriate target. Complete neurolysis provided by a larger lesion may also improve degree and duration of pain relief, reduce number of required lesions, and decrease procedure time and potential x-ray exposure [3]. However, the larger lesions created by BRFA also have the potential to damage adjacent unintended structures and require additional equipment/electrode configuration creating technical challenges for the inexperienced interventionalist. Currently, BRFA has been studied and may have more indications for structures with a more inconsistent neural anatomy like the sacral lateral branches of the sacroiliac joint, genicular nerves of the knee, and vertebrogenic and discogenic pain [4].

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Part II
Indications for RFA

Chapter 6
Cervical Spine

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Anatomy

The cervical spine is the most superior portion of the vertebral column, linking the skull to the thoracic spine, with seven distinct vertebrae numbered C1–C7, intervertebral discs, ligaments, associated nerves, and joints.

Vertebrae

As with all vertebrae of the spinal column, the cervical vertebrae are made up of a body, spinous process, vertebral foramina, bilateral transverse processes, and pairs of superior and inferior articular facets. The cervical vertebrae have three distinguishing features unique to the cervical spine: a triangular vertebral foramen which encases the spinal cord, posteriorly bifid spinous processes, and anteriorly bilateral transverse foramina which carry the vertebral artery, vein, and sympathetic nerves [1].

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The atlas (C1) articulates with the occiput of the head superiorly and C2 inferiorly and is distinct in its anatomical structure from other cervical vertebrae in that it has no vertebral body nor spinous process [2]. The atlas has bilateral lateral masses, connected with the anterior and posterior arch, with each lateral mass consisting of a superior articular facet to the occipital condyles and an inferior articular facet to the superior articulate facets of C2. The anterior arch and transverse ligament of the atlas have an articulation with dens of the axis, and the posterior arch contains a groove for each vertebral artery and C1 spinal nerve [2]. C2, the axis, has a dens, or odontoid process, superiorly from the anterior portion of C2 to articulate with the anterior arch of the atlas (C1), creating the medial atlanto-axial joint, allowing independent rotation of the head. The superior articular facets of the axis (C2) articulates with the inferior articular facets of the atlas (C1) to form the two bilateral, lateral atlanto-axial joints. C7, named vertebra prominens, has a much larger and singular spinous process, which is similar to those in the thoracic vertebrae [3].

Intervertebral Discs

Cervical intervertebral discs, similar to their function in the rest of the spinal cord, facilitate motion, transmit weight, and provide stability of the spine [3]. Each disc has four parts with the central nucleus pulposus, surrounded by annulus fibrosus, and two end plates, which are attached to the body of the vertebrae. Cervical intervertebral discs are thicker anteriorly which causes physiological lordosis of the neck [3].

Joints

The cervical spine has two groups of joints, those present throughout the vertebral column and those specific to the cervical spine. The two joints present throughout every level of the vertebral column are the disc joint and zygapophyseal joints or facet joints [4]. The disc joint is between two adjacent vertebral bodies joined by an intervertebral disc, made of fibrocartilage, making it a symphysis or a cartilaginous joint [4]. The facet joint is formed by the articulation of superior and inferior articular processes from adjacent vertebrae; this is termed a synovial joint. Facet joints guide motion at that segmental joint level of the spine and determine the type of motion that can occur there. The plane of the cervical facets is usually an oblique plane with an approximately 45-degree angle between the transverse and frontal planes [5].

The joints specific to the cervical spine are the single medial atlanto-axial joint and bilateral lateral atlanto-axial joints and bilateral atlanto-occipital joints as discussed above as well as the uncovertebral joints. The uncovertebral joints or

Luschka's joints are small synovial articulations in the region between C3 and C7 [5]. The joints are formed between uncinate process below and uncovertebral articulation above, allowing for flexion and extension.

Nerves

Cervical spinal nerves are similar to the remainder of the spinal cord with each being a mixed nerve, formed from nerve fibers of the dorsal, afferent sensory root, ventral root, and the efferent motor root. In the cervical spine, all spinal nerves emerge from the spinal column through the intervertebral foramen except for C1, which emerges between the occipital bone and the atlas (C1) [6]. Thus, the cervical nerves are numbered by the vertebra below, except spinal nerve C8, which exists below vertebra C7 and above vertebra T1 [6].

Each dorsal ramus has a lateral and medial branch, which give off both a deep and superficial medial branch division [7]. The lateral branch of the dorsal C4–C8 nerve root innervates the longissimus cervicis and splenius cervicis muscles, and the C8 lateral branch innervates the iliocostalis cervicis. The superficial division of C4, C5, and C6 medial branch innervates the semispinalis cervicis and semispinalis capitis and gives cutaneous innervation in C4–C6 dermatomal regions [7]. The deep medial branch division of C4–C8 innervates the multifidus muscle, gives C8 cutaneous innervation and most importantly, gives the innervation of the articular branch to the joint above and below the medial branch. The lateral division of the dorsal C3 nerve root innervates the splenius capitis, semispinalis capitis, longissimus capitis, and superficial posterior cervical muscles. The deep division of the C3 medial branch innervates the semispinalis capitis and multifidus muscles. The superficial division of the C3 medial branch has a special name, the third occipital nerve, which serves as a communicating branch to GON, articular branch to C2–C3 joint, and cutaneous innervation over rostral end of neck and occiput below protuberance and laterally toward mastoid process [7].

As mentioned above, in the cervical spine for facet joints C4–C8, each facet joint is innervated by two vertically adjacent spinal medial branches of the deep division [8]. For example, the C3–C4 facet joint receives innervation from both the medial branch of C3 and C4. The one exception to this is the C2–C3 facet, which is innervated solely by the superficial medial branch of the C3 dorsal ramus or the third occipital nerve (TON), and C1–C2 does not have a facet joint [8].

Conclusion

The interventional pain physician should learn the anatomy of the cervical spinal structures prior to moving forward with any ablative technique. This requires study of the human anatomy, imaging, and disease states.

Work-up

Neck pain is the third most common chronic pain condition in the United States, with annual prevalence rates ranging between 15% and 50%, and lifetime prevalence rate is as common as 67% [9–11]. Cervical facetogenic pain is estimated to be responsible for 36–60% of neck pain cases [12–14]. Accurate diagnosis of pain etiology is a prerequisite for successful treatment of axial neck pain, given the numerous surrounding anatomic generators of pain. While multiple structures are known to cause neck and upper extremity pain, distinguishing features of cervical facet joint pain considered as somatic referred pain and radicular pain have been described as shown in Table 6.1 [12–16].

Common sources of pain that respond to cervical radiofrequency ablation include cervical and thoracic facet degeneration, soft tissue and facet injury from cervical whiplash, and cervical post-laminectomy pain. When headache is the dominant symptom after whiplash, pain referred from the C2–C3 facet joint (third occipital neuralgia) accounts for 53% of cases. Due to fact that cervical facets are a common cause of chronic neck pain and cervicogenic headache, cervical radiofrequency ablation is an intervention that is highly utilized for appropriately selected patients. Thorough diagnostic workup to rule out other causes of axial neck pain, with or

Table 6.1 Distinguishing features of cervical somatic referred pain and radicular pain

	Somatic pain	Radicular pain
Causes	Facet joint pain Myofascial syndrome Discogenic pain	Disk herniation Spondylosis Annular tear Spinal stenosis
Symptoms quality	Deep Aching Poorly localized Neck worse than arm No paresthesia Covers a wide area No radicular or shooting pain	Sharp Shooting Well localized Arm worse than neck Paresthesia is very reliable Well-defined area Radicular distribution
Modification	Worse with extension Better with flexion No radicular pattern	Worse with flexion Better with extension Radicular pattern
Radiation	Neck to head, shoulder blades, upper back, radiation below elbow—unusual, no radicular pain	Follows nerve root distribution, radiation below elbow common, radicular and shooting pain
Signs		
Sensory alterations	Uncommon	Probable
Motor changes	Only subjective weakness Atrophy is rare	Objective weakness Atrophy may be present
Reflex changes	None	Commonly expressed but seen occasionally

without referred pain, includes an accurate clinical history, physical exam, X-ray, MRI, or CT imaging, as well as possible electrodiagnostic testing. Although physical and neurological examination are useful in excluding other causes of axial neck pain, range of motion, local tenderness over the cervical articular pillars, and extension-based facet pain are not considered diagnostic of zygapophysial joint pain in the cervical spine [17–24].

There is no evidence that a diagnosis of cervical facetogenic pain could be made solely with diagnostic imaging alone, as there is no evidence that common degenerative changes found on cervical magnetic resonance imaging (MRI) correlate with axial neck symptoms, except with disk herniations and spondylosis. Imaging, MRI, computed tomography (CT), radiography, and single-photon emission computed tomography scanning have all shown to be nondiagnostic specifically for cervical facet-mediated pain [25–28]. The cumulative findings from history, physical examination, and radiologic assessment may better help identify patient's candidacy for diagnostic cervical medial branch nerve blocks as a rational step in the diagnosis of cervical facetogenic pain, as well as to assess their candidacy for subsequent radiofrequency ablation.

The definitive diagnosis of cervical facet-mediated pain typically relies on the use of local anesthetic blocks, either an intra-articular facet joint injection or a block of the nerves supplying the facet joint (i.e., the dorsal primary rami or medial branches). Due to potential false-positive results following local anesthetic blocks, before proceeding with cervical facet radiofrequency ablation, many physicians will perform diagnostic and confirmatory "double blocks" to more accurately identify the cervical facet joint as the primary pain generator [29–35].

Technique

Diagnostic Block Technique

Medal branch nerve blocks are local anesthetic blocks of the nerves that transmit sensory information, including pain, from facet joints, and are used to determine whether or not the facet joint is the source of one's pain. Barnsley and Bogduk described this for cervical facet joint pain [36]. Over time, the procedural technique has been refined as described by the (Interventional) Spine Intervention Society guidelines [37, 38].

The location and courses of the medial branch nerves have been described after anatomic cadaveric dissection [39]. The medial branch nerves course horizontally across the middle (convexity or "waists") of the cervical articular pillars. The target point for each medial branch nerve block injection is the geometric center of the pertinent articular pillar. Blockade is achieved by injection of no more than 0.5 mL of local anesthetic (e.g., lidocaine 2% or bupivacaine 0.5%) so that there is sufficient anesthetic to block the medial branch nerve (minimizing false-negative

response) but not an excess amount that could disperse and anesthetize adjacent structures (minimizing false-positive response).

The following procedures described should be performed in a procedure suite or operating room with patient safety in mind, including regular infection control measures and availability of image guidance and resuscitation equipment. A pre-procedure assessment should be completed including:

A. Answer patient's questions
B. Check for contraindications (pregnancy, anticoagulation status, allergies, infection, etc.)
C. Informed consent
D. Confirm index pain being addressed including intensity and location
E. Finalize selection of facet joints/medial branch nerves being targeted

The patient should change into a gown to assist with sterility and avoidance of sullying clothing. The technique may be performed in a posterior or lateral approach. The patient should be positioned depending on the approach. For example, if a lateral approach is selected, the patient should be positioned in a lateral decubitus position with the side to be treated in the up position. The lateral approach may not be as advantageous if a bilateral injection is planned due to the need to reposition the patient in the opposite lateral decubitus position to target the contralateral side. On the other hand, if a posterior approach is planned, positioning the patient in the prone position is recommended. In the prone position, placing a pillow under the chest or forehead can assist in positioning. Alternatively, commercial cervical pillows with an opening for the face are available and can be useful to achieve moderate flexion of the cervical spine.

Proper sterile technique should be followed. The skin overlying the targeted area is prepped with an antiseptic solution (chlorhexidine and alcohol or povidone-iodine) and then draped. The proceduralist should be in appropriate attire including a surgical cap, mask, and protective lead (for fluoroscopic guidance). Hands should be washed and sterile gloves used.

1. Fluoroscopically Guided Technique

   (a) Medial Branch Nerves C3–C6

   In the lateral approach, lateral fluoroscopic views are obtained and optimized such that the bilateral articular pillars of the target level(s) are superimposed. The needle target is at the geometric center of the articular pillar. The overlying skin is anesthetized. A spinal needle (usually a 25 or 22 gauge) is then advanced coaxially under intermittent fluoroscopic guidance toward the center of the articular pillar where the media branch nerve courses. Bony contact is then made. An AP view can be obtained to demonstrate the medial-lateral position of the needle tip. Then, 0.5 mL or less of a local anesthetic is injected after negative aspiration. The procedure is repeated for each medial branch nerve targeted. Then the needles are removed, the skin is cleaned, and a bandage is applied.

If the posterior approach is used, AP fluoroscopic views are initially obtained to visualize the articular convexities or "waists" of the targeted level(s). Local anesthesia is used to anesthetize the skin of the posterior neck. A spinal needle is then advanced ventrally under intermittent fluoroscopic guidance toward the lateral-most aspect of the articular pillar at the articular waist. Depth of the needle is then confirmed in the lateral view. The lateral view should be optimized such that the bilateral articular pillars are superimposed. The needle is then advanced ventrally until the needle tip is at the geometric center of the articular pillar. After negative aspiration, 0.5 mL or less of local anesthetic is then injected. The procedure is repeated for each medial branch nerve targeted. Then the needles are removed, the skin is cleaned, and a bandage is applied.

(b) C7 Medial Branch Nerve

The course of the C7 medial branch nerve is slightly different than that of the C3 through C6 nerves in that the C7 medial branch nerve usually passes forward over the bony surface of the superior articular process of the C7 vertebra, somewhere between its peak and the base of the transverse process, and in some individuals, it is more superficial to the bone rather than immediately adjacent to it [40]. Therefore, the above-described techniques are adjusted to target location of the C7 medial branch nerve. Thus, the target point of the needle is at the lateral aspect of the curved surface of the articular process up near its peak (in the lateral fluoroscopic view, appears more cephalad and ventral compared to C3–C6). Injection of local anesthetic at the bony surface is carried out, and then the needle is withdrawn about 4 mm, and another injection of local anesthetic is made.

(c) Third Occipital Nerve (TON) to the C2–C3 Facet Joint

The C2–C3 facet joint is innervated by a single nerve, the third occipital nerve. The general course of the TON is that it passes horizontally across the C2–C3 joint, somewhere between the superior and inferior aspect of the foramen. There are three target points for blocking the TON which lie in a vertical line over the middle of the joint in the lateral view:

(i) A high one at the level of the apex of the C3 superior articular process
(ii) A low one at the level of the bottom of the C2–C3 foramen
(iii) A middle one halfway in between the other two

The TON can be targeted via the lateral or posterior approach similar to the C3–C6 medial branch nerves as describe above.

2. Ultrasound-Guided Technique

For ultrasound-guided TON block, the mastoid process is identified by palpation, and the superior end of a longitudinally oriented high-frequency linear ultrasound transducer is placed at the inferior border of the mastoid process and is identified. Then, moving the transducer about 0.75 inches in a posterior direction, the arch of C1 and the articular pillar of C2 are identified. Slowly moving

the transducer caudally, the C2–C3 joint is visualized. The TON can be visualized superficial to the C2–C3 joint.

Beginning at the C2–C3 joint, subsequent facet joints are identified with this process by moving the transducer caudally while counting the "hills" which represent the articulations of each facet joint. Once the targeted facet joint levels are identified, the transducer is rotated toward the external acoustic meatus until the medial branch nerve is identified in the "valley" between the adjacent facet joints. The medial branch nerve will appear as a hyperechoic dot surrounded by a hypoechoic halo.

Once the targeted TON or cervical medial branch nerve is visualized, a 3 ½-inch spinal needle is inserted through anesthetized skin anterior to the transducer in an out-of-plane approach and is advanced with an anterior to posterior trajectory toward the TON or medial branch nerve. Once the needle tip is adjacent to the nerve, and after negative aspiration, 0.5 mL or less of local anesthetic is injected and can be visualized surrounding the nerve [41].

Once the procedure is completed, the needles are removed, the skin is cleansed, and adhesive dressings can be applied. The patient should be transported to an observation area and monitored. The patient's index pain and pain level should be assessed and compared to the duration of the local anesthetic utilized in order to determine the diagnostic result. It has been recommended to perform two separate diagnostic blocks on separate occasions to decrease false-positive results [42].

Radiofrequency Ablation Technique

Radiofrequency ablation (RFA) of the medial branch nerves, also known as radiofrequency medial branch neurotomy and facet joint denervation with the use of radiofrequency technology, is a treatment that evolved from earlier concepts of trying to alleviate facet joint pain by interrupting the nerves that transmit pain signals from the joints. Initially, denervation of the facet joints was attempted by injection of phenol [43], by cryotherapy [44], and by surgical neurectomy [45], but these attempts either failed to provide relief or had unwanted and unacceptable side effects such as neuroma formation and deafferentation pain. Radiofrequency ablation of the medial branch nerves has subsequently evolved over the last several decades. The (International) Spine Intervention Society has published practice guidelines that describe the most effective technique, [46] variations of which will be discussed here. This technique involves placing a radiofrequency electrode adjacent and parallel to each medial branch nerve to be targeted. This is followed by applying radiofrequency energy to coagulate a length of the nerve along its accessible course, thereby changing the chemical nature of the nerve fibers without changing the structure (like boiling an egg), such that they cannot conduct pain signals.

In addition to the facilities and equipment needed for medial branch nerve blocks, one will need a radiofrequency generator capable of generating a thermal radiofrequency field, specialized insulated needles with exposed active tips, radiofrequency probes, and a return plate (grounding pad).

Similar to the performance of cervical medial branch nerve blocks, a preprocedure assessment should be performed. The patient is then taken to the procedure room and positioned as one would for a medial branch nerve block. Proper sterile technique should be followed. The skin overlying the targeted area is prepped with an antiseptic solution (chlorhexidine and alcohol or povidone-iodine) and then draped. The proceduralist should be in appropriate attire including a surgical cap, mask, and protective lead (for fluoroscopic guidance). Hands should be washed and sterile gloves used.

Similar patient positioning is used for radiofrequency ablation as is for medial branch nerve block. Fluoroscopic guidance of the needle is similar as well. The needles utilized come in different gauges and lengths of exposed tips, and some have specialized exposed tips to create larger lesion sizes. Most often, 18, 20, or 22 g insulated needles with 5 mm or 10 mm exposed active tips are utilized for cervical medial branch nerve radiofrequency ablation. The exposed active tip of the needle is advanced through the anesthetized skin and positioned adjacent and parallel to the course of the medial branch nerve targeted with the tip of the needle at the geometric center of the articular pillar in the lateral view. In the AP view, the needle should be adjacent to the bone of the articular waist of the pillar.

After confirmation of proper needle placement, a radiofrequency probe is placed into the needle, and sensory stimulation at 50 Hz is carried out. The patient should report stimulation and recapitulation of their index pain between 0.1 and 0.5 V. Then motor stimulation at 2 Hz is carried out at 2 to 3 V. There should be no stimulation of the upper extremity at 2 to 3 times the voltage required for sensory stimulation. If upper extremity motor stimulation is identified, the needle must be repositioned away from the cervical nerve root. Once sensory and motor testing have been performed with appropriate findings, and after negative aspiration, then local anesthetic (lidocaine 2% × 1 mL) is injected. After waiting for the local anesthetic to take effect, a radiofrequency lesion is made at 80 degrees Celsius for 60–90 seconds. If the patient experiences any pain or discomfort during the lesion process, the lesioning should be halted, and more local anesthetic should be injected, or more time should be given for the local anesthetic to take effect. Once the lesion is complete, the needle is then repositioned in parallel superiorly and inferiorly by about 2–3 mm, and additional lesions are made. This technique is repeated at each targeted level. This technique is also adapted to the TON and C7 medial branch nerve block given their aforementioned anatomic considerations.

At the end of the procedure, prior to removing the needles, a long-acting local anesthetic, such as bupivacaine 0.5% × 0.5 mL, can be injected with or without a corticosteroid such as dexamethasone for patient analgesia. The needles are removed, the skin is cleansed, and adhesive dressings are applied. The patient should be transported to an observation area and monitored, and a cold pack can be applied.

The American Society of Interventional Pain Physicians published comprehensive evidence-based guidelines for facet joint interventions for the management of chronic spinal pain [47].

Complications

Complications of cervical radiofrequency ablation are rare, but possible complications may include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect. Further a dysesthesia, "sunburn"-type feeling, may be described following cervical RFA which has been found to be self-resolving. Although the risk for cervical nerve root damage is present, it can be mitigated by the use of safe technique under fluoroscopic guidance and sensory and motor testing prior to lesioning.

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Chapter 7
Thoracic Spine

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Anatomy

Structure and Function

The zygapophyseal (facet) joints are synovial joints located between the articular processes of each lamina and provide stability of the spine while limiting the excursion of each motion segment. The structure of this joint changes from the upper, mid- and lower thoracic segments. There are two joints (z joints) within an intervertebral disc and with their respective ligaments form a stable motion segment between two adjacent vertebrae allowing for range of motion of the axial spine. The articular facets are covered by cartilage, and the joints are engulfed in a fibrous capsule lined with synovium and synovial fluid with an estimated volume of 1 cc or less. Each facet reveals fibrous annular menisci that likely originate medially from the ligamentum flavum or laterally from the joint capsule. This likely generates pain with distraction and/or inflammation. The orientation of the facet joint in the upper thoracic spine is similar to the cervical spine in that the joint line is relatively flat with a slight forward slope, while the lower thoracic segments mimic the lumbar facet

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_7

orientation. All thoracic joints are in the frontal plane and vary between 0 and 30 degrees from vertical, allowing for movement in all three planes. The innervation of this joint is from the ramus medialis of the thoracic rami dorsalis or medial branch nerve. Each thoracic facet joint accepts innervation from two medial branch nerves: the exiting somatic nerve at the adjacent level and the descending medial branch nerve from above. For example, the T7–T8 facet joint is innervated from the descending T6 and T7 medial branch nerves. The location of the medial branch nerve in the thoracic spine typically correlates with the superior lateral edge of the transverse process from T1 to T10. The exception is T11–T12 which has similar landmarks to the lumbar medial branch orientation at the junction between the superior articular process and the transverse process.

Clinical Significance

Following systematic review of therapeutic thoracic facet joint interventions, evidence for therapeutic thoracic facet joint nerve blocks is fair. The evidence for intra-articular injections of the thoracic facet is not available, and due to lack of literature, the use of radiofrequency neurotomy in the thoracic spine is limited. The indication for thoracic medial branch nerve injections is to aid in the diagnosis and treatment of axial thoracic spine pain originating from osteoarthritis and joint sprains from both degeneration or inflammation. Due to the unreliability of conventional radiographic imaging, controlled local anesthetic blocks of the medial branch nerves are considered the most reliable means of diagnosis (Fig. 7.1). With the high variability of evidence for radiofrequency neurotomy, it is critical to appreciate the anatomical difference in the trajectory of the medial branch nerve from T1 to T10 at the superior lateral border of the transverse process (Fig. 7.2). In addition, the use of sensory stimulation prior to rhizotomy can aid in optimizing needle placement and will be discussed further in this chapter.

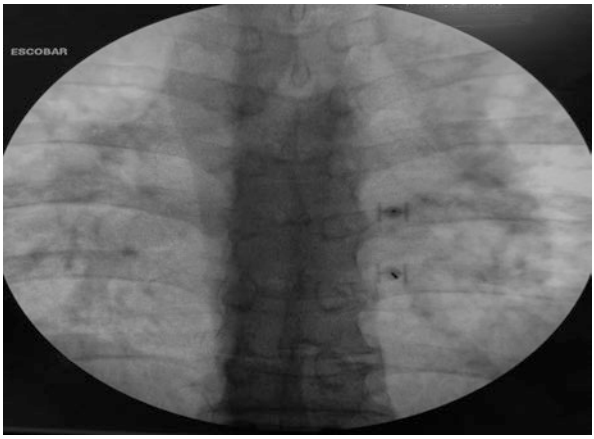

Fig. 7.1 Escobar A diagnostic medial branch block of the right T7–T8 facet joint (Medial branch of T6, T7)

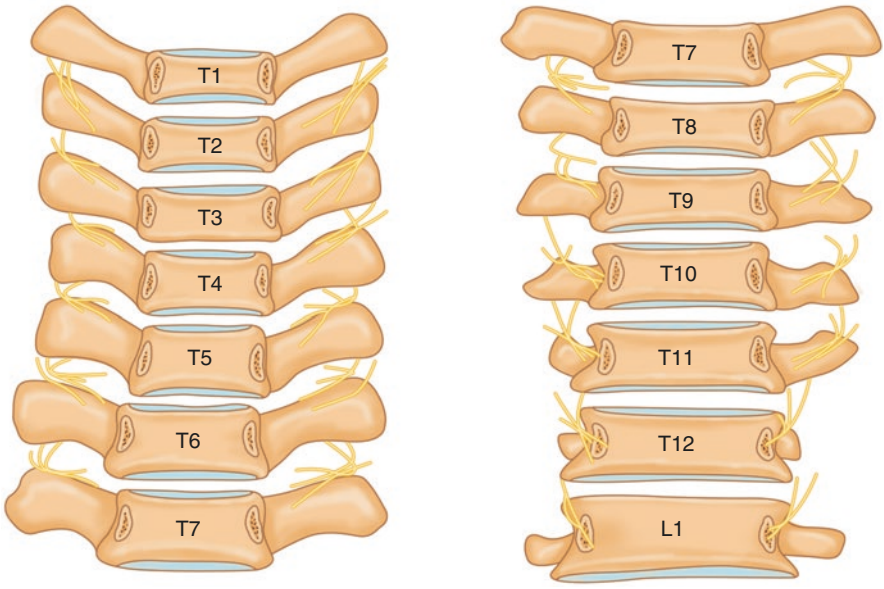

Fig. 7.2 Bogduk N (ed)

Conclusion

The knowledge of anatomy of the thoracic facet joints is critical to understanding the best practices of thoracic facet joint radiofrequency ablation. The interventional physician should understand normal anatomy, disease processes, and radiological anatomy and variation.

Work-Up

Clinical Presentation

The workup of thoracic pain starts with a thorough history and physical examination followed by the indicated laboratory and diagnostic tests. The clinician should give consideration to the patient's comorbidities, risk factors, symptoms, and pain referral patterns with an attention to acuity. Specifically, the clinician should first rule out any life-threatening etiologies, such as cardiovascular, pulmonary, or neurologic pathologies. For example, a thoracic aortic aneurysm rupture or dissection should be suspected in an elderly patient with a history of atherosclerosis and poorly controlled hypertension presenting with acutely worsening back pain. In a patient on anticoagulation with new-onset neurological deficits, one should rule out an

epidural hematoma. Spinal cord injury needs to be ruled out in a trauma patient with new neurologic dysfunction or anatomical abnormalities or compression fractures or if there is a question of spinal column metastases. If any of these potentially life-threatening pathologies are suspected, the clinician should obtain appropriate imaging modalities and prompt coordination of care.

Once urgent conditions are ruled out, the clinician may consider other etiologies of thoracic pain. A thorough history and physical exam alone may guide the clinician to the diagnosis. For example, neuropathic pain complaints in a thoracic dermatomal distribution with a history of herpes zoster rash may be sufficient to suggest post-herpetic neuralgia. At other times, the clinical presentation may warrant further investigation. Skeletal deformity on examination is an indication for imaging to assess for mechanical instability, scoliosis, kyphosis, and fractures. If the presentation indicates myelopathic or radicular pain, a sympathetic slump test and upper quarter screen may be employed along with imaging, electrodiagnostic tests, and possibly laboratory data.

The most common causes of localized thoracic back pain in a non-dermatomal distribution are muscle pain and zygapophysial joint pain. Zygapophysial joint pain, or facetogenic pain, usually presents with localized pain over the affected levels with radiation in a non-dermatomal distribution. Facetogenic pain is less common in the thoracic spine when compared with cervical and lumbar spondylosis. The prevalence of facet-mediated thoracic pain is reported around 42% [1], although this number is somewhat controversial given the lack of objective diagnostic reference methods. A patient's history, physical examination, and imaging may suggest facet joint syndrome, but do not confirm the diagnosis. Facet arthropathy is the most frequent form of facet pathology. Facet arthropathy is more common in patients over 50 years of age and generally follows a progressive clinical course rather than an acute process [2]. Patients may complain of pain exacerbated by maneuvers of extension and rotation that is alleviated by flexion. In comparison to radicular pain, facetogenic pain does not usually present with neurological findings such as weakness or sensory deficits. In 2012, Cohen et al. reported in *Nature Reviews Rheumatology* that the only physical exam finding that correlates with facet arthropathy is paraspinal tenderness, which was only a weak association. The term "facet loading", which places increased pressure on facet joints by having the patient extend and rotate the spine, is no longer considered a reliable physical exam sign to support facet related pain. The concept of "facet loading" was developed from a small retrospective study, but larger higher-quality studies were not able to replicate the findings. Although imaging is often ordered when the clinical presentation suggests facetogenic pain, there are no studies supporting effective clinical correlations between symptoms and degenerative changes from imaging. Medial branch nerve blocks and intra-articular blocks have been used to support the diagnosis of facet-related pain generators [3, 4]. However, these blocks do not confirm the diagnosis of facet-mediated pain but rather suggest a prognostic response to radiofrequency ablation [4–8].

Diagnostic Laboratory Tests

Blood tests are not routinely ordered in the workup for thoracic back pain, unless the clinical picture points toward an infectious and/or inflammatory etiology (e.g., history of IVDU, active tuberculosis, systemic lupus erythematosus). For example, if there is a suspicion of osteomyelitis, then acute phase reactants and a complete blood count are indicated along with appropriate imaging. If the clinical picture points toward an infectious etiology, then the appropriate laboratory tests and imaging should be obtained (e.g., CRP, WBC, radiographs).

Electrodiagnostic Procedures

Electrodiagnostic studies are very sensitive indicators of peripheral and central nervous system pathology. These tests can aid in the diagnosis but do not identify the underlying disease process. Electrodiagnostic tests commonly assist in the diagnosis of peripheral neuropathy, diabetic neuropathy, and radiculopathies but cannot determine the underlying cause (e.g., herniated disc, osteophytes). Electromyography (EMG) distinguishes if muscle weakness is due to the nerve that supplies its respective motor innervation. In EMG, fine needles are inserted into the muscle of interest to measure the muscle's electrical activity upon stimulation from the brain or spinal cord. Nerve conduction studies (NCS) are used to detect nerve damage. During the procedure, two sets of electrodes are used to stimulate the nerve that innervates the muscle of interest. The electrical signals of the nerve that is being stimulated are recorded. EMG/NCS studies are used to identify the anatomical location of injury, the type of nerve fibers involved, severity of injury, and pathological entity. Evoked potential studies measure the time it takes for the brain to respond to sensory stimulation, which is useful for evaluating whether there is a nerve conduction pathology in question (e.g., multiple sclerosis). Two sets of electrodes are used. One set of electrodes stimulates a sensory nerve. A second set of electrodes is placed on the scalp to record the speed of nerve signal transmission to the brain.

Quantitative sweat testing (QST) and sympathetic skin response (SSR) are useful if painful diabetic neuropathy or complex regional pain syndrome is in question. Laser-evoked potentials (LEPs) and contact heat potentials (CHEPs) provide an objective assessment of the function of the spinothalamic tract. Laser-evoked potentials generate radiant heat and activate A∂ and C nociceptor fibers in the spinothalamic tract, where pain and temperature sensations are transmitted to the cerebral cortex. When there is a lesion in the spinothalamic tract, small fiber neuropathy, for example, LEPs, will be abnormal.

Diagnostic Imaging Tests

Radiography can be used in the initial evaluation of mechanical instability, skeletal deformities (e.g., scoliosis), and fractures. Computerized tomography (CT) scans can detect soft tissue structures that may not be seen on radiography, such as intervertebral disc ruptures, spinal stenosis, tumors, and facet arthrosis. CT scan is the most sensitive for detecting facet arthrosis. Magnetic resonance imaging (MRI) is used to evaluate bony structures and soft tissues, including discs, ligaments, tendons, musculature, the spinal cord, and nerve roots as well as the neuroforamen. MRI may reveal ligamentum hypertrophy, epidural fibrosis, disc herniation or rupture, and impingement of the spinal cord or nerve roots, including the degree of stenosis of the central canal, lateral recess, and/or neuroforamen. An MRI may also be ordered if there is a suspicion for an infection, tumor, or inflammatory process as outlined in Table 7.1. Ultrasonography (US) is increasingly being used for diagnosis of neuromusculoskeletal conditions given its superior safety profile and ability to directly image muscles and nerves. US is particularly useful if nerve entrapment is suspected. US can effectively localize the area of impingement. In addition to its diagnostic capabilities, US can be used for image-guided procedures.

Diagnostic Imaging Procedures

Myelograms are used to enhance radiographs and CT scans. Contrast dye is injected into the intrathecal space, which aids in the evaluation of spinal cord or nerve compression on radiograph or CT scan. Discography may be employed when the intervertebral disc is thought to be the cause of pain. During discography, contrast dye is injected through a needle placed into the disc to evaluate disc integrity and provocation of patient's pain. Computerized tomography scans taken immediately after dye injection should show the areas of damage. Bone scans can detect and monitor bone disorders such as osteomyelitis or a vertebral fracture. Radioactive dye is injected into the blood stream, which will collect in specific areas of irregular bone metabolism or abnormal blood flow.

Image-guided selective nerve root blocks may be employed to identify a specific nerve in question. The most reliable diagnostic methods for determining facet-mediated pain is with image-guided medial branch blocks or intra-articular facet joint blocks [9]. Intra-articular injections or medial branch blocks have limited diagnostic utility and hence better serve as prognostic indicators of response to radiofrequency lesioning of the medial branches of the posterior ramus [9, 10, 12–15].

There are several limitations of the utility of intra-articular and medial branch blocks. Specifically, both blocks have a high false-positive rate. The false-positive

Table 7.1 Differential diagnosis of thoracic pain

Skeletal deformity:
Scoliosis
Kyphosis
Fractures (e.g., vertebrae and ribs)
Muscular/myofascial:
Fibromyalgia
Muscular trauma, sprain, or strains
Myofascial
Neuroma with trigger points
Mechanical degeneration
Inflammatory arthritis:
Ankylosing spondylitis
Rheumatoid arthritis
Spondylitis
Facetogenic:
Facet arthrosis
Intraspinal facet cysts
Discogenic
Herniated intervertebral disc
Vertebrogenic
Vertebral compression fracture
Neoplasms (e.g., metastasis from lung, breast, or prostate cancer)
Central neuropathic pain:
Thalamic pain syndrome
Post-stroke pain
Post-spinal cord injury pain
Peripheral neuropathic pain:
Post-herpetic neuralgia (PHN)
Painful diabetic neuropathy (PDN)
Complex regional pain syndrome (CRPS)
Spinal cord and nerve root:
Spinal cord injury (SCI)
Spinal epidural hematoma
Paraspinal hematoma
Herniated or ruptured disc
Spinal stenosis
Spondylolysis
Spinal cord inflammation:
Multiple sclerosis
Systemic lupus erythematosus
Guillain-Barre syndrome
Chronic postsurgical pain:
Chronic post-thoracotomy pain (incidence 33–91%) [16, 17]
Chronic post-mastectomy pain (incidence 20–72%) [18–23]
Phantom breast pain (incidence 10–55%) [24]
Chronic thoracic pain after cardiac surgery [25]

(continued)

Table 7.1 (continued)

Miscellaneous:
Infectious:
Osteomyelitis (e.g., *Staphylococcus aureus* in intravenous drug use)
Discitis
Pott disease, also known as tuberculous spondylitis
Herpes zoster virus or post-herpetic neuralgia
Cardiovascular
Myocardial infarction, or demand ischemia
Thoracic aortic aneurysm rupture or dissection
Refractory angina
Pulmonary
Pneumonia
Pneumothorax
Pulmonary embolism
Gastrointestinal (e.g., peptic ulcer disease)
Kidney injury or kidney stones
Retroperitoneal hematoma

rate of medial branch blocks in the thoracic spine was reported at 55% for single blocks using lidocaine [7]. False-positive blocks may be seen with injectate volumes as small as 0.5 mL since this volume may spread over 6 square centimeters leading to inadvertent blockade of the intermediate and lateral branches along with the medial branches [11]. In the case where inadvertent blockade occurs, the paraspinous musculature may be the pain generator rather than the facets. Other causes of false-positive medial branch blocks include placebo response, excessive superficial local anesthetic injection, and the use of sedation [8]. In general, most studies point toward medial branch blocks providing superior prognostic value over intra-articular blocks for radiofrequency denervation [10].

Technique

The prevalence of thoracic facet-mediated pain, and pain originating from other anatomical structures in the thoracic spine, is less of that found in the cervical and lumbar spine [26–28]. Nonetheless, it causes significant morbidity and limitation to those suffering from it [29–31]. Zygapophyseal joints have been reported to be the source of chronic thoracic pain in 43 to 48% of those patients [26, 27].

The course of the thoracic medial branches varies depending on the vertebral level, and it differs from lumbar medial branches, which course closer to the superior articular process, in that they are expected to run from the superolateral to the inferomedial corner of the transverse process [3]. Therefore, for most thoracic levels, the best radiological landmark to place the needle for a diagnostic block or radiofrequency (RF) denervation should be closer to the superolateral corner of the thoracic vertebral transverse process (Fig. 7.3).

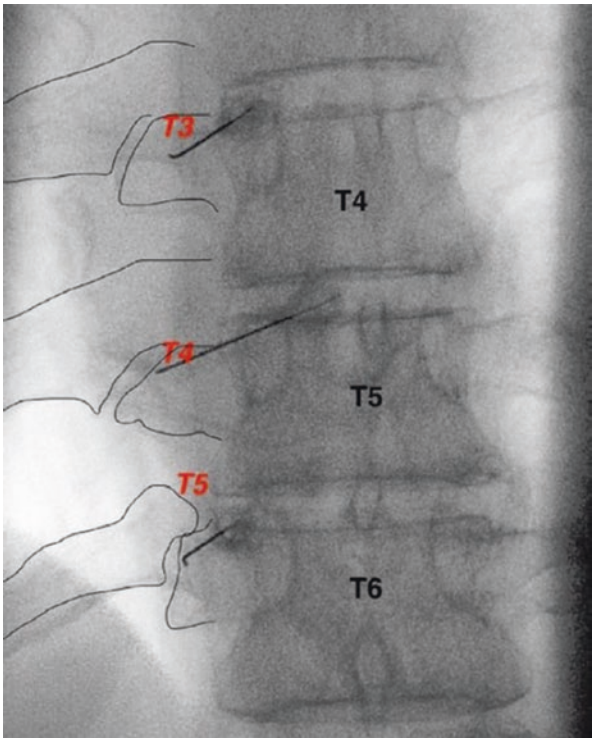

Fig. 7.3 From: Sanders [34] diagnostic medial branch block of the left T4-T5-T6 facet joint (Medial branch of T3, T4, T5)

The targets at the mid-thoracic spine (T5–T8) might be less reliable since the nerves at these levels pass to the posterior compartment through the intertransverse space. This challenge will require altering the technique by varying the angle of needle placement, performing multiple needle positionings, and achieving larger lesions by, for example, using cooled radiofrequency [32] or by considering sensory testing prior to performing a denervation. As lower thoracic levels approach the upper lumbar levers, the location of these branches may be assumed to approximate the location of lumbar medial branch targets.

Thoracic Medial Branch Blocks: Technique

As it is the case in the in the lumbar and cervical spine, anesthetic blockade of the thoracic medial branches will aid in the diagnosis of thoracic pain originating from the facets joints, and it will be predictive of response to medial branch radiofrequency ablation.

As discussed previously, the cadaveric study by Chua et al. [3] established that thoracic medial branch nerve location varied among thoracic levels, and it was

different to that of the lumbar levels. Since this publication, and as depicted in Fig. 7.3, it has been assumed that:

1. The medial branches of T1 to T3 typically descend across the dorsal surface of the inferior transverse process.
2. The medial branches from T4 to T8 pass through the intertransverse space and most likely can be found in the proximal one-third and superior to the transverse process.
3. The superolateral aspect of the transverse process is the anatomical target for thoracic medial branch blocks from T9 to the T10 level.
4. For the T11–T12 levels, the target remains similar to that of lumbar medial branches, that is, closer to the confluence of the superior articular process (SAP) and the transverse process.

The guidance described above should be used to identify the targets with intermittent and low-dose multi-planar fluoroscopic guidance. The use of collimation will improve image contrast by attenuating the effects caused by the lungs. The superolateral corner of the transverse processes should be used as a safe depth landmark for the placement of a 22- or 25-gauge spinal needle and to avoid pneumothorax. A small amount of contrast may be used to confirm lack of vascular uptake while confirming appropriate spread of the injectate. To increase diagnostic value, a small volume of local anesthetic (0.5 ml) should be used. There is a high false-positive rate following medial branch blocks; therefore, performing a second diagnostic procedure with concordant pain suppression is recommended. Commonly, lidocaine is used for the first diagnostic block, and a response of at least 70% pain reduction for the duration of the anesthetic effect (1–2 hrs.) is expected to consider it a valid test. A second blockade using bupivacaine with the same pain suppression parameters and with a duration of effect of this anesthetic (4–8 hours) should follow.

Thoracic Medial Branch Radiofrequency Ablation: Technique

With ensuring accurate diagnostic response to thoracic medial branch blocks, RF ablation will be indicated. Regardless of the type of radiofrequency used, the angle in which the RF cannula is placed is more critical than that of the needle in the diagnostic block. To increase the likelihood that the lesion will cover the path of the medial branch, and understanding that most RF cannulas project the bulk of the thermal lesion lateral to the active tip, placement of the needle more parallel to the targeted medial branch is imperative [33]. This will require more shallow and planned angles of attack that differ depending on the levels to be treated:

From T1 to T4 and T9 to T10, the RF cannula should be angled so that the active tip covers the superior lateral edge of the corresponding inferior transverse process.

From T5 to T8, the RF cannula should be angled toward the proximal one-third of the inferior transverse process and then directed slightly cephalad.

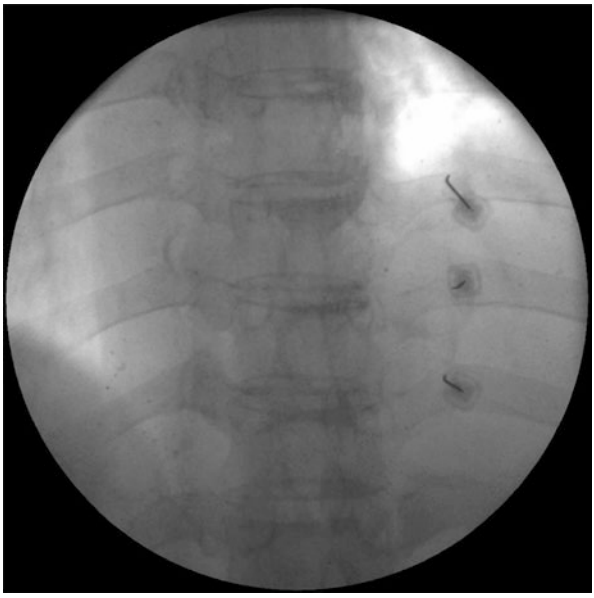

Fig. 7.4 Fluoroscopy-guided radiofrequency on the right T7, T8, and T9 thoracic medial branches. (From: Chang [35])

For T11–T12, the RF cannula should be angled toward the confluence of the SAP and the inferior transverse process.

As with the diagnostic blocks, while using anterior posterior fluoroscopic views, contacting the periosteum at the superolateral corner of the transverse processes should be used as a safe depth landmark during the initial approach; oblique and lateral fluoroscopic views will confirm proper placement and reduce the chance of a pneumothorax. From this starting point, the cannula is rotated and passed over the superior border of the transverse process and slowly advanced 2–3 mm with an angle that will depend on the level as it is described above (Fig. 7.4). Other factors that influence the lesion size, and therefore therapeutic outcomes, are the time and temperature applied for lesioning, type and size of RF needle, the number of lesions performed, and the use of either saline or local anesthetic prior to starting RF. The principles guiding the use of impedance checks, sensory and motor testing, are the same as for the RF treatments in the other segments of the spine.

Complications

Although complications of thoracic radiofrequency ablation are rare, they include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation neuritis. Unique complications for all thoracic interventional spine procedures include inadvertant pleural puncture causing a pneumothorax or hemothorax, that manifests primarly as dyspnea and ipsilateral chest pain, and can be safely managed if identified and treated promptly.

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Chapter 8
Lumbar Spine

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Anatomy

The facet joint is a diarthrodial joint connecting the inferior articular process to the super articular process of two adjacent vertebrae [1]. The joint is composed of an articular cartilaginous surface with a synovial fold, encapsulated by a fibrous capsule that provides a low-friction interface to facilitate motion (Fig. 8.1). At a microscopic level, the capsule is composed of two layers, a denser collagenous outer layer and an elastic inner layer. The outer collagenous fibers demonstrate complex orientations—superiorly, the fibers are oriented medial to lateral to resist distraction, whereas inferiorly, the fibers are oriented inferior to superior to limit forward rotation [2]. This outer layer is structurally reinforced by the multifidus muscle [2].

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_8

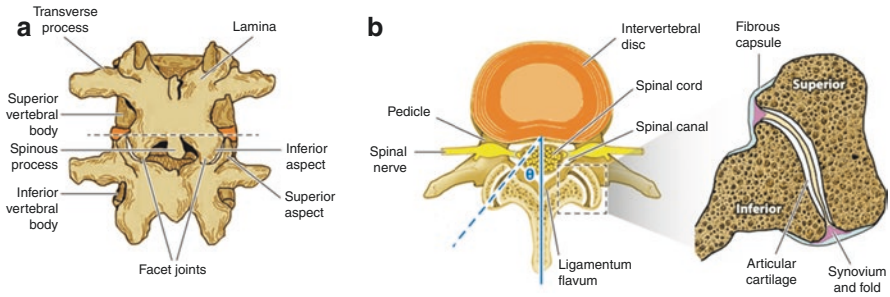

Fig. 8.1 Facet joint anatomy. (**a**) Posterior view of the motion segment. (**b**) Axial view of the motion segment and a closer look (*right*) at the facet joint and its individual components Sagittal orientation angle (θ) refers to the facet joint's orientation with reference to the sagittal plane

Function

Due to its intricate structural construction, facet joints function to support the stability of the spine while preventing injury by limiting excessive motion. Their sagittal orientation arises from the superior articular process facing dorsomedially, with the inferior articular processes directed ventrolaterally, supporting both compressive loads and structural blocks to motion [4]. Furthermore, this sagittal orientation allows for flexion and extension while limiting extreme side-to-side range of motion. This intrinsic stability protects the neural elements from potentially dangerous motions, such as excessive torsion, shear, or translation [2].

Innervation

Histologic studies have demonstrated that the lumbar facet joints are richly innervated with encapsulated, unencapsulated, and free nerve endings [5]. This innervation provides both nociceptive and proprioceptive feedback to the brain. Nociceptive information is transmitted through C and A-δ afferents, while low-threshold, rapidly adapting mechanoreceptors transit proprioceptive information [6]. Various substances and peptides had been implicated as the carrier of neuronal messages by facet nerve endings. Substance P, calcitonin-gene-related peptide, and neuropeptide Y are found in nociceptive fibers [6, 7]. Most of these substances are also found in sympathetic nerve transmission peptides, hence supporting findings that it has sympathetic nerve supply. Inflammatory mediators such as prostaglandins and the inflammatory cytokine interleukin 6 and tumor necrosis factor have been found in facet joint cartilage and synovial tissue [6].

Biomechanics

Together, the intervertebral disc and the facet joints connect the adjacent vertebrae, stabilize the spine, and facilitate articulation. The inferior articular process transverses caudal from the lamina and meets the superior articular process of the adjacent vertebrae forming the facet joint, as shown in Fig. 8.1a. Primary constituents of the facet joint include the subchondral bone, articular cartilage, synovium, and fibrous capsule, as shown in Fig. 8.1b [3]. In general, the orientation of the facet joints at each spinal level varies in the cervical, thoracic, and lumbar region in order to modulate range of motion and effective load bearing to maintain spinal function at those levels. Due to this regional dependence, relative to the sagittal plane, the orientation of the articular surfaces (angle θ), for which these protrusions provide support, changes from one spinal level to the next (Fig. 8.1b) [3]. The largely sagittal orientation of the lumbar facet joint, in combination with the high degree of mutual convexity and concavity of the opposing joint surfaces in this region, gives it a "C" shape [3, 8]. Biomechanically, this permits a greater range of motion in terms of flexion but higher resistance to axial rotation and lateral bending [4].

(i) Dual Innervation
Each facet joint receives dual supply of innervation from two medial branch nerves: one arising at the given level and one from one segment above (Fig. 8.2). For example, at the L4–L5 level, the exiting L4 nerve root gives rise to the dorsal primary ramus, which in turn gives rise to the medial branch at that level. This L4 medial branch will transverse onto the superior articular process of L5 under the mamilloaccessory ligament, where it will innervate the caudal portion of the L4–L5 facet joint. The descending branch of the L4 medial branch will

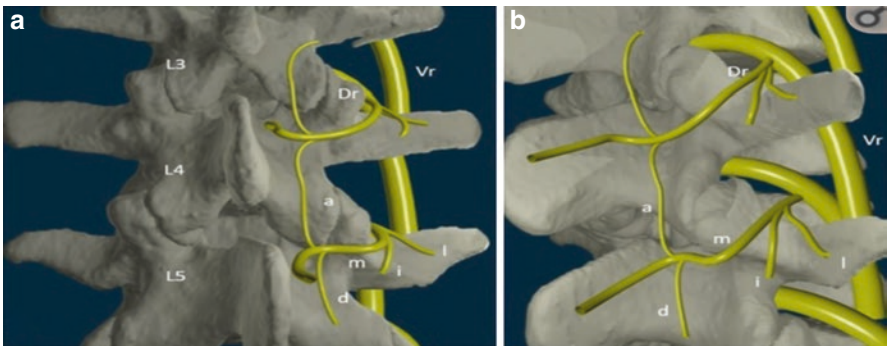

Fig. 8.2 Innervation of facet joints (L3–4, L4–5 levels). Vr ventral ramus, Dr Dorsal ramus, m medial branch, i intermediate branch, l lateral branch, a ascending branch, d descending branch, Pasterior (**a**) and Posterolateral (**b**) view of the lumbar spine [9]

transverse to the next level for innervation of the superior portion of the L5–S1 facet joint. The L5 innervation is unique, in that, the exiting L5 nerve root gives rise to the dorsal ramus itself that runs along the junction of the sacral ala and superior articular process of the sacrum [6]. At this level, it is the L5 dorsal primary ramus, rather than the medial branch, that is the target for blockage and ablation.

Lumbar Pain

Work-up

Facet joints, discs, and the sacroiliac joints can all be a source of chronic low back pain. Lumbar facet joints have been shown to be the most common source of chronic low back pain (compared to discs and sacroiliac joints) with a prevalence of 21–41%. It is by far the most common source of chronic low back pain in the >65- years-old population [10–13]. Microfractures and cartilage tears have also been shown to a source of facet-mediated pain, but this is less common, but these are usually seen in the acute low back pain setting and cannot be detected by routine imaging [14]. Diagnosing the facet joints as the source of pain in patients suffering from low back pain includes history taking, a physical exam, imaging, and diagnostics blocks, with diagnostic blocks being the most specific and sensitive test for confirming facet-mediated low back pain.

History and Physical Exam

Facet-mediated low back pain is most commonly characterized as axial low back pain that does not radiate beyond the knees and is worsened by maneuvers that place excess stress on the facet joints such as extension and lateral rotation; however, history and physical exam are still poor diagnostic indicators of facet-mediated low back pain when compared to diagnostic facet blocks [15, 16]. Among patient-reported symptoms, absence of radiating pain below the knee and absence of pain with Valsalva maneuver have been shown to correlate with a positive response to diagnostic facet blocks [15, 17]. Revel and colleagues used 7 criteria (Table 8.1) to assess lumbar facet- mediated pain and compared it to diagnostic facet blocks and found that patients with five out of seven symptoms correlated with a positive response to intra-articular diagnostic facet blocks with a sensitivity of 92% and specificity of 80% [18]. However, Laslett and colleagues reported low sensitivity and high specificity using Revel's criteria and did not recommend it as a screening tool.10 Age over 65 -years-old has been shown to correlate with a positive diagnostic facet block [18–20].

Table 8.1 Revel's Criteria to asess lumbar facet-mediated pain

Revel's criteria (presence of 5 of 7 variables)
Age over 65 years
Pain well relieved by recumbency
Pain not exacerbated by coughing
Pain not exacerbated with forward flexion
Pain not exacerbated with hyperextension
Pain not exacerbated with flexion
Pain not exacerbated with extension-rotation

In terms of physical exam findings, isolated low back pain with straight leg raise test, localized paraspinal tenderness, and reproduction of pain with extension-rotation has been shown to weakly correlate with a positive response to diagnostic facet blocks [15, 21–24]. However, other studies have shown no correlation with pain reproduction with extension-rotation, back pain with straight-leg raise test, as well as other physical exam manuevers [25–27].

Ultimately, the gold -standard for diagnosing facet-mediated low back pain comes down to diagnostic facet blocks.

Imaging

The role of radiologic imaging in diagnosing lumbar facet-mediated pain is controversial. Most of the studies published evaluate the use of single- photon emission tomography (SPECT) [28]. Studies looking at the correlation between response to diagnostic facet blocks or injections and SPECT results are mixed [16, 24, 29–34].

Studies looking at magnetic resonance imaging findings of facet pathology have also had mixed results when correlating with lumbar facet medial branch blocks, intra-articular injections, and radiofrequency ablation. Stojanovic and colleagues studied 127 patients and found a correlation between findings of facet degeneration or hypertrophy and > 50% relief following a diagnostic medial branch block ($p = 0.04$), but did not find any correlation between MR findings and relief with radiofrequency ablation [35]. In addition, Cohen et al. did not find correlation between MR findings and radiofrequency ablation responses [27].

The role of computed tomography (CT) in identifying patients with facet-mediated low back pain was studied by Schwarzer and colleagues [16]. They took 63 patients and had them undergo a CT scan followed by diagnostic intra-articular facet joint injections. There was no significant correlation between CT findings and response to facet joint injections.

In conclusion, history taking, physical exam, and radiologic should all play a role in the workup of facet-mediated lumbar pain; however, none of these should exclusively rule in or rule out patients who may benefit from facet blocks or radiofrequency denervation.

Revel's criteria include (1) age over 65 years, (2) pain well relieved by recumbency, (3) pain not exacerbated by coughing, (4) pain not exacerbated with forward flexion, (5) pain not exacerbated with hyperextension, (6) pain not exacerbated with flexion, and (7) pain not exacerbated with extension-rotation.

Lumbar Diagnostic Medial Branch Block and Radiofrequency Ablation Technique

Positioning

The patient lies in the prone position with the head turned to one side (Image 8.1). A pillow can be placed below the lower abdomen of the patient. This helps in reducing the lumbar lordosis, tilting the pelvis backward and moving the iliac crest posteriorly away from the lumbosacral junction.

Fluoroscopy is mandatory for the conduct of lumbar medial branch blocks, as it allows visualization of bony anatomy and can confirm contrast spread. Although

Image 8.1 C-arm oblique tilt
The patient is placed prone with the head to one side. The c-arm is obliqued 25–35 degrees over the lumbar spine. This allows ideal visualization of the facet joints and the junction between the superior articular process and the transverse process. No caudal tilt is needed when performing medial branch blocks. (Courtesy of Kailash Pendem, MD)

fluoroscopy does not directly visualize the medial branch nerve, it can assist based on anatomical landmarks [36].

The use of computerized tomography (CT) scan can be costly and adds radiation exposure, despite the high resolution of imaging, compared to fluoroscopy. CT does not allow for placement of a RFA cannula in a parallel fashion to the medial branch nerve and therefore should not be used for thermocoagulation [37]. For the purpose of the rest of this technique section, we will be discussing the use of fluoroscopy for both diagnostic MBB and RFA.

The lumbar facet joints and the superior articular process can be clearly identified when the C-arm is positioned over the lumbar spine in an oblique angulation of 25–35 °. Caudal angulation of the C-arm is not necessary for medial branch blocks. However, the C-arm can be tilted caudally between 25 and 30 ° when performing the radiofrequency ablation (Image 8.2).

This caudal tilt allows the radiofrequency cannula to be placed in the most parallel position to the medial branch nerve that lies within the groove between the transverse process and the super articular process, as it slopes inferomedially [38].

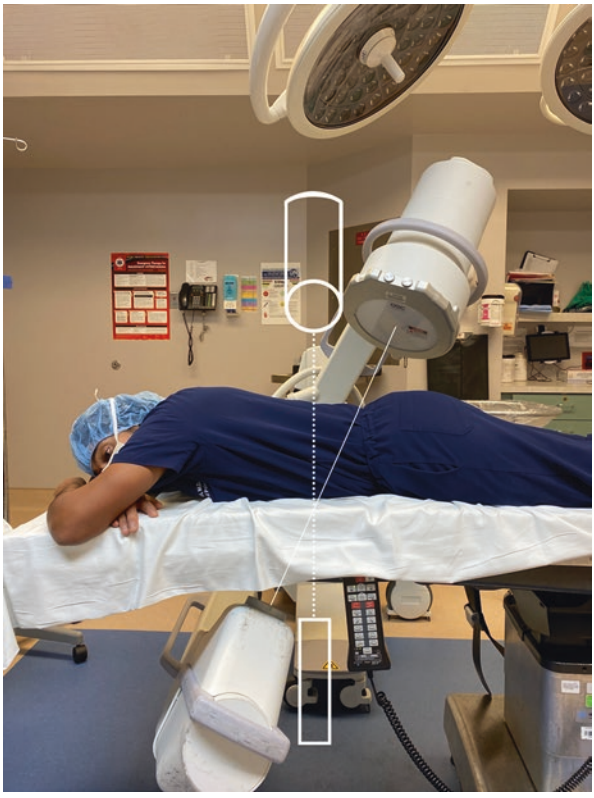

Image 8.2 C-arm oblique and caudal tilt
There is also a 25–30-degree caudal tilt when placing radiofrequency needles. This allows for optimal placement of the active tip of the RFA cannula that is parallel to the medial branch nerve. (Courtesy of Kailash Pendem, MD)

Diagnostic Lumbar Medial Branch Block (MBB) Technique

The skin and subcutaneous tissues can be anesthetized with 1% lidocaine overlying the targets. A 22- or 25-gauge spinal needle can be placed through the skin in a trajectory that is coaxial with the axis of the x-ray path. It is ideal for the needle to remain in a coaxial position until it is seated at the bony junction of a transverse process and the super articular process. After aspiration, a small volume of anesthetic can be placed at each level (0.5% Marcaine or 1% lidocaine). Lumbar medial branch blocks should be performed with less than or equal to 0.5 mL (total volume) to reduce the spread to adjacent structures including spread to the neural foraminal, epidural space, or posterior back muscles [37, 39]. The needles are then removed.

The patient should be instructed to assess their percentage or degree of pain relief, as well as their functional improvement. This should be clearly documented by the physician to assess whether they are a candidate for radiofrequency ablation.

Of note, the screening test of choice prior to a lumbar radiofrequency ablation is a medial branch block. The recommendation is that greater than or equal to 50% reduction in pain is considered a positive block. Medication usage, activity change during the duration of the block, and satisfaction of the patient's pain relief may be considered secondary outcomes when assessing to proceed with the radiofrequency ablation [37, 40].

However, intra-articular facet joint injections with steroids can be used for therapeutic purposes in some patients. This may include younger athletic patients who are with suspected inflammatory facetogenic pain. Denervating such multifidi muscles may be a relative contraindication [41]. Also, intra-articular injections may have a value in patients who are pacemaker dependent or with implantable defibrillators [42].

There is an increased risk of false-positive blocks when sedation is routinely used for diagnostic or prognostic facet joint injections. If this needs to be done for patient comfort, the physician should give the lowest dose of short-acting sedation, ideally without opioids [37].

Lumbar Radiofrequency Ablation (RFA) Technique

The lumbar radiofrequency ablation approach is similar to lumbar medial branch blocks. However, the C-arm is angled 25–30° caudally to the actual plane [Fig. 8.2]. This allows for the active tip of the radiofrequency cannula to be placed in the most parallel position to the medial branch nerve. A similar trajectory that is coaxial with the axis of the x-ray path is used for the radiofrequency needle. The radiofrequency needle is placed against the superior margin of the transverse process and the junction of the superior articular process of the facet. Then, the radiofrequency cannula is walked off the superior margin of the transverse process and advanced 2–3 mm to

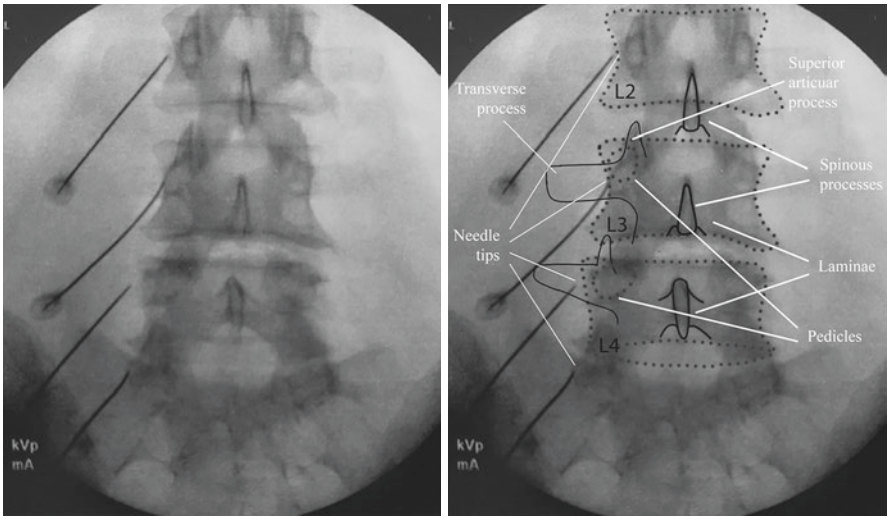

Image 8.3 Fluoroscopy AP image
Bony anatomy relevant to the both lumbar medial branch blocks and radiofrequency is shown. Four radiofrequency cannulae are placed at lumbar 2, 3, 4, and 5 (left side). This clearly shows placement at the junction between the transverse process and the superior articular process. The cannulae enter both laterally and caudally for optimal placement parallel to the medial branch nerve. (Courtesy of Kailash Pendem, MD)

the position of the active tip, along the course of the lumbar medial branch nerve (Images 8.3, 8.4, and 8.5). This can also have a higher likelihood of ablation of the nerve where the medial branch is trapped beneath a calcified mamillo-accessory ligament [43].

Sensory testing is then conducted, and the patient should report pain or paresthesia during the stimulation at 50 Hz at less than 0.5 V. Motor stimulation is also completed at 2 Hz at no less than three times the sensory threshold or 3 V for safety and effectiveness purposes [38]. The patient should be monitored, so there is no reported pain or stimulation, which affects the corresponding myotomal distribution of lower extremities.

This should be completed carefully to prevent any movement of the radiofrequency cannula. Each level then is anesthetized with 0.5 mL of 1 or 2% lidocaine. Lesions are then created at 80 °C for 90 seconds.

Complications

Complications of lumbar radiofrequency ablation are rare, but possible complications may include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect. Further a dysesthesia, “sunburn”-type

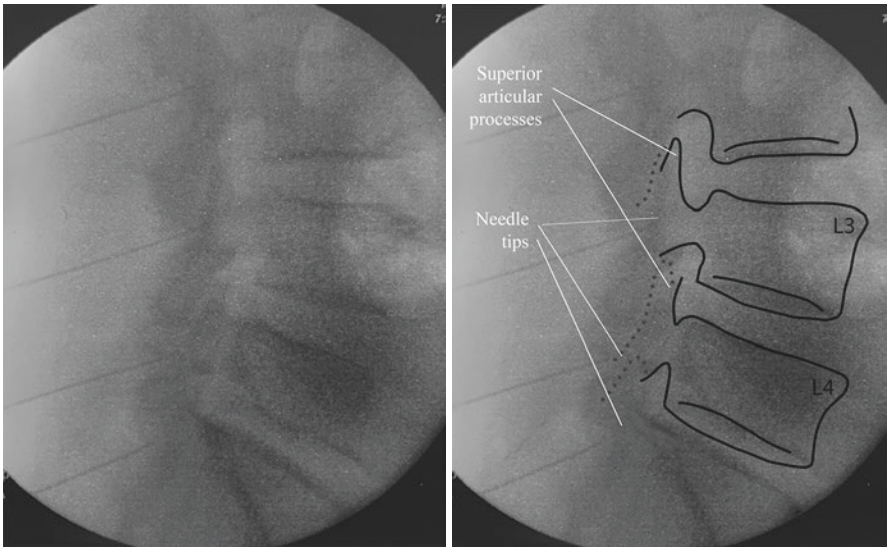

Image 8.4 Fluoroscopy lateral image
RFA needles are placed at the base of the superior articular process and transverse process at lumbar 2, 3, 4, and 5. There is an angulation of these cannulae. They are placed away from the intervertebral foramen. (Courtesy of Kailash Pendem, MD)

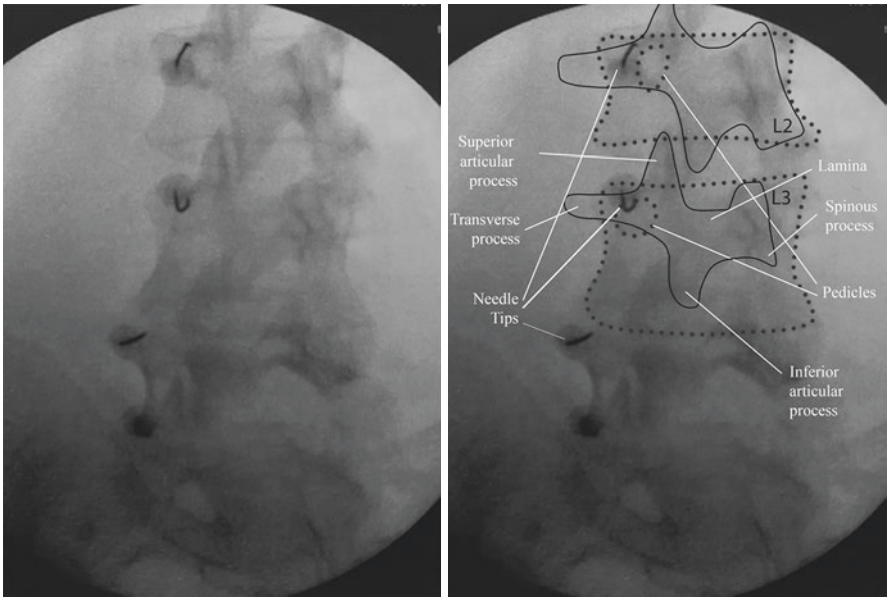

Image 8.5 Fluoroscopy oblique image
Four radiofrequency cannulae are placed at lumbar 2, 3, 4, and 5 (left side). This clearly shows placement at the junction between the transverse process and the superior articular process (Courtesy of Kailash Pendem, MD)

feeling, may be described following lumbar RFA which has been found to be self-resolving. Although the risk for lumbar nerve root damage is present, it can be mitigated by the use of safe technique under fluoroscopic guidance and sensory and motor testing prior to lesioning.

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Chapter 9
Vertebral Body

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Anatomy

The sinuvertebral nerve was first described in 1850 by Hubert von Luschka of Germany. This nerve arises bilaterally from the ventral ramus of each spinal nerve just distal to the dorsal root ganglia and supplies both proprioceptive and nociceptive fibers. Upon separation from the ventral ramus, it travels approximately 3 mm and is joined by a branch of the gray ramus communicans. This branch from the gray ramus communicans contributes sympathetic neurons to the sinuvertebral nerve. The nerve then takes a recurrent course and re-enters the spinal canal through the osteofibrous foramen formed by the deep anterior intraforaminal ligament located just caudal to the pedicle. Once midline, these fibers then dive into the posterior aspect of the vertebral body through the basivertebral foramen (BVF) and become the basivertebral nerve (BVN) (see Figs. 9.1, 9.2, and 9.3) [1–8].

This transition from the sinuvertebral nerve to the basivertebral nerve was first observed by Sherman in 1963. Sherman observed a "large solitary nerve trunk" entering the vertebral body through a bony tunnel in the posterior cortex (now known as the BVF) entering midline and slightly above equidistant from the superior and inferior endplate. Once in the BVF, the BVN traverses approximately 30–50% (measuring from posterior to anterior) into the vertebral body. At this point, the BVN bifurcates to the superior and inferior endplate. This bifurcation, or just proximal to it, is the target for the ablative procedure discussed in this chapter. After

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_9

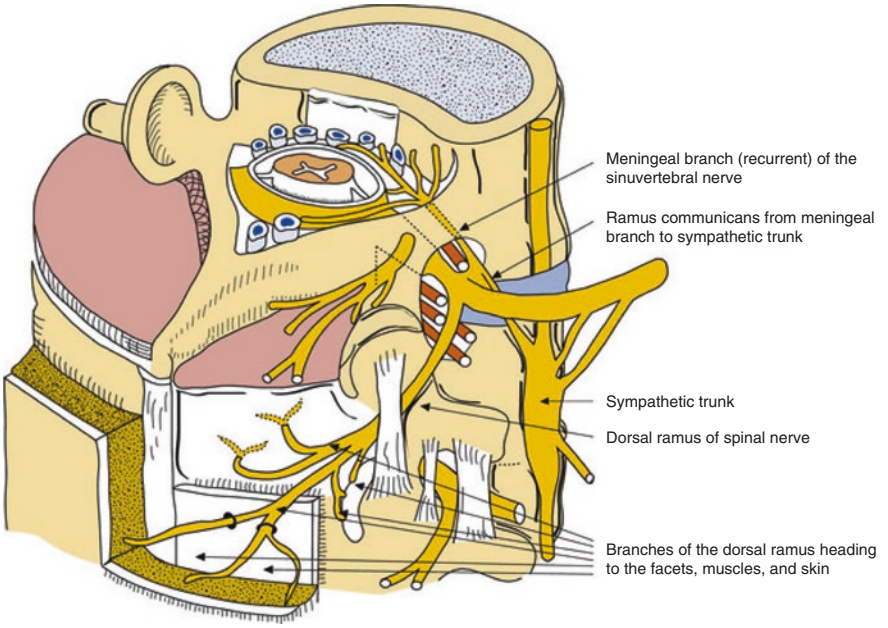

Fig. 9.1 This figure shows the separation of the nerve fibers from the ventral ramus joining with a branch of the gray ramus communicans. The branch from the gray ramus communicans contributes sympathetic neurons to the sinuvertebral nerve. At which time, it becomes the sinuvertebral nerve and starts its recurrent course back into the spinal canal

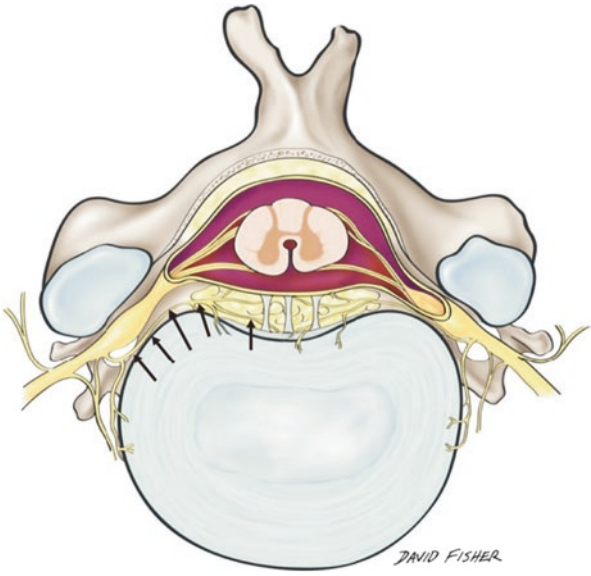

Fig. 9.2 This figure shows an axial view of the sinuvertebral nerve (indicated by black arrows) on its recurrent course into the spinal canal navigating midline

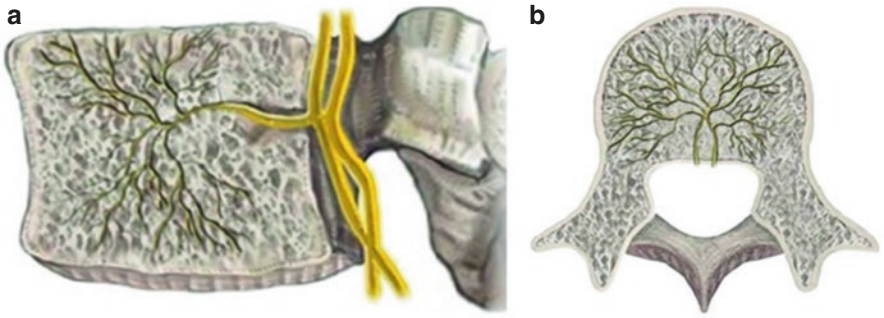

Fig. 9.3 This figure shows a (**a**) sagittal and (**b**) axial view of the sinuvertebral nerve as it enters the vertebral body through the basivertebral foramen, becoming the basivertebral nerve. Note that this foramen is located slightly superior of the midline between the superior and inferior endplate and exactly midline in the axial view. Once approximately 30–50% from posterior to anterior, the basivertebral nerve splits cranially and caudally and begins to arborize to the superior and inferior endplates of the respective vertebral body

the bifurcation, the nerve continues to arborize culminating at the endplate/disc junction. Subsequently, the arborized nerve ending was shown to have an increased density in regions of vertebral endplate microdamage [1–8].

In the sacrum, and more importantly S1, the course of the sinuvertebral nerve into the vertebral body is slightly altered. At this level, a large plexus of nerves emanate from both the left and right branches of the anterior sacral nerve. These nerves penetrate into the lateral border of S1 as they pass through their respective left and right anterior sacral foramen. They continue toward the center, running just above the equator (25–40% down from the superior endplate at S1). This will be the target for the ablation of the BVN at S1. Once the two sides converge, the nerves form a large cluster in the center of the vertebrae, bifurcate, and arborize cranially and caudally to their respective endplates in a similar fashion as seen in the lumbar vertebral bodies [9]. In both the lumbar and sacral vertebrae, the BVN loses its myelin sheath shortly after entering the VB, which effectively prevents the nerve from regenerating after the ablative proedure.

Degeneration of the vertebral endplate/intervertebral disc complex is a common cause of low back pain. The native, healthy disc is avascular and aneural, excluding some small nerves and blood vessels surrounding the periphery of the annulus [10, 11]. The adjacent endplate and vertebral bodies, however, are highly vascularized and innervated. It is these vessels that supply the disc with the necessary nutrition to maintain healthy cells in the nucleus pulposus [12]. As the disc degenerates, the vertebral endplate also starts to degenerate. As stated previously, microscopic studies have shown that with an increase in endplate degeneration, there is an upregulation of nerve fibers giving evidence that endplate damage is a significant source of low back pain [13, 14]. This concept is supported by imaging studies correlating endplate abnormalities with pain, intraoperative reports that have described the endplate is painful when touched, and clinical data demonstrating that back pain is

resolved after the destruction of the BVN and its branches during vertebral augmentation procedures [15–17].

Workup

Low back pain (LBP) is the most common musculoskeletal condition affecting adults with a lifetime prevalence of up to 84%. Chronic LBP (CLBP) is described as LBP lasting for greater than 6 months.

There are many different possible sources for CLBP. The main origins of this pain are from the muscles, fascial structures, vertebral endplates, nerve roots, facet joints, and intervertebral discs (IVDs). In this chapter, we will focus on how to correctly diagnosis CLBP caused by irritation of sinuvertebral/basivertebral nerve which occurs due to degeneration of the complex vertebral endplate/disc junction [18, 19].

The diagnostic evaluation of patients with CLBP can be very challenging and requires complex clinical decision-making. However, the correct identification of the source of the patient's pain is paramount in providing a therapeutic plan and providing relief for the patient. The first job of the physician is to get a thorough history of the patient's pain. This must include the pain's onset, duration, location, characterization, severity, alleviating and aggravating factors, as well as if the pain radiates. Next a full-bodied and comprehensive physical exam must be performed which will further help pinpoint the patient's pain generator. Along with history and physical exam, you may need to order X-rays and advanced imaging such as magnetic resonance imaging (MRI) and/or computerized tomography (CT) scans [20, 21].

We will now discuss how to use all of this information to identify which patients will benefit from ablation of the basivertebral/sinuvertebral nerve. The type of pain from an irritated endplate will be purely axial and somatic in nature. Therefore, we can rule out patients that are with mainly radicular pain and neurogenic claudication.

In brief, radicular pain is pain that radiates from the back into the leg in a dermatomal distribution. Disc herniation is the most common cause, and inflammation or compression of the adjacent nerve is the most common pathophysiological process. Neurogenic claudication is caused by lumbar spinal stenosis due to venous congestion and hypertension around the lumbar nerve roots. Pain is exacerbated by lumbar extension and relieved lumbar flexion.

Now we are left with the CLBP generators that most commonly cause pain that is axial in nature. The main culprits are facet joint syndrome, sacroiliac joint (SIJ) pain, discogenic pain, and, our focus for this chapter, vertebrogenic pain. Although vertebrogenic pain is not a diagnosis by exclusion, the other causes of axial back pain will be discussed in brief in order to distinguish these etiologies from each other.

Facet Joint Syndrome

Pain from facet joint syndrome is characterized as non-radicular in nature, and it tends to be off-center. Unlike vertebrogenic pain, facetogenic pain increases with hyperextension, rotation, lateral bending, and walking uphill [22, 23]. Facetogenic pain is also more prominent in the elderly population, whereas vertebrogenic pain would be more likely in patients aged 35–65.

Before getting an MRI or CT scan, lumbar X-rays must be performed and can give worthy insight into ruling in/out facet joint syndrome [22]. Particularly, dynamic X-rays (flexion/extension views) are of value as they may show column instability causing an overloaded and painful facet joint. It is difficult to diagnose lumbar facet syndrome using advanced radiologic images since there are no pathognomonic findings. With MRI, there are nonspecific signs of osteophyte formation, fluid in the joint, and hypertrophy of the joint complex. CT is the preferred imaging method due to an increased clarity of the osseous structures. The final diagnosis can be made by performing medial branch blocks or facet joint injections. A positive indication is considered if the patient gets >80% relief after two separate injections [23, 24].

Sacroiliac Joint (SIJ) Pain

The SIJ is another leading source of pain in many patients who present with CLBP. During the physical examination, it is important to examine the patient for pain with movement of this joint. The pain is normally located over the buttocks just lateral to the sacrum and may radiate down the leg but rarely below the knee [25]. There are many SIJ provocative tests which will not be discussed in this chapter, and unfortunately, SIJ provocative testing has been shown to lack sensitivity and specificity. In most patients, advanced imaging will do little to help guide your diagnosis, but if you are suspecting a rheumatologic cause of the patient's pain, one could consider an MRI to look for articular effusion and inflammation. To further rule in/out the SIJ as the source of the patient's low back pain, an SIJ diagnostic injection can be performed to see if the patient receives substantial (>50%) relief [25, 26].

After ruling out facet joint syndrome and SIJ pain, we are left with discogenic versus vertebrogenic causes of axial CLBP. Differentiating between these two can be difficult, but there are some subtle distinctions that will help with the diagnosis.

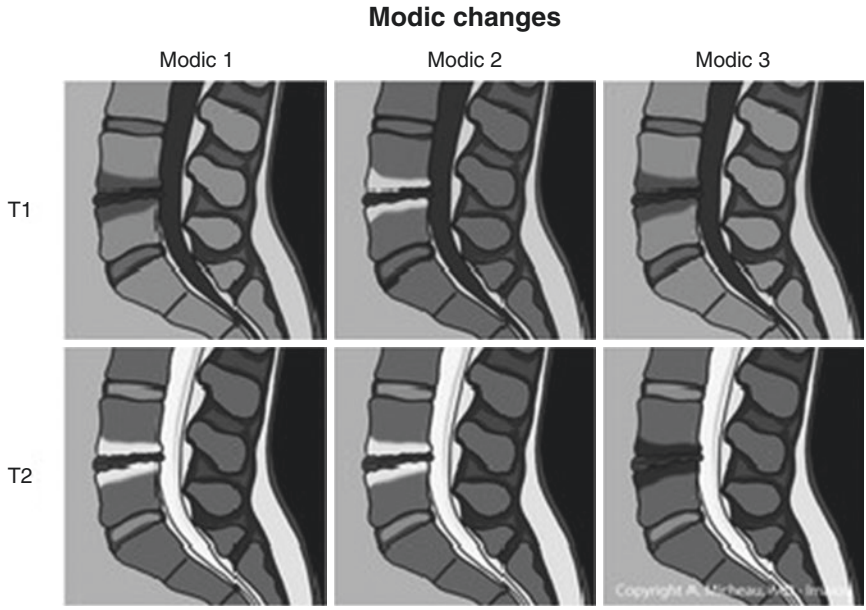

Fig. 9.4 This figure shows a representation of how Modic changes present on MRI T1 and T2 weighted images. Modic type 1 will be dark on T1 and bright on T2. Modic type 2 will be bright on both T1 and T2. Modic type 3 will be dark on both T1 and T2

Discogenic Versus Vertebrogenic Pain

Vertebrogenic and discogenic back pain has been estimated to constitute 39% of all causes of CLBP [27]. Discogenic pain is characterized by the degradation of the vertebral disc with dehydration of the nucleus pulposus with accompanying radial/concentric fissures in the surrounding annulus fibrosus. Vertebrogenic pain is characterized by the degeneration of the smooth endplate adjacent to the disc that serves as the nutrient porous barrier between the disc and the vertebral body. This pain is what is carried by the fibers of the basivertebral nerve which is the target for the ablation.

Both of these etiologies will present with central axial pain that will radiate across the lumbar region. During physical exam, the patient may have increased pain with forward flexion especially while seated. Pain is most severe when trying to lift weight from the floor while in a seated position. Pain may be relived with extension.

The main difference between these etiologies will be seen with advanced imaging, mainly MRI. With vertebrogenic pain, changes in the endplates, such as invaginations and edema in the vertebral bodies (Modic type I–II), can be seen (see Fig. 9.4). In patients with isolated discogenic pain, the endplate will still be intact, but there can be a presence of a high-intensity zone (HIZ) within the annulus of the disc (see Fig. 9.5).

In conclusion, if a patient presents to your office with axial CLBP without radicular symptoms, you have ruled out the facet joint and the SIJ as the pain generator,

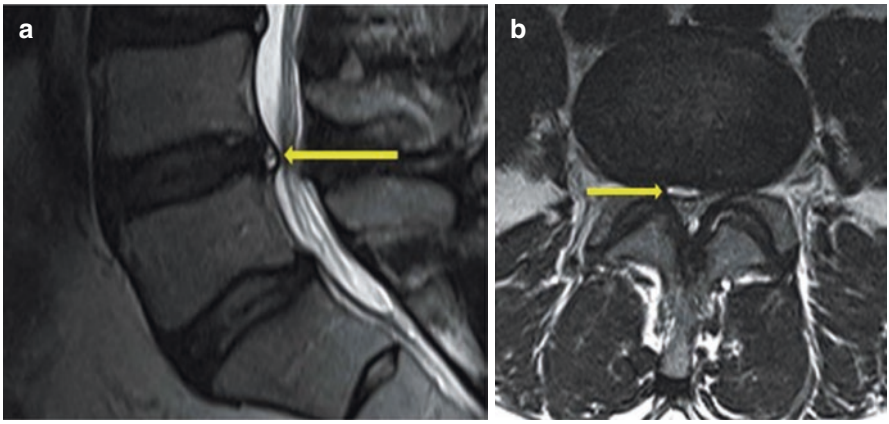

Fig. 9.5 These images show the presence of a high-intensity zone (HIZ) within the annulus if the disc indicated by the yellow arrow on MRI T2-weighted images in both (**a**) lateral and (**b**) axial views

and the patient has degenerative endplate changes on MRI, it would be prudent to consider basivertebral nerve ablation as your next course of action to help alleviate the patient's debilitating pain.

Procedural Technique

The procedure is performed in either a hospital or outpatient ambulatory surgical center. The patient is pre-medicated with antibiotics as prophylaxis against infection. The procedure is performed with the patient in a prone position. The patient is placed under general anesthesia or conscious sedation depending on the patient's comorbidities. The patient is draped in proper surgical sterile fashion using a full laparotomy drape.

At each level being treated, fluoroscopy and standard anatomic landmarks are used to identify the location of entry at the skin to optimize your docking position on the pedicle. In an AP view, this location should correspond to 1–3 cm lateral of the tip of the transverse process at the treated level. Of note, you may use a single C-arm or a bi-plane approach. This procedure requires multiple AP and lateral images; for the sake of time, bi-plane imaging may be preferred. To begin the procedure, the skin and deep tissues are anesthetized down to the pedicle using a 25-gauge spinal needle. Next, a small stab incision is made with a scalpel. The introducer cannula is advanced and docked on the superior lateral aspect of the pedicle. Once proper positioning on the posterior aspect of the pedicle is confirmed in both AP and lateral views, the physician slowly descends through the pedicle. During this descent, the physician should take multiple AP and lateral images to assure that they will enter the posterior wall of the vertebral body at the optimal place which will allow them to access the trunk of the BVN. One pitfall of the

procedure is descending down the pedicle too hastily. Not obtaining optimal imaging during the decent may cause the trocar to be too far lateral when reaching the posterior aspect of the vertebral body which will cause the curve cannula to end up more anterior within the vertebral body than desired during the next stage of the procedure. An ablation that is anterior to bifurcation point of the BVN will not cause a proper lesion of the nerve and thus not relieve the patient's pain. A more serious issue would be if the trocar is advanced too far medial before reaching the posterior aspect of the vertebral body which could cause a breach in the medial wall of the pedicle, in turn causing a possible nerve root injury. This precise decent through the pedicle is made from superior lateral to inferior medial in order to obtain an optimal starting position for the curved cannula (Fig. 9.6).

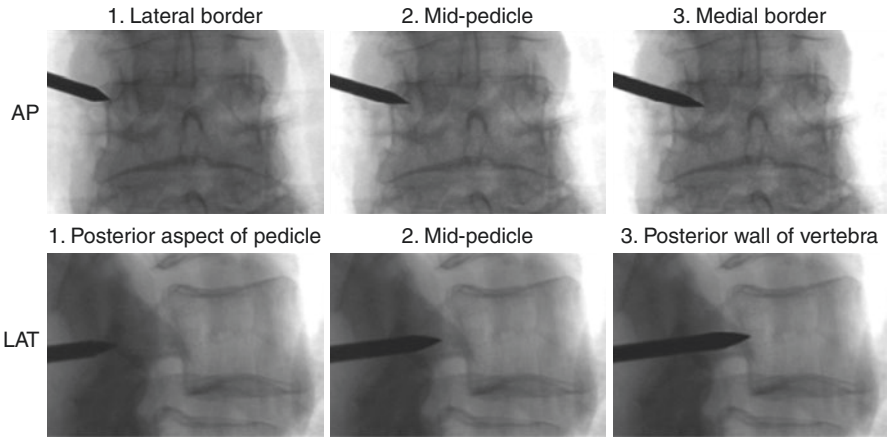

Fig. 9.6 These images show AP and lateral fluoroscopic images as you safely descend and traverse through the pedicle. Note that the starting position is in the superior lateral aspect of the pedicle heading in an inferior medial direction

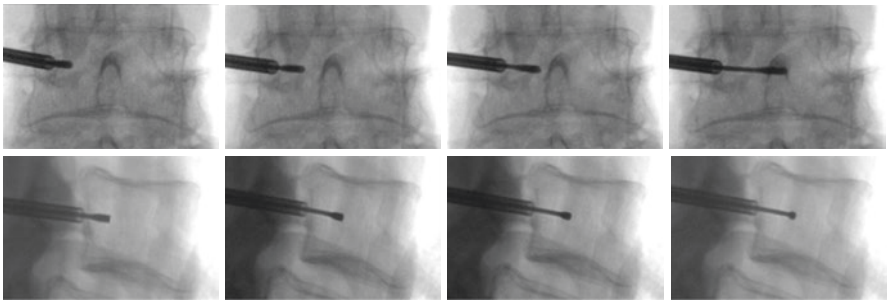

Fig. 9.7 This figure shows many AP and lateral views of the meticulous advancement of the curved stylet. The final placement is noted in the rightmost images with the stylet ending midline in the AP view and between 25% and 40% Between posterior and anterior walls in the lateral view

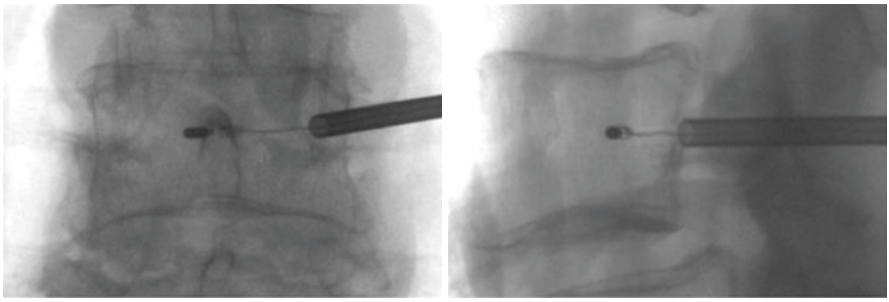

Fig. 9.8 This figure shows the final position of the radiofrequency probe within the created curved channel. Once this positioning is obtained, confirmed ablation may commence

Once through the pedicle, the physician must now access the trunk of the BVN before it bifurcates to each endplate. The introducer trocar is exchanged with a smaller plastic cannula/curved nitinol stylet assembly. This curved cutting tool facilitates the creation of a curved path from the posterior wall to the pre-determined target located at the terminus of the BVN. The target endpoint of this channel is located in the midline of the vertebral body in the AP view and between 25% and 40% when measuring posterior to anterior in the lateral view (Fig. 9.7). This target will be determined prior to the procedure by looking at the patient's axial and lateral views of the MRI.

Finally, the curved nitinol stylet is removed, and the radiofrequency probe is introduced into the created channel and positioned at the terminus of the BVN. Once the position of probe is confirmed in both the AP and lateral views (Fig. 9.8), the wire is connected to the RF generator. Lastly, the bipolar RF probe is activated, and the temperature at the tip is maintained at a constant 85 °C for 15 minutes in order to create an approximately 1 cm spherical lesion within the vertebral body over the trunk of the BVN. After 15 minutes is complete, the RF probe is removed, and the straight and curved cannula are removed. The site is cleaned, and a pressure dressing is applied over each stab incision. A staple or stitch may be placed but is usually not necessary. The patient is now ready for postoperative management. The patient can return home the same day once they recover from sedation [28].

Complications

In addition to bleeding and increased pain, BVN radiofrequency ablation also increases risk of epidural leak, nerve damage, or paralysis. Care must be taken under fluoroscopic guidance in order to assure maintenance of an intra-pedicular trajectory with trochar throughout the procedure. There is also a higher infection

risk due to the stab incision on the skin and longer duration of procedure when compared to other types of radiofrequency procedures.

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Chapter 10
Spinal Metastasis and Spinal Tumors

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Abbreviations

CT	Computed tomography
EBRT	External beam radiation therapy
MR	Magnetic resonance
MWA	Microwave ablation
NSM	Nonsurgical management
PET	Positron emission tomography

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_10

RFA	Radiofrequency ablation
RT	Radiation therapy
SBRT	Stereotactic body radiotherapy
VA	Vertebral augmentation
VB	Vertebral body
VCFs	Vertebral compression fractures

Introduction of Percutaneous Ablation of Spinal Neoplastic Disease

The growth of malignant tumors in the osseous tissue of the spine has been recognized since the latter portion of the nineteenth century, and this location has been one of the most common points of tumor spread thought to be due to the ample vascular supply along with the potential for antegrade spread through the arterial supply and bidirectional spread through Batson's plexus [1, 2]. Approximately 1.7 million patients are diagnosed with cancer in the United States annually, and 40% will go on to develop spine metastatic disease [3, 4]. Between 30 and 70 percent of these patients with metastatic disease will have spinal metastases, and about one third of all newly diagnosed cancers in the United States will have symptomatic spinal metastases as their initial presentation [5–8].

Most of the spine metastases will be found in the thoracic spine (70%) followed by the lumbar spine and sacrum (22%) and the remainder within the cervical spine [9]. These metastases will commonly present with fractures of the vertebral bodies and are one of the most common causes of pain and disability in this patient population [10, 11]. The fracture causes pain as does the tumor cytokine stimulation of endosteal nociceptors, osteoclast-mediated osseous destruction, and spinal cord or nerve root compression which occurs in 10–20% of patients and is most often due to tumor involvement of the posterior vertebral body (VB) or posterior elements [12, 13]. Pain and neurologic deficits associated with spinal metastases lead to impaired mobility and overall diminished quality of life [14].

This disability is often profound, and with most of the patients having an average survival time of 1 year or less, the optimal treatment is one that is focused on a rapid and minimally invasive way to reduce pain and increase their quality of life by providing mechanical stability and reducing the spinal tumor burden. Standard treatments include chemotherapy, radiation therapy, surgery, and image-guided ablation, and advancements of these treatments have resulted in an increased life expectancy for these patients and an increased need to have their metastatic spinal disease effectively remedied [15–18]. The optimal approach is a patient-centric treatment designed to produce the best results with the least disability for each particular patient.

One of the most common treatments for palliation of pain is fractionated external beam radiation therapy (EBRT). While this treatment is usually effective, up to 40% of

patients may not receive pain relief, and up to 65% will have some persistent pain after treatment [19]. Stereotactic body radiotherapy (SBRT) is an image-guided external beam radiotherapy that has been shown to provide better pain relief and local tumor control but is less commonly used for metastatic disease and can be associated with such adverse events as vertebral compression fractures (VCFs) and radiation-induced myelopathy [20]. Recently, radiofrequency ablation (RFA) and vertebral augmentation (VA) used along with or in lieu of radiation therapy have been recognized as promising therapeutic techniques [21–23]. In addition to RFA, other minimally invasive and efficient thermal procedures such as microwave ablation and cryoablation have also materialized as viable treatment option in the palliation of spinal metastases.

Radiofrequency ablation uses a high-frequency alternating electrical current that causes local ion agitation and produces frictional heat within the local tissue resulting to controlled local coagulation necrosis and little effect on the surrounding structures. RFA has been shown for many years to be an established and safe way to induce focal tissue destruction and is now commonly used in treating spinal metastatic disease [24–27].

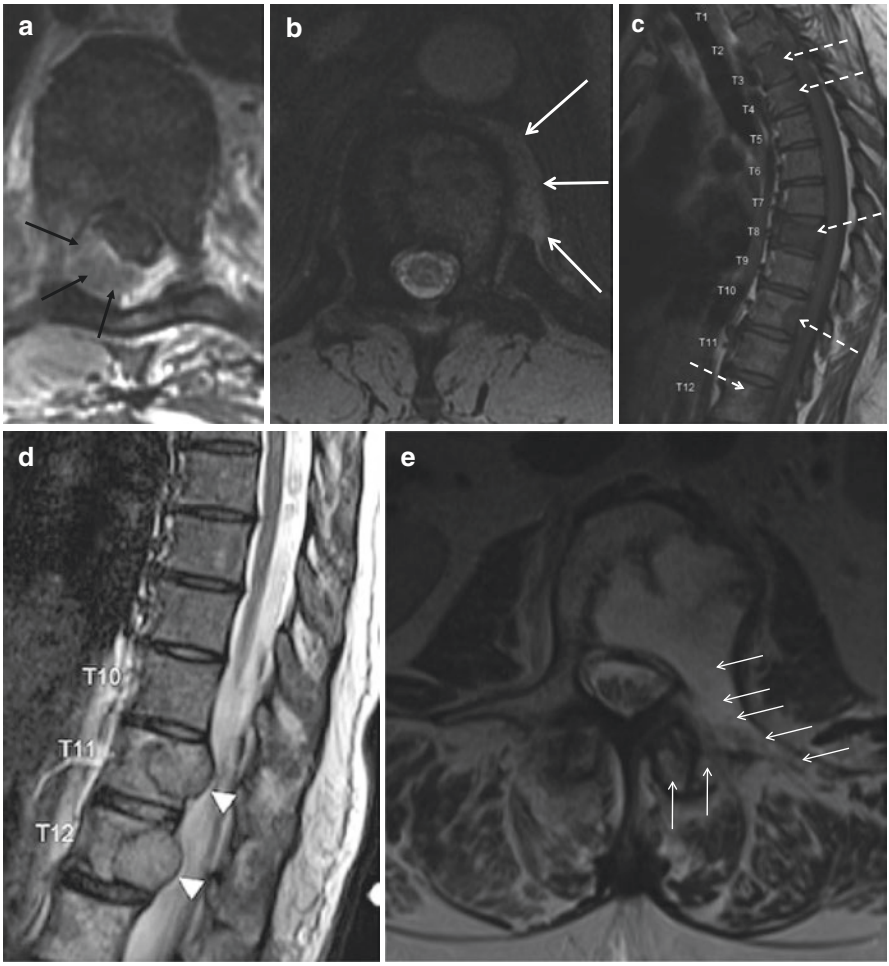
Radiofrequency ablation of spinal metastases is typically used in conjunction with cement or vertebral augmentation to stabilize the pathologic lesion and support the vertebral body. There are numerous studies, including prospective trials, showing that RFA with cement augmentation is an effective treatment for painful spinal metastases [22, 23, 28–31].

The effective application of RFA and other minimally invasive thermal ablation techniques involves the appropriate diagnosis and patient identification, characterization of the type of metastasis, assessment of spinal instability, and selection of the appropriate treatment modality. Different treatment modalities may be combined to achieve the optimal result of ablating the tumor, stabilizing the vertebral body, minimizing active bone destruction, and providing optimal pain relief for the patient.

Optimizing the Diagnostic Accuracy of Spinal Metastases

Separating benign versus malignant vertebral compression fractures (VCFs) is important as the majority of both types of fractures occurs in the same age group and the presence of a malignancy affects treatment planning and prognostic determination [32]. Certain benign fractures including those that are more chronic are more easily identified due to preservation of normal signal within the medullary bone of the vertebral body [32, 33] but acute osteoporotic VCFs may be difficult to differentiate from neoplastic compression fractures.

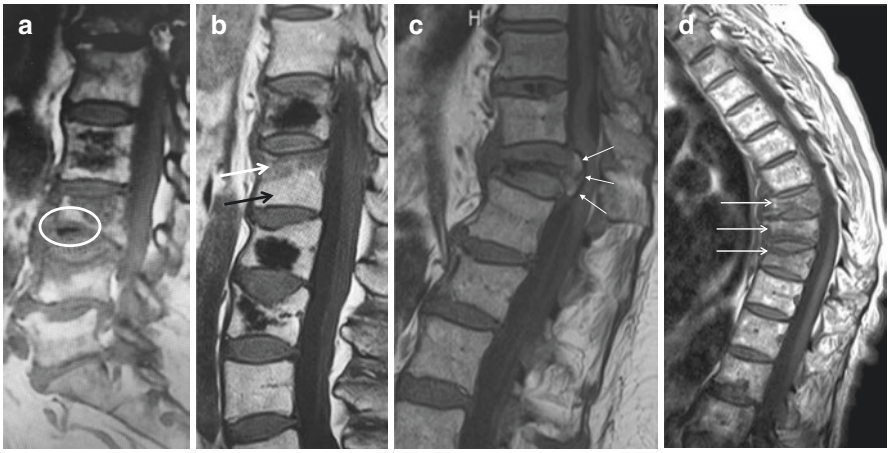
There are imaging findings that may be useful to distinguish between benign and malignant VCFs [34]. The primary imaging modality used in assessing VCFs is magnetic resonance (MR) imaging. The MR imaging findings that can be helpful in discriminating between benign and metastatic fractures include the following which favors a neoplastic process: an epidural mass or encasing epidural mass, a focal paraspinal mass, other metastases, a convex border of the vertebral body, and abnormal signal intensity of a pedicle or the posterior elements (Fig. 10.1a–e) [34]. The



Figs. 10.1 (**a**–**e**) The MR imaging characteristics that are used to distinguish between benign and malignant VCFs that favor malignancy include: an epidural mass (black arrows in **a**), a focal paraspinal mass (white arrows in **b**), other metastases (dashed white arrows in **c**), a convex border of the vertebral body (white arrowheads in **d**), and abnormal signal intensity of a pedicle or the posterior elements (small white arrows in **e**)

MR imaging characteristics that favor a benign process include air within the vertebral body, normal bone marrow adjacent to the region of edema within the VB, retropulsion of a posterior wall bone fragment, and multiple compression fractures (Fig. 10.2a–d) [34].

Other imaging modalities may be used to detect malignant involvement of the spine including x-rays, computed tomography (CT), positron emission tomography (PET), and PET combined with CT scanning. It can be difficult to diagnose neoplastic VCFs on x-ray until the involvement is severe, but a characteristic sign of malignant involvement is the loss of the pedicle as seen on the anteroposterior view (Fig. 10.3a). Nuclear medicine bone scan is a very sensitive modality in detecting



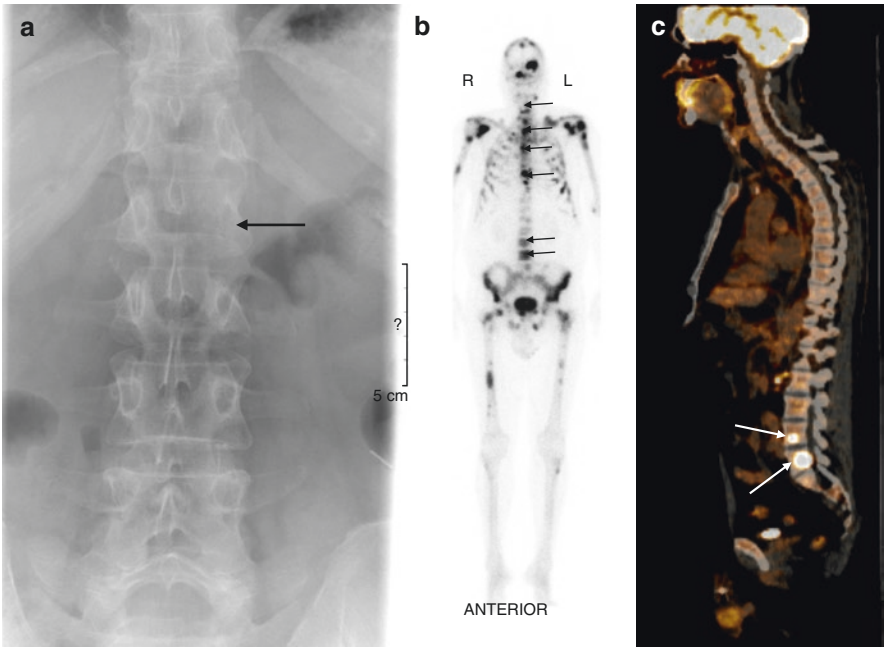
Figs. 10.2 (**a**–**d**) The MR imaging characteristics that are used to distinguish between benign and malignant VCFs that favor a benign process include: air within the vertebral body (black area within the white circle in **a**), normal bone marrow (black arrow in **b**) adjacent to the region of edema (white arrow in **b**) within the VB, retropulsion of a posterior wall bone fragment (white arrows in **c**), and multiple compression fractures (white arrows in **d**)

spine metastatic disease in all, but lytic spinal disease and lesions in the posterior elements and posterior VB wall are especially prominent (Fig. 10.3b). Positron emission tomography is the most sensitive modality for tumor detection and can be combined with CT or MR imaging for very accurate localization of the tumor involvement (Fig. 10.3c).

Management of Metastatic Spine Disease

The management of metastatic spine disease requires multidisciplinary input [35], and radiation therapy remains the current standard of care for local control and pain palliation of vertebral metastases. Despite its efficacy, radiation therapy has limitations which include certain types of neoplasms that respond less favorably to radiation therapy (e.g., sarcoma, renal cell carcinoma, non-small cell lung cancer, and melanoma) [36], cumulative radiation tolerance of the spinal cord which often precludes retreatment of recurrent tumor or progressive tumor at adjacent vertebrae [37], and providing radiation therapy to patients often excludes them from certain systemic chemotherapy clinical trials. The surgical options for treating spinal metastatic disease include stabilization, corpectomy, and gross tumor resection and are often reserved for scenarios involving metastatic spinal cord compression or instability and can be of limited benefit in management of spinal metastases due to the prominent morbidity of the surgery and patients' often poor functional status and short expected life span.

Over the past decade, percutaneous, image-guided thermal ablation has been increasingly used in a multidisciplinary management of vertebral metastases. These



Figs. 10.3 (**a**–**c**) Imaging signs of spinal metastatic disease. An anteroposterior x-ray shows the loss of the inferior portion of left pedicle at the L1 vertebral level (black arrow in **a**) that was later confirmed to be a renal cell carcinoma metastasis by percutaneous biopsy. An anterior view of a nuclear medicine bone scan done with technetium-99 m MDP shows metastatic prostate carcinoma throughout the skeleton and the spine (black arrows in **b**). A sagittal view of a PET/CT scan shows increased radiotracer uptake in the lumbar spine vertebral bodies (white arrows in **c**) indicative of metastases in this patient with known metastatic breast cancer

procedures are typically performed in an outpatient setting under moderate or deep conscious sedation and require minimal recovery time; also, these procedures do not hinder or compromise adjuvant radiation or chemotherapy. Percutaneous ablation for vertebral metastases is performed to achieve pain palliation and/or local tumor control and is very often combined with vertebral augmentation for fracture and structural stabilization or fracture prevention in patients who have not responded to or have contraindications to radiation therapy. In cases of osseous oligometastatic disease, ablation may be performed with curative intent.

Spine Radiofrequency Ablation

The majority of spine ablation literature focuses on radiofrequency ablation (RFA) of painful vertebral metastatic lesions. RFA is a frictional heat generated by a high-frequency, alternating current (375–600 kHz) that produces an oscillation of charged tissue molecules resulting in protein denaturation and tissue necrosis at temperatures ranging from 60° to 100 °C with thermal effect dependent upon the

electrical-conducting properties of the target tissue and the characteristics of the electrode [38]. Radiofrequency ablation is typically used for treatment of vertebral lesions with no or very limited extra-osseous components involving the vertebral body and/or pedicles or posterior elements and is mainly used for lesions which are primarily osteolytic as the higher intrinsic impedance of osteoblastic lesions can prevent the circuit from generating sufficiently high temperatures to ensure cell death thereby rendering RFA ineffective [39].

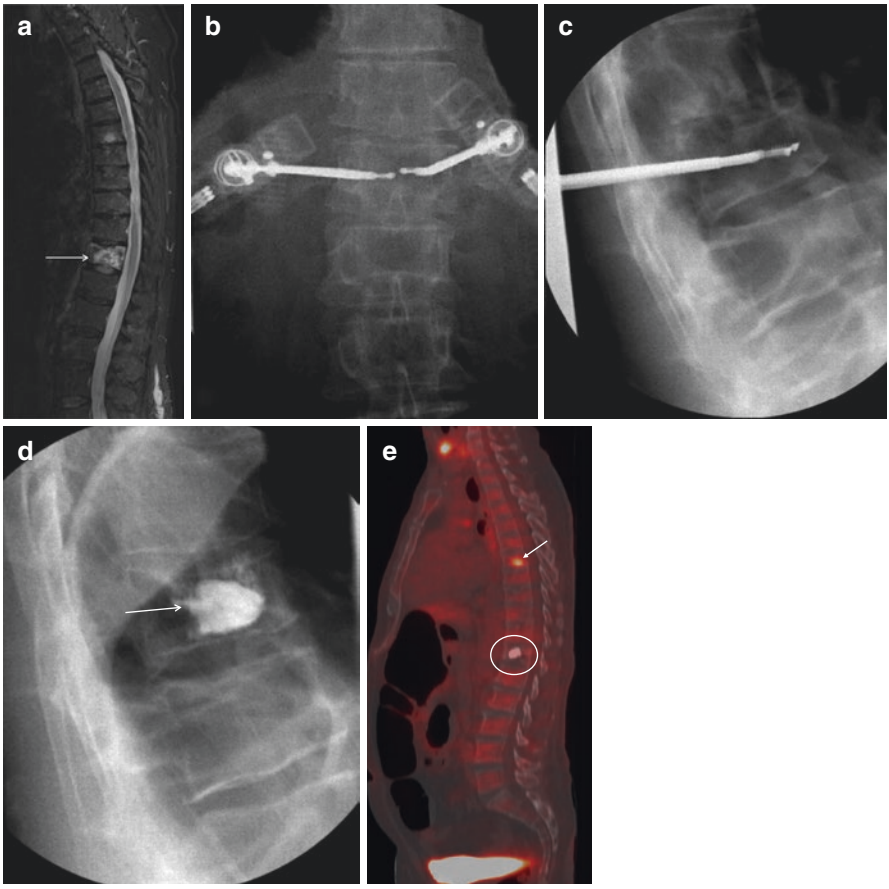
There have been multiple studies demonstrating the safety and effectiveness of RFA in the treatment of painful metastatic spine disease. Sandri et al. [31] reported the retrospective results of 11 patients who underwent RFA followed by cement augmentation and reported a mean pain score decrease from 8 out of 10 prior to augmentation to a 1.8 out of 10 at 72 hours after augmentation to 1.9 six weeks after the RFA and cementation [40]. In a multicenter study, investigators treated 128 vertebral metastases in 96 patients resulting in significant pain palliation with improved pain scores and decreased opioid usage in majority of patients at 1-week, 1-month, and 6-month intervals following the ablation and with no major complications [41]. Local tumor control was demonstrated in a study of 55 patients with vertebral metastases and was achieved in 89%, 74%, and 70% of cases at 3-month, 6-month, and 1-year post-procedure time points with a median follow-up of 34 weeks [42]. Local tumor control was also demonstrated in 33 tumors ablated in 27 patients utilizing bilateral simultaneous radiofrequency ablation achieving local tumor control in 96% of tumors with a mean follow-up, 24.2 weeks (Fig. 10.4) [43]. The majority (94%) of lesions involved the posterior vertebral body and/or pedicle, and 67% of the tumors were 75% or greater of the vertebral body volume. In all of these studies, there were no major complications and no progression to metastatic spinal cord compression at treated levels.

The CAFÉ trial published by Berenson et al. [44] reported the efficacy of balloon kyphoplasty compared to nonsurgical management (NSM) for patients with malignant VCFs. This trial showed a statistically significant improvement in Roland Morris Disability score at the 1-month follow-up time point compared with patients undergoing NSM. They also reported prompt and statistically significant pain relief 1 week following the procedure that persisted throughout the length of the 1-year study.

Sayed et al. reported that their analysis of the literature had pre-treatment pain scores ranging from 7.51 to 8.1 that decreased to between 1.4 and 1.8 after treatment in patients undergoing RFA and vertebral augmentation [23]. They reported pain scores of 5.77 before treatment and 2.61 after which were consistent with previously reported data. They also discussed that patients in their study did not have statistically significant reduction in pain until 1 week after the procedure, which could reflect the known response to patients with neoplastic fractures that they don't respond quite as well in regard to pain reduction as compared to patients with non-neoplastic fractures [45]. Despite the possibility of a short delay in pain relief when treating patients with neoplastic fractures with RFA and cement augmentation, the rate of pain relief is still significantly faster than the four to six weeks necessary to achieve the entirety of palliative relief following conventional fractionated external beam radiotherapy which is a typical standard treatment used in patients with metastatic spine disease [46].

Bone Health in Patients with Cancer

The National Comprehensive Cancer Network (NCCN) Task Force Report entitled Bone Health in Cancer Care was written to address the significant problems stemming from compromised bone health in patients with cancer [47]. Both



Figs. 10.4 (**a**–**e**) A 63-year-old man with metastatic lung cancer and painful T12 lesion. Sagittal STIR magnetic resonance imaging (MRI) (**a**) shows a pathologic T12 compression fracture with near complete marrow replacement of the vertebral body extending to the posterior wall without central canal or neuroforaminal extension (white arrow in **a**). Simultaneous bipedicular radiofrequency ablation was performed to achieve local tumor control and pain palliation along with vertebral augmentation for pathologic fracture stabilization. Prone anterior-posterior (**b**) and lateral (**c**) fluoroscopic images during simultaneous bipedicular radiofrequency ablation show transpedicular placement of bipolar electrodes with medial articulation of the tips to achieve confluent coalescent ablation zones. Lateral fluoroscopic image (**d**) shows post-ablation vertebral augmentation (white arrow in **d**). Sagittal F-18 fFluorodeoxyglucose (FDG) pPositron eEmission tTomography/computed tomography (PET/CT) (**e**) demonstrates lack of FDG avidity in the T12 lesion with post-ablation change (white circle in **e**) (note uptake in the untreated T7 lesion [white arrow in **e**] seen on the pre-ablation MRI) and local tumor control with no evidence or residual or recurrent tumor

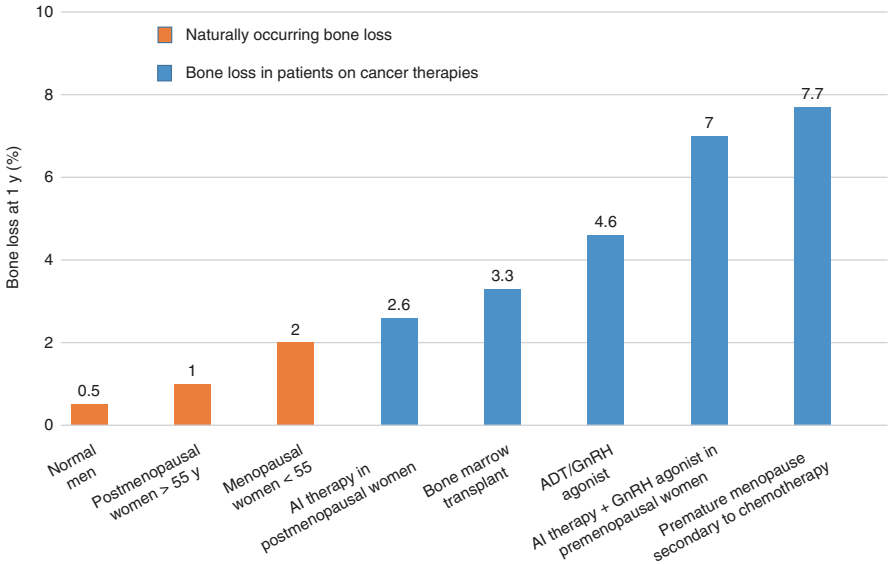


Fig. 10.5 Proportional effects of normal physiologic processes and various cancer treatments on the loss of bone mineral density

osteoporosis and metastatic disease typically affect the over 55 age group disproportionately, and low bone density and osteoporosis can be a significant health issue for the aging population especially in those patients with cancer. Major osteoporotic fractures are associated with increased mortality rates and chronic pain but, unlike cancer, can be prevented with lifestyle modifications and medication therapy [48, 49].

Certain neoplasms and/or treatments for those neoplasms can have a significantly negative effect on bone mineral density and on bone physiology (Fig. 10.5). Certain cancer types produce hormones that can produce osteomalacia or osteoporosis in addition to having a negative effect on bone metabolism [47]. Hormone deprivation that results from certain cancer treatments can also exacerbate bone loss [47]. Cancer treatments that suppress gonadal function via antiestrogen and antiandrogen mechanisms can accelerate bone loss and are often used in conjunction with glucocorticoids which also have a negative effect on bone health. These medications are commonly used as treatments for hematologic malignancies and as supportive agents for other tumors. Radiation therapy has a well-known negative effect on bone strength, and the rate of VCFs after stereotactic body RT has been reported in up to 39% of treated patients [50].

All of the various components of the cancer type, the cancer treatment, and the native physiology combine to increase fracture risk [51]. Some lifestyle factors that are commonly associated with cancer such as smoking and excessive alcohol intake are also more common in patients with cancer. In addition, some of the medications commonly used in this patient population such as some antidepressants, anticoagulants, and proton pump inhibitors can be additive in causing additional bone loss.

Table 10.1 National Comprehensive Cancer Network (NCCN) recommendations regarding bone health and vertebral augmentation

Emphasizes accelerated bone loss in cancer treatment patients
Reports the high risk of ovarian failure in breast CA patients
Discusses supplementation and medical therapies
Supports radiation for pain control in metastatic disease
Supports vertebral augmentation in managing pathologic fractures as well as surgery in unstable osseous disease
Consideration for radiofrequency (RFA) or cryoablation for painful lesions for radiation therapy (RT) failure

The National Comprehensive Cancer Network (NCCN) is an alliance of 21 of the leading cancer centers found around the world and intermittently produces educational programs with recommendations on how to provide the best quality and most effective care for those patients being treated for their cancer. Some of the highlights of a recent task force report include discussions of the accelerated bone loss in cancer patients, the need for medical support, the support for radiation therapy for pain control, support for vertebral augmentation in managing pathologic fractures, and the consideration of RFA for painful metastatic lesions (Table 10.1).

Treatment Considerations for Pain and Symptom Control

It is difficult to overstate the importance of pain and symptom control as it has been documented that patient survival is linked to the effectiveness of the pain and symptom control [47]. Spine RFA with or without cementation contributes substantially to patient pain relief and is commonly used together with radiation therapy to maximize the patient's symptom control. Most clinicians believe that the optimal symptom management is attained by adjuvant administration of both therapies due to the dual pain generating features of spinal metastases that produce pain from the mechanical disruption of the integrity of the spine and from the biological pain generation of the cancer itself.

Stratification of Lesions in the Ablative Treatment of Spinal Metastases

One of the key features in the treatment decision-making for patients with spinal metastatic disease is whether or not the spine is stable. One of the most commonly used tools to determine this is the Spine Instability Neoplastic Score (SINS) which uses a comprehensive set of features including the location of the tumor, the amount of pain or pain relief when loading the spine, the quality of the bone lesion, the spinal alignment, the degree of vertebral body collapse, and the involvement of the posterior

Table 10.2 Spinal instability neoplastic score (SINS)

1. *Patient specific*	
Pain	
Mechanical pain	3
Occasional pain but not mechanical	1
Pain-free	0
2. *Spine specific*	
(1) *Location*	
Junctional spine: occiput–C2, C7–T2, T11–L1, L5–S1	3
Mobile spine: C3–C6	2
Semi-rigid spine: T3–T10	1
Rigid spine: S2–S5	0
(2) *Spinal alignment*	
Subluxation/translation	4
Kyphosis/scoliosis	2
Normal	0
(3) *Presence of vertebral compression fracture*	
≥ 50% collapse	3
< 50% collapse	2
No collapse with ≥50% body involved	1
None of the above	0
3. *Tumor specific*	
(1) *Type of lesion*	
Osteolytic	2
Mixed	1
Osteosclerotic	0
(2) *Posterolateral involvement of spinal elements*	
Bilateral	3
Unilateral	1
None	0
Total SINS	
0–6	Stable
7–12	Potentially unstable
13–18	Unstable

elements (Table 10.2). Spinal stability is only one of many components that are used to determine patient management but can be difficult to judge, especially for the non-spine specialist, and the objective SINS score can help oncologists and primary care physicians with the decision of if and when to refer the patient to a spine specialist. The SINS criteria will also help spine specialists in determining the appropriate treatment and treatment combination by estimating the degree of spine instability. Scores of 7–12 indicate possible instability, and scores of 13–18 indicate an unstable spine, so any SINS score greater than 7 should warrant consultation with a spine specialist [52].

Spine instability resulting from a neoplastic processes is not the same as instability from spine trauma and is characterized by multiple features such as loss of spine

integrity, movement-related pain progressive deformity, and neurologic compromise. There is a clearly established role for surgery in patients with neurologic compromise, but impending neurologic compromise as predicted by the SINS score is a key component in the decision-making process that emphasizes the need to add a stabilization component to the spine metastasis treatment.

One of the consistent features of oncologic instability is mechanical or activity-related pain, and pain that is worsened by load-bearing movement and relieved by being recumbent is typical for the pain caused by spine metastases [52]. This feature is commonly seen to the point that some reports state that more than half of the patients presenting with spine metastases have mechanical neck or back pain [53, 54]. There are other features of osseous invasion of tumor that can produce pain such as periosteal or neural stretching or increased venous pressure that are not associated with instability.

Based on the size of the tumor and the more compromised the patients underlying bone quality plus the SINS score based on pain, tumor location, spinal alignment, vertebral body collapse, type of lesion, and the involvement of the posterior elements, risk stratification can be made to predict the risk of osseous collapse. In the case of multiple spinal lesion, the stability scores are considered separately and are not additive. Each lesion should be considered separately in the workup of metastatic disease, and the SINS system does not provide for a global spinal score and does not predict the outcome of the interaction of multiple lesions. It should also be emphasized that the SINS score is only one component of many factors when considering if the patient needs procedural or surgical intervention. Other modifying factors that contribute to spine disease and are not part of the SINS scoring system include contiguous and non-contiguous multiple levels of spinal disease, previous laminectomies or fusion surgery, previous radiaiton therapy, patient body weight and activity level, and tumor histology. All of these factors may have additional influence on the patient's fracture risk.

Treating Patients with Radiofrequency Ablation and Vertebral Augmentation

When the patient is in pain and the VB is at risk of collapse, the decision is typically made to augment the vertebra with cement in addition to the RFA of the metastatic lesion. Prior to treatment, the clinician needs to consider a number of different factors including the patient's physical examination, location of the metastasis(es), the approach to the vertebral body, and the type of vertebral augmentation procedure.

Prior to RFA and VA augmentation, a physical examination should be performed. The condition of the patient and their degree of debilitation can be objectively assessed using the Karnofsky performance status scale that categorizes the condition of the patient from normal to moribund or dead (Table 10.3). One of the most important portions of the physical examination is to assess for and document any neurologic and/or motor deficits that are present so this can be noted to be the patient's baseline prior to any treatment [55]. Motor deficits may progress apart

Table 10.3 Karnofsky performance status (%)

100	Normal to no complaints	No evidence of disease	Able to carry on normal activity and to work; no special care needed
90	Able to carry on normal activity	Minor signs of or symptoms of disease	
80	Normal activity with effort	Some signs of or symptoms of disease	
70	Cares for self	Unable to carry on normal activity or to do active work	Unable to work; able to live at home and care for most personal needs; varying amount of assistance needed
60	Requires occasional assistance	Able to care for most of their personal needs	
50	Requires considerable assistance	Frequent medical care	
40	Disabled	Requires special care and assistance	Unable to care for self; requires equivalent of institutional or hospital care; disease may be progressing rapidly
30	Severely disabled	Hospital admission is indicated although death not imminent	
20	Very sick	Hospital admission necessary; active supportive treatment necessary	
10	Moribund	Fatal processes progressing rapidly	
0	Dead		

from any therapeutic treatment of the spine, and establishing a baseline for later comparison is important. The physician exam must include palpation and closed fist percussion of the spine and paraspinal musculature to assess for tenderness. The posterior superior iliac spine is often tender with any type of back pain, and this should be assessed as well [55].

Differentiation from pain from a neoplastic origin may be difficult to separate out from pain due to discogenic or facetogenic back pain. Separating these types of pain often requires disc injections, facet injections, and nerve blocks. In benign processes, these can be therapeutic in addition to providing diagnostic information and can be used to accurately localize the pain generator. After the primary pain generator is found, the region of maximum tenderness can be focused upon and treated optimally. Additionally, after the patients' pain is decreased from therapeutic injections, they are often better able to lie in a prone position for the RFA and VA procedures. It is preferable to proceed with injections prior to vertebral augmentation as the cement may obscure the target of the injection.

Access to treat thoracic and lumbar vertebral levels are similar with the lumbar vertebral bodies usually accessed by way of a transpedicular approach and the thoracic vertebral bodies accessed via a parapedicular approach. Metastatic

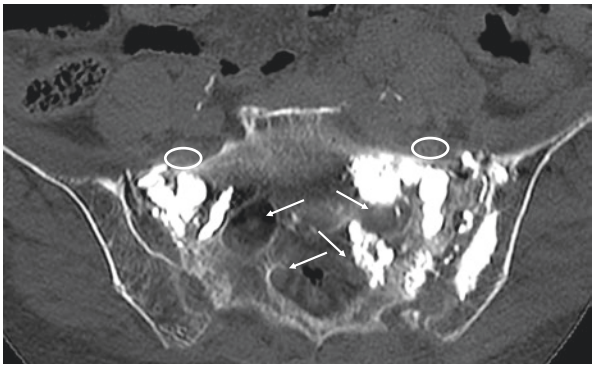


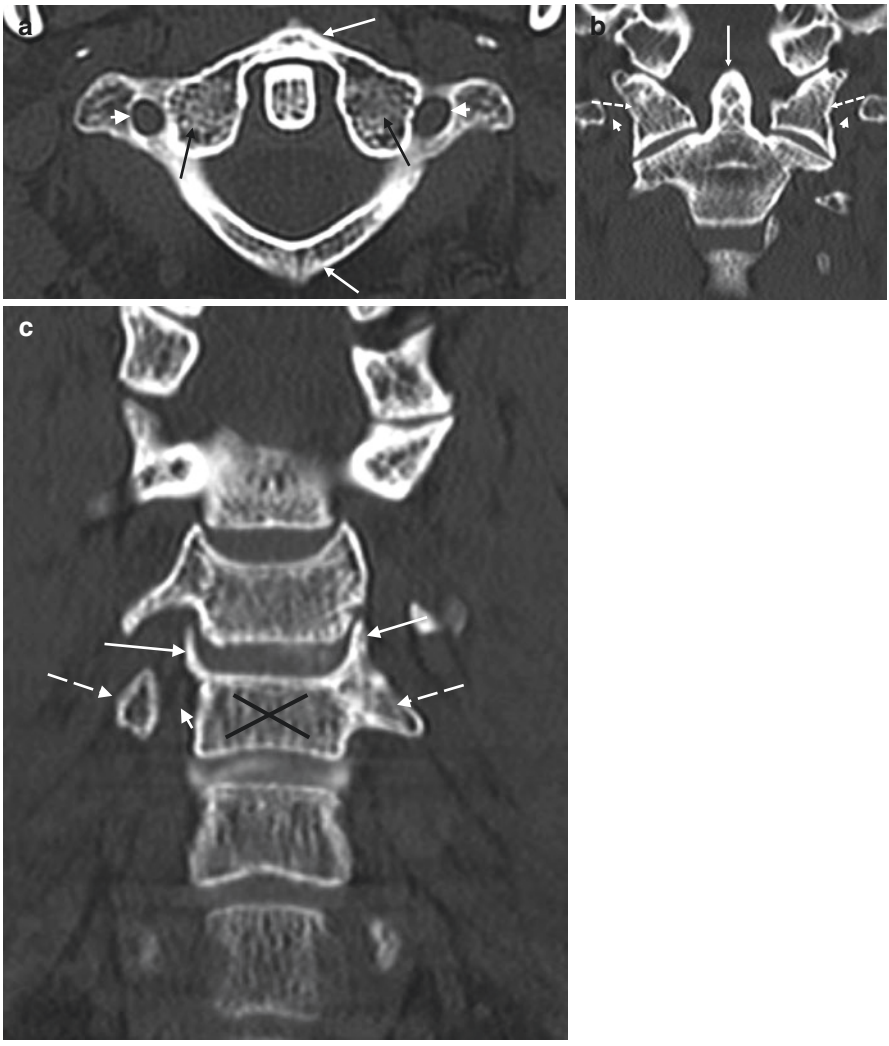
Fig. 10.6 Pertinent sacral anatomy to note when performing sacral RFA and augmentation are the sacral foramina (white arrows) and the lumbosacral plexus (within the white ovals). Bone cement from sacral and ilium augmentation is seen as the white material within the osseous structures

involvement may destroy some of the landmarks such as the pedicle itself (Fig. 10.3a), thereby making the approach more difficult. It is useful to understand the different approaches to the vertebral body as this can give the clinician an alternate route if a portion of the anatomy for one particular approach is obscured [56]. Experienced practitioners can also extrapolate one level's anatomy to the area that is obscured and proceed at areas of tumor involvement using the level above and below as extrapolated landmarks. Access through a pedical or a portion of the vertebral body is perfectly acceptable, and the ultimate goal for any access is to optimize the ablation of the tumor and have ideal needle position for the VA.

The vertebral augmentation provides additional structural support and pain relief. The additional pain relief comes through the exothermic reaction of the cement that is injected into the VB. This cement is typically injected into the anterior one third of the vertebral body to lessen the chance of extravasation into the spinal canal or neural foramina. When injecting cement, it should be kept in mind that the rate of extravasation of cement is increased due to the destruction of the native bone by the tumor, and greater care must be taken to avoid symptomatic extravasation.

Access and RFA of the sacrum is technically divided into access to the ala and body, and due to the lack of differentiated intervertebral discs in the sacrum, it is not difficult to treat two or more levels of the sacrum through a single access point. When treating the sacrum, it is important to avoid the sacral foramina and spinal canal and the lumbosacral plexus that is present just anterior to the sacral ala bilaterally (Fig. 10.6). If the sacral neural foramina or the lateral portion of the sacrum is difficult to visualize due to bone destruction, contrast may be injected into the epidural space or sacroiliac joints.

The cervical spine is characterized by two unique-shaped vertebrae and five similarly shaped vertebrae. The C1 level has lateral masses with an anterior and posterior arch and transverse processes through which the vertebral arteries pass (Fig. 10.7). The lateral masses articulate with the occiput of the head and are weight-bearing. The C2 vertebra has unique anatomic features such as an odontoid process and lateral masses with superior and inferior articular facets and transverse processes with foramen transversarium (Fig. 10.7b). Augmentation may need to be



Figs. 10.7 (**a**–**c**) The C1 vertebra is characterized by the anterior and posterior arches (white arrows on the axial view in **a**), the lateral masses (black arrows in **a**), and the foramen transversarium (white arrowheads in **a**). The C2 vertebra has an odontoid process (white arrow on the coronal view in **b**) and lateral masses (dashed white arrows in **b**) with superior and inferior articular facets and transverse processes with foramen transversarium. The anatomic components of C3 to C7 consist of the uncinate processes (white arrows on the coronal view in **c**), the transverse processes (dashed white arrows in **c**), and the foramen transversarium (white arrowhead in **c**) and the vertebral body itself (black x in **c**)

performed on the weight-bearing portions of these vertebrae, and access to the involved osseous structures is performed to avoid damage to the internal carotid artery and jugular vein, the vertebral arteries, and the nerve roots. A manual

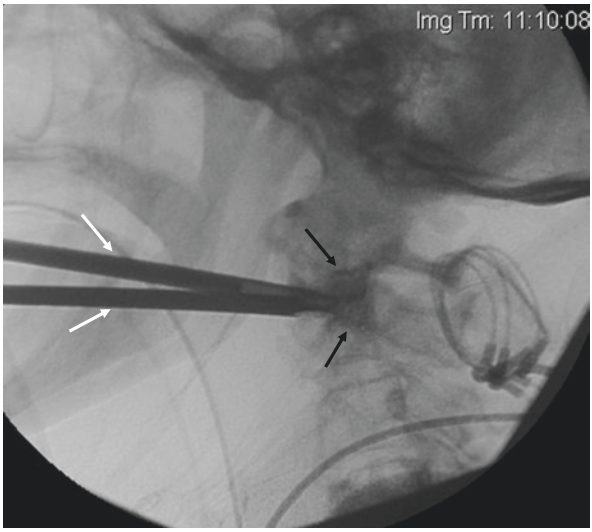


Fig. 10.8 Two 11-gauge needles (white arrows) are used to access the vertebral body of C2 to inject bone cement (black arrows)

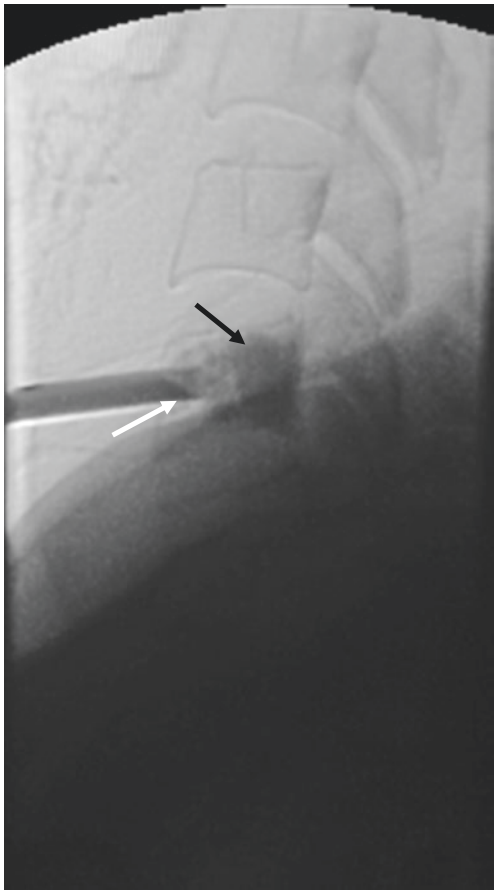


Fig. 10.9 An 11-gauge needle (white arrow) is placed into the anterior portion of the C6 vertebral body, and then cement is injected (black arrow)

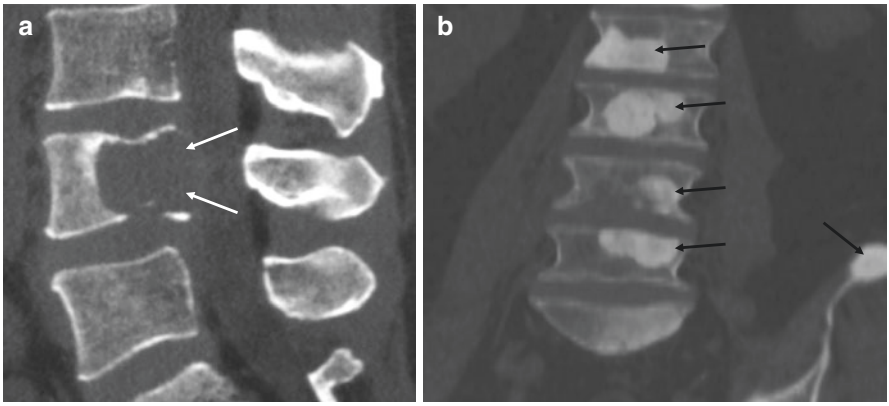
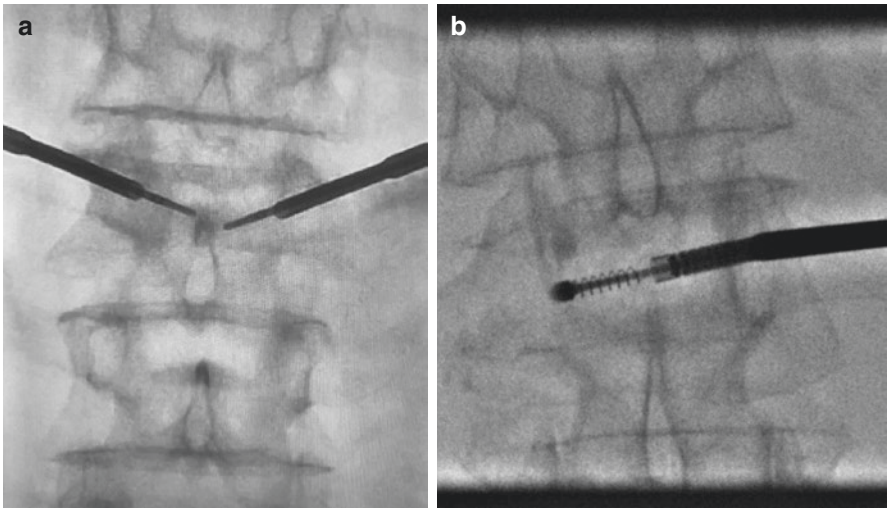


Fig. 10.10 Sagittal CT reconstruction (**a**) shows a lytic osseous lesion (white arrows in **a**) from a plasmacytoma. Coronal CT reconstruction shows osteoblastic bone metastases (black arrows in **b**) from metastatic prostate carcinoma

compression technique used anteriorly and a CT-guided approach posterolaterally are common ways to access the upper cervical spine. The C2 vertebral body and odontoid process may also be accessed transorally (Fig. 10.8). The anatomic components of the C3 to C7 vertebrae are similar and consist of the uncinate processes, the transverse process, and the foramen transversarium along with the vertebral body itself (Fig. 10.7c). The superior and inferior articular facets are similar in these vertebrae, and the vertebral arch consists of the lamina, pedicles, and spinous processes. The anterior approach to the C3 to C7 vertebral bodies avoids damage to the trachea and esophagus and the internal carotid artery and vein pushing aside the tracheoesophageal complex and major vessels with one's second and third fingers. The needle should be placed in the center or anterior 1/3 of the vertebral body (Fig. 10.9).

When choosing what to use for cementing the VB after RFA, the use of cavity creation with kyphoplasty may be useful to help prevent symptomatic extravasation of the cement. The preoperative imaging should be evaluated to assess for tumor destruction of portions of the VB, especially those locations such as the posterior wall that could predispose to cement extravasation into the spinal canal or neural foramina. It is important to know that the cement amount necessary to adequately stabilize the VP is equal to 15–25% of the non-compressed thoracolumbar vertebrae [57–60]. This amount is sufficient to treat the pain from the neoplastic process and to re-establish the strength and stiffness of the vertebral body [57–60]. In addition to the correct amount, it is necessary to incorporate the cement into the surrounding interstices of the bone that is uninvolved with the neoplasm. When performing a balloon kyphoplasty, the type of tumor should be assessed whether it is lytic or sclerotic (Fig. 10.10) as it is typically more difficult to expand the balloon in an osteoblastic lesion. The order of the combined RFA and VA procedure should also



Figs. 10.11 (**a**–**b**) Examples of two different RFA ablation systems. The bilateral transpedicular approach with two straight needles and RFA performed with cool RF with an OsteoCool system (Medtronic, Dublin, Ireland) that is shown in a and a typically unilateral transpedicular or parapedicular approach using a curved articulating bipolar RF probe that can be placed in different parts of the vertebral body that is shown in **b**

be performed in that order as any type of manipulation of the metastatic lesions could potentially spread tumor to other areas of the body [61].

After physical examination is performed, the imaging reviewed, the determination of the correct pain generator deduced, and the technical aspects of the RFA and VA decided upon, the patient is then ready for the procedure. There are a number of different ablation systems that can be used including OsteoCool Radiofrequency Ablation System (Medtronic, Dublin, Ireland) and the STAR Tumor Ablation System (Merit, Salt Lake City, UT, USA). The OsteoCool system utilized cool RF technology, and tumors are typically ablated via a bilateral transpedicular approach with two straight needles (Fig. 10.4b,c and 10.11), and the RFA zone encompasses the entire vertebral body. The STAR tumor ablation RF probe is a bipolar probe that is typically placed unilaterally and has a curved articulating design that can be placed at multiple places within the vertebral body (Fig. 10.11b). Thermocouples present within the probes provide temperature profiles of the ablation zones, and the time and temperature combination is used to monitor the size of the ablation zone.

A procedure is technically successful if the VB is accessed via whatever technique is utilized, and the spinal neoplasm is completely ablated prior to the planned cement augmentation. Typically, a balloon or implant kyphoplasty technique is favored due to less extravasation risk and the increased chance of attaining a more anatomic alignment [62]. The procedure can be done under moderate or deep sedation or general anesthesia at the discretion of the operating physician. Typically, fluoroscopy is used to guide the procedure, but CT can be used in cases where

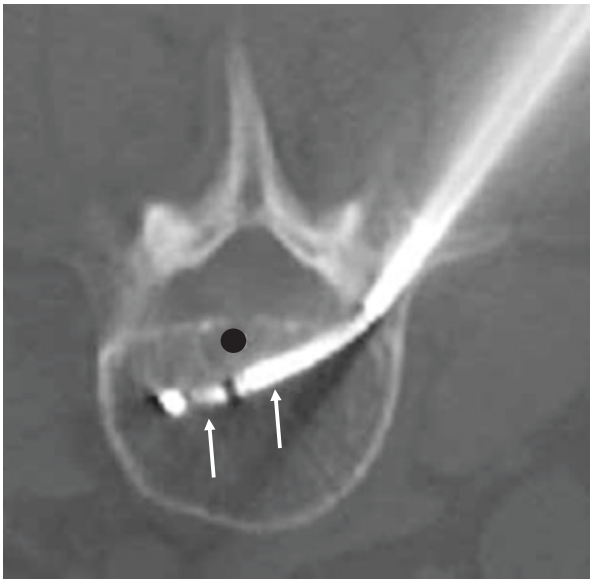


Fig. 10.12 Computed tomography guidance with an articulating RF probe (white arrows) targeting a metastatic lesion along the posterior portion of the central vertebral body (black circle)

accurate ablation is essential (Fig. 10.12). The thermal energy is applied in the appropriate manner to completely ablate the tumor, and the probe can be repositioned as needed. In the vast majority of cases, cement augmentation will follow the RFA to provide additional structural stability as the tumor can weaken the vertebral body, and additional treatments such as radiation and the RFA itself can further weaken the vertebra.

There is an increased risk of VCFs following radiotherapy, and this risk is well-known and not insubstantial ranging from 11% to 39% [50, 63]. It is thought that the radiation damages the collagen portion of the bone and can produce osteonecrosis, both of which can dramatically weaken the bone. In cases of radiation therapy using more than 20Gy per fraction especially in patients with osteolytic tumors or with spinal malalignment, the risk of VB fracture is very high. Most experienced clinicians will cement all or nearly all of the vertebrae they treat with RFA given this increased risk of fracture and to allow additional radiation therapy to be used without undue increase risk of fracture.

Patient follow-up after RFA and cement augmentation should be guided by the patient's full clinical scenario including what type of cancer they have, the degree of metastatic involvement, and other comorbidities. Typically, they are followed closely by their oncology team, but they should have at least one follow-up in 2–6 weeks to ensure their level of pain and functional improvement are satisfactory. Longitudinal follow-up of the ablation zone can be assessed either with dedicated imaging studies or with other surveillance imaging studies that the patient will be undergoing to monitor their neoplastic condition.

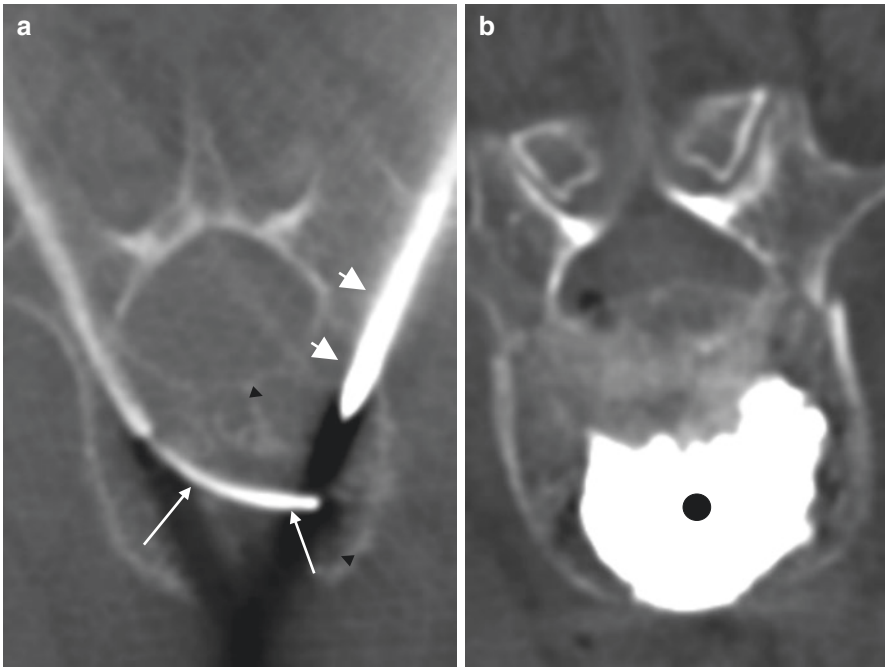


Fig. 10.13 (**a**–**b**) Axial CT images taken during a microwave ablation of a metastatic vertebral body lesion (black arrows in **a**) shows a microwave prove (white arrows in **a**) and contralateral needle access (white arrowheads in **a**). Vertebral augmentation was performed after the MWA with bone cement seen on the axial CT image (black circle in **b**)

Other Thermal Ablation Modalities Used in the Treatment of Spinal Metastases: Microwave Ablation

Recently, some newer therapeutic strategies have shown success in reaching durable local control of the disease [64]. In addition to the various treatments for the management of spinal metastases and RFA, other percutaneous ablative therapies are available to treat patients with osseous metastases [65]. These therapies are performed with the use of different imaging modalities for guidance and include cryoablation, microwave ablation, and laser treatments [66, 67]. As with RFA, these treatments are nearly always accompanied by vertebral augmentation that is performed after the ablation (Fig. 10.13).

Microwave ablation (MWA) is a thermal ablation technique that uses electromagnetic waves to induce heating effect in the target lesion resulting in coagulative necrosis of the target lesion tissue [68]. This produced heat destroys tumor cells and coagulates blood vessels [69]. Among ablative therapies, MWA has multiple advantages, such as improved convection profile, increased bone conductivity with less heat sink effect, shorter duration, larger ablation volumes, and optimal heating of the necrotic masses with higher thermal efficiency [69–74].

Microwave ablation of tumor cells is primarily achieved using electromagnetic methods resulting in tumor destruction using devices with frequencies ranging between 900 and 2500 MHz. Electromagnetic microwaves heat matter by agitating water molecules in the affected and surrounding tissue producing friction and heat which induce cellular death via coagulation necrosis [70]. Microwave ablation is more effective in high-impedance tissues like the bone because poor thermal conduction in the bone is a limiting factor in radiofrequency ablation. Osseous relative permeability and low conduction help microwaves penetrate deeper and are more effective in thermal ablation compared with radiofrequency ablation [68].

Similar to RFA, reduction in pain from ablation procedures is thought to be attributable to a combination of proposed mechanisms including the destruction of pain nerve fibers in the periosteum and bone cortex, reduction in the size of the tumor burden and volume, and coagulative necrosis of the tumor cells with a resultant decrease in the production of nerve-stimulating cytokines such as interleukins and α-tumor necrosis factor [69, 72].

A disadvantage of microwave ablation is that it has an ablation zone that cannot be visualized in real time as can be done with cryoablation and MRI-guided focused ultrasound. The ablation size also varies according to the combination of wattage and time, and an accurate ablation zone size depends upon reliance on manufacturer guidelines. These guidelines can be problematic as most of them were calculated for use in soft tissue not bone. Heat transmission through cancellous bone is typically less efficient, rendering prediction of the ablation zone somewhat inaccurate. The first generation of microwave devices had a ceramic tip design that was more fragile than other tumor ablative devices. Given that fragility, MWA with these devices required more extensive drill access to approximate tumors in sclerotic or hard bone. The newer devices have more durable tips and are not nearly as fragile as the first generation models.

Overall, microwave ablation is a promising, safe, and effective treatment for osseous tumors that can result in effective ablative treatment of spinal metastatic disease. As with RFA, microwave ablation typically results in a prominent reduction in pain, improvement of patient function, and a substantial degree of local tumor control.

Summary and Conclusion

The spine is the most common osseous structure for metastatic spread of cancer, and the disability associated with spinal metastases is often profound. Radiation therapy is commonly used to treat metastatic spine disease and is an effective treatment but can cause some adverse events and increase the risk of vertebral fracture. Radiofrequency ablation uses a high-frequency alternating electrical current to produce heat that provides thermal ablation for metastatic disease, and minimally invasive percutaneous spine radiofrequency ablation has proved safe and effective in management of selected patients with vertebral metastases. Spinal RFA has

typically been used in conjunction with cement vertebral augmentation to provide optimal stability of the spine. The effective application of spinal RFA and cement augmentation involves optimizing the diagnosis of spinal metastatic disease which has a characteristic appearance on imaging. This characteristic appearance includes a convex border of the vertebral body, the presence of an epidural mass or paraspinal mass, multiple lesion, and the involvement of the posterior elements. Spinal RFA has been shown to be safe and effective and has multiple studies that demonstrate the efficacy of this treatment followed by vertebral augmentation. Multidisciplinary input can optimize the treatment of spinal metastases, and one of the most important considerations is the maintenance of bone health in patients with metastatic disease as there are multiple factors that can contribute to vertebral fractures in patients with metastatic disease including hormone production by certain cancers, hormone deprivation treatment for other cancers, and glucocorticoid treatment. One of the essential assessments for the necessity of treatment includes the Spine Instability Neoplastic Score that gives an objective score that reflects the degree of spinal stability compromise, and the greater the degree of instability, the greater the need for treatment. The overarching treatment plan for a spinal neoplasm includes a comprehensive physical examination, assessment of the patient's imaging, confirmation that the tumor is the pain generator, validation of the appropriate spinal approach, and confirmation of the appropriate RFA and VA devices that will be used. There are other thermal ablative treatments such as microwave ablation that may be used for spinal metastases. This therapy has been shown to be effective but is less well studied than RFA and is not nearly as widely available. Regardless of the type of ablative treatment that is used, a successful treatment is one that completely ablates the tumor with subsequent vertebral augmentation that regains as much anatomic alignment as possible. Spinal RFA has been shown to be very effective for reducing pain and optimizing symptom control. This is absolutely essential for patient comfort and has been directly inked to the patient's survival. These procedures have appropriately become a part of the multidisciplinary treatment algorithm for certain subgroup of patients with spinal metastases to achieve pain palliation and/or local tumor control.

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Chapter 11
Sacroiliac Joint

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Anatomy

The human pelvis is a bowl-shaped ovoid comprised of the paired appendicular hip bones and the sacrum. It not only provides the bony architecture which contains and protects the reproductive organs and lower viscera, but it also acts as the structural and functional junction between the trunk and lower extremities. The sacrum itself compromises the bulk of the posterior pelvic wall; the hip bones are joined anteriorly by the pubic symphysis and posteriorly by the sacroiliac joints (SIJ), the largest joints in the human body [1].

Historically classified as an amphiarthrodial joint, the SIJ is now more commonly accepted as diarthrodial since it largely demonstrates characteristics of a typical synovial joint. It follows then, that the joints have a complex structure, with a bony component, internal synovial lining, both hyaline and fibrous cartilage, surrounding ligaments and to some degree at least, an articular capsule. That said, the SIJ differs from other large synovial joints as well, especially when compared to the

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_11

typical spheroidal synovial joint. This is a reflection of not only its size, internal makeup, and complexity, but also its unique function.

Perhaps more than any other joint system, investigation of the posterior pelvis and SI joint reveals a pattern of inherent variability, adding greatly to the complexity of this structure. Whether investigating the bony macro-anatomy, the shape and configuration of the joint space itself, or the specific neural pathways and patterns of innervation to the joint, variability abounds. Not only is there significant person-to-person differences in these areas, there is often significant intrapersonal variation side to side [2, 3].

Areas of particular clinical concern regarding the anatomy of the SI joints include function, bony structure, cartilaginous and ligamentous relations, and, perhaps most significantly to this text, its innervation.

Function

Normal rotational motion was observed in the human SI joint in the mid-nineteenth century, and soon thereafter came descriptions of the cartilage spanning the joint [4]. While opinions currently vary in regard to the amount of motion the joint is capable of (and the implications therein), it is likely that the joint moves less than 3° longitudinally and transversely [5]. Since no musculature acts directly upon the SIJ, whatever motion it does express is done passively.

The specific function of the joint has also been disputed; what is clear is that it plays a unique and specific role in the human condition and is a critical factor in locomotion. Since the weight of the entire upper body (upper extremities, head, torso, and spinal column) sits squarely upon the sacrum, the SI joints are under significant and repeated stress. The pelvis must, therefore, be constructed in a model of both efficiency and strength. Primarily composed of lower density trabecular bone covered by more dense cortical bone, this composition allows for a relatively light weight, yet very strong, pelvic ring. The sacral side of the joint tends toward trabecular bone, while that of the ilium is typically more cortical.

The architecture of the SIJ complex is such that the sacrum is essentially locked into the pelvic ring, in part due to a robust system of ligamentous reinforcement, but also through the unique bony nature of the joint itself. The numerous interlocking and matching ridges and depressions of both the sacral and iliac articular surfaces may be adaptive, reflective of the joints' inherent role in providing stabilization of the pelvic ring [6], which in turn allows for weight-bearing and ambulation.

Functioning as stress-relieving mechanism, the SI joints help to moderate forces traversing the pelvic girdle and to transmit vertical forces between the upper and lower body during ambulation. Additionally, the planar aspect of the joint and the strong reinforcement of the numerous ligaments that surround it allow for a subtle gliding motion [7].

While it is now widely accepted that the SIJ often contributes to pain in the lumbar spine, pelvis, buttocks, and lower extremities (up to 20% of lower back pain

cases may involve pain originating from the SIJ [8]), this was not always the case. The role of the joint in pain was not always apparent. One of the earliest retrievable studies of SIJ anatomy, motion, and function detailed the natural history of its degeneration, but notably did not specifically mention pain as an identifiable or known issue relating to the joint [4]. Over time, the joint was suspected of contributing to back pain syndromes, but hard evidence was lacking. It is now known that the periarticular sacroiliac tissues contain nerves, nerve fascicles, and mechanoreceptors; this suggests an innate ability for the joint to experience and transmit pain [9, 10].

As with any other joint, the SIJ is susceptible to the age-related degenerative process as well as other arthridites. While some have referenced age-related spontaneous SI joint fusion, this is a misnomer; the joint does not truly fuse with age; it simply becomes stiffer and ankylotic and loses what little motion it once had [5]. When this natural process couples with osteopenia or osteoporosis, the sacrum is prone to fracture. Often referred to as sacral insufficiency fractures, several authors have noted that that these tend to run vertically and parallel to the SI joint itself, in a sense mirroring the joint. This reinforces the notion of the joint as a stress-relieving mechanism, for it has been noted that without the SIJ, the pelvis would be prone to fracture. Bogduk may have expressed this best when he eloquently noted that "in teleological terms, a solid ring of bone will not work; it will crack, and the sacroiliac joint is there in anticipation of that crack [7]."

Bones

The sacrum is a roughly-isosceles triangular-shaped bone upon which rests the vertebral column. The base of the triangle corresponds to the top of the S1 segment; the lateral portions of the bone correspond to the legs of the triangle, while the coccyx represents the vertex point. The sacrococcygeal junction is known as the sacral apex. The sacrum is wedged between the paired ilia, and the confluence of these structures constitutes the left and right sacroiliac joints.

It is perhaps easiest to consider the sacrum for what it actually is: the fusion of the five sacral vertebrae into one solid mass. Despite its distinctive size, shape, and nature, it does have some common anatomy with its more cranial siblings, including suggestion of vestigial sacral intervertebral discs ventrally and the remnants of sacral spinous processes dorsally. In addition, much of the body of the sacrum is comprised of the lateral mass on each side of the midline, representing the fused sacral transverse processes.

Dorsally, the triangular shape of the sacrum is readily apparent (Fig. 11.1). The cranial-most aspect of this triangle, the base of the sacrum, is a centrally seated, shallow, and flat depression which serves as the de facto superior endplate of S1 and constitutes the lumbosacral articular surface. Posterior and slightly lateral to this are found the superior articular processes of the sacrum (generally referred to as the SAPs of S1), which interlock with the inferior articular processes of the lowest

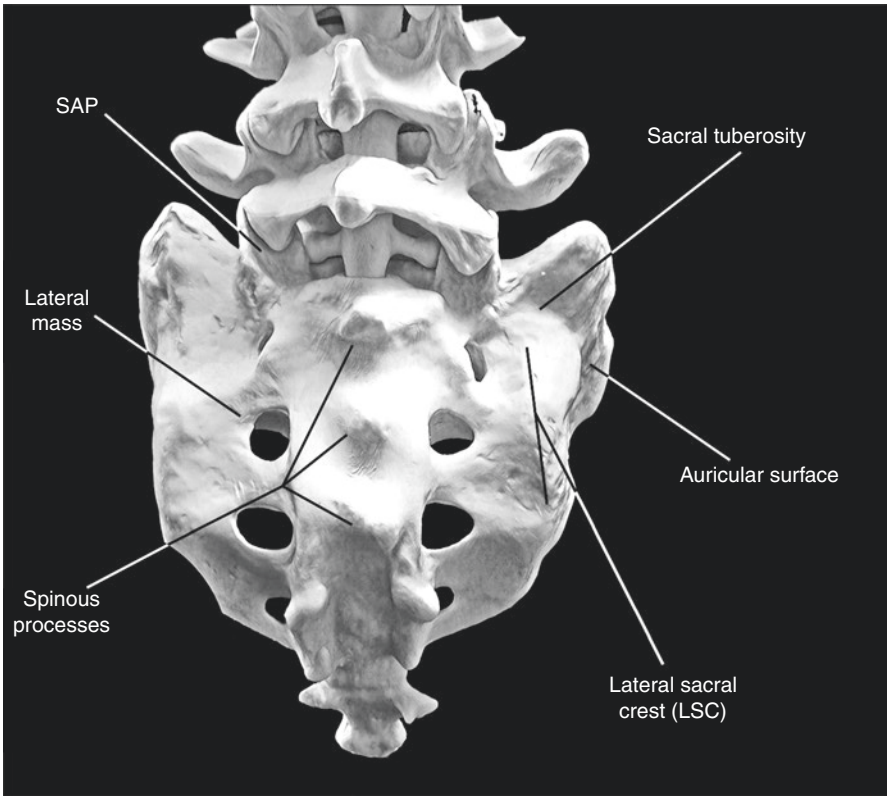

Fig. 11.1 Sacrum and lower lumbar spine, dorsal view. SAP superior articular process of the sacrum (S1)

lumbar vertebra (typically L5), forming the lumbosacral facet joint. Slightly inferolateral to the SAPs lie small bony protuberances known as the sacral tuberosities, which are important sites of ligamentous attachment. Extending caudal to this structure are the sacral tubercles, together known as the lateral sacral crest.

Perhaps the most readily apparent and prominent of all sacral structures are the neural foramina of S1–S4. A series of small, paired tunnels connecting the dorsal and ventral surfaces of the sacrum, these openings allow passage of the sacral nerve roots from the spinal canal into the posterior pelvic cavity, where they form the sacral plexus. The sacral spinous processes are visible in the midline, forming the medial sacral crest, better visualized from a lateral position (Fig. 11.2).

When viewing the sacrum from the lateral position, the articular surfaces become apparent and roughly correspond to the S1–S3 levels. These upper three segments not only constitute the bulk of the sacrum itself but also serve as the primary area of articulation with the ilium. The articular surface is largest cranially, smallest at its caudal end, and within the overall articular surface are two distinct regions. The first is an ear-shaped surface formally known as the *auricular surfac*e, which

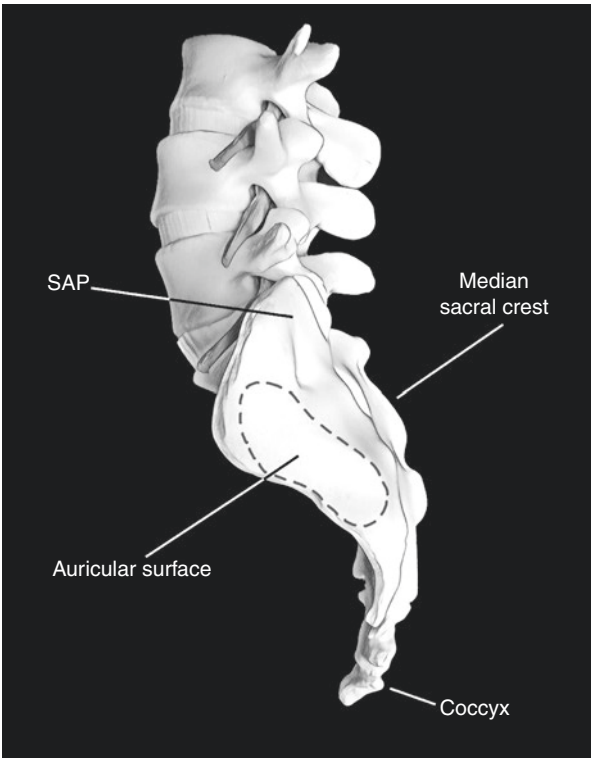

Fig. 11.2 Lumbosacral spine, lateral view. SAP superior articular process of the sacrum (S1)

compromises about 1/2 of the total joint area. Slightly dorsal and superior to the auricular surface lies a rough, irregular area that serves as a point of ligamentous attachment. At approximately S2, there is a significant depression within the sacral articular surface, which accepts a similarly shaped iliac prominence known as Bonnaire's tubercle.

From both the lateral and sagittal view, the curved nature of the sacrum becomes apparent; its anterior surface is distinctly smooth and concave and the posterior surface irregular and convex. Internally, the sacral spinal canal extends from the lumbosacral junction and terminates at the sacral hiatus, an opening just cranial to the apex.

The ilium is the largest and uppermost aspect of the pelvic bone and is mainly divided into the iliac crest and the ala (or wing) of the ilium (Fig. 11.3). The crest runs around the superior-most aspect of the ilium, from anterior to posterior; at each end are located the anterior-superior iliac spine (ASIS) and the posterior-superior iliac spine (PSIS), respectively. From this crest or ridge drops a wide, smooth, and shallow bowl, a ventral concavity known as the iliac fossa. The medial aspect of this bowl leads to the iliac side of the SIJ and in the other direction stretches forward, extending to form the pelvic brim and acetabulum, joining its contralateral partner at the pubic symphysis. Viewed laterally, the portion of the pelvic bone superior to the acetabulum and still beneath the crest is the wing of the ilium.

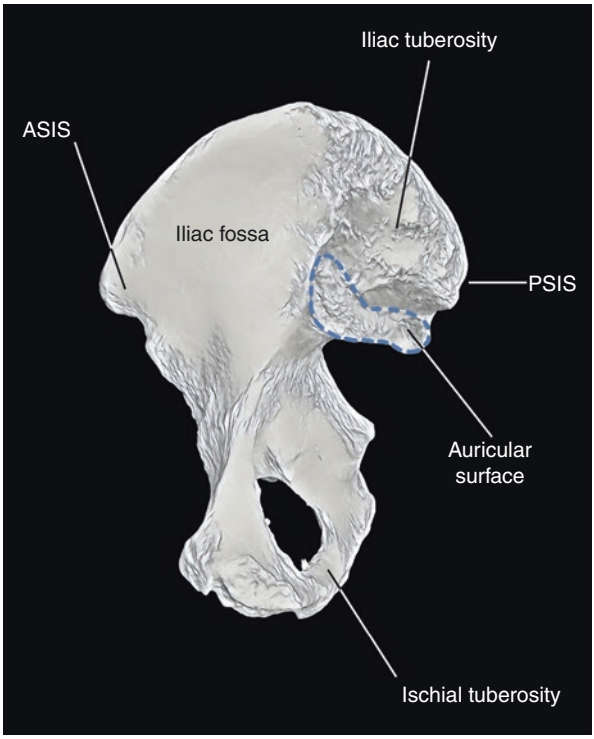

Fig. 11.3 Ilium, medial view. ASIS anterior-superior iliac spine, PSIS posterior-superior iliac spine

From a medial view, the articular surface of the ilium is appreciated, roughly bounded anteriorly by the ridge of the fossa, superiorly by the iliac tuberosity, posteriorly by the posterior superior iliac spine (PSIS), and inferiorly by the posterior inferior iliac spine.

The Sacroiliac Joint

The SI joint itself is approximately 1–2 mm wide, with a concave articular surface on the sacral side and a corresponding convex iliac surface. The sacral surface is generally a rough, irregular moonscape of shallows and ridges, valleys, and prominences, all matched by corresponding reciprocal topography on the ilium, allowing the joint to effectively lock together. From the AP view, the joint runs longitudinally and has a sinuous appearance. This twisted joint plane can further be observed by viewing axial cuts: the upper sacrum (S1) is wider dorsally, while the lower sacrum is wider ventrally.

Variants in joint shape have been observed; Prassopoulos et al. found an "accessory" SIJ configuration in 19% of the 534 patients studied with pelvic CT. This

articulation in the posterior-superior aspect of the joint was noted more often in the elderly and obese, suggesting the possibility that this accessory SIJ could be an acquired condition [11].

References to a total joint surface area of up to 17 cm^2 have been made [12], but a 2017 study using CT surface rendering in over 250 patients found an average surface area of about 12–14 cm^2. Three prominent morphological classes of joint shape were observed: scone shaped (Type 1), auricular (Type 2), and crescent-shaped (Type 3.) About 2/3 of joints were Type 2, and together Types 1 and 3 made up the remaining 1/3. Interestingly, a crescent-shaped joint was more frequently associated with pain in women, but not in men. A slightly larger average surface area was noted in men and was found to correlate with pain in both sexes [13].

Cartilage

The SI joint contains both cartilaginous and ligamentous tissue. The upper portion of the joint (at approximately the L5 level) is primarily ligamentous, the lower portion (S4) is cartilaginous, and the two types are found in roughly equal measure in the mid-sacral region of the SIJ [11].

Some authors have argued that the sacral side of the joint is primarily hyaline cartilage and the iliac side mostly fibrous, while others indicate a mix of the two on both sides. There is little disagreement, however, about the fact that the cartilage on the sacral side of the joint is thicker (1–3 mm.) Furthermore, the thin layer (<1 mm) of cartilage on the iliac side is more prone to osteoarthritic changes with age. A possible explanation for this was put forth by Kampen and Tillman, noting that different forces act on the sacral side of the joint as compared to the iliac and that this, at least in part, explains how and why they differ structurally and biochemically. In particular, the iliac side of the joint is subject to more stress during ambulation and thus is more prone to degenerative change [14].

The capsule of the SIJ can be difficult to define given the extent of the surrounding ligaments, and indeed its integrity as a true capsule remains somewhat in question. Using MR imaging, Puhakka et al. found that only the distal 1/3 of the joint resembles a true synovial joint with a joint capsule and that in other ways, the SIJ more closely resembles the strong fibrous connection of a symphysis [15].

When Fortin et al. performed SIJ arthrography on 76 patients who then underwent post-injection CT, over 60% demonstrated significant contrast extravasation. Most of this was subligamentous and dorsal, but some was also noted to leak into adjacent neural-containing structures (i.e., the S1 foramen) and some ventrally towards the lumbosacral plexus. Contrast was even noted to extravasate superiorly, reaching the sacral ala and the L5 nerve root sheath. It was postulated that these flow patterns could have significant implications in terms of SI pain symptoms and presentation [16].

Ligaments

As with bony anatomy and innervation, the ligaments of the SI joint can vary significantly in terms of their exact position but in general can be divided into intrinsic and extrinsic. Intrinsic ligaments have their origin and insertion within the joint itself and include the anterior sacroiliac (ASL), interosseous (ISL), posterior sacroiliac (PSL), and the long posterior sacroiliac ligament (LPSL.) Extrinsic ligaments include the iliolumbar (ILL), sacrotuberous (STL), and sacrospinous (SSL.) Together, this robust collection of primary (as well as some less significant secondary) ligaments serves to securely couple the sacrum and the ilia, forming a solid yet flexible ring.

The fan-like *anterior sacroiliac ligament* covers the entire ventral aspect of the joint and has upper, middle, and lower portions stretching from the anterolateral sacrum and to the anteromedial ilium (Fig. 11.4.) The ASL may converge with and blend into the joint capsule. It is well innervated and thought to contribute to SI complex pain.

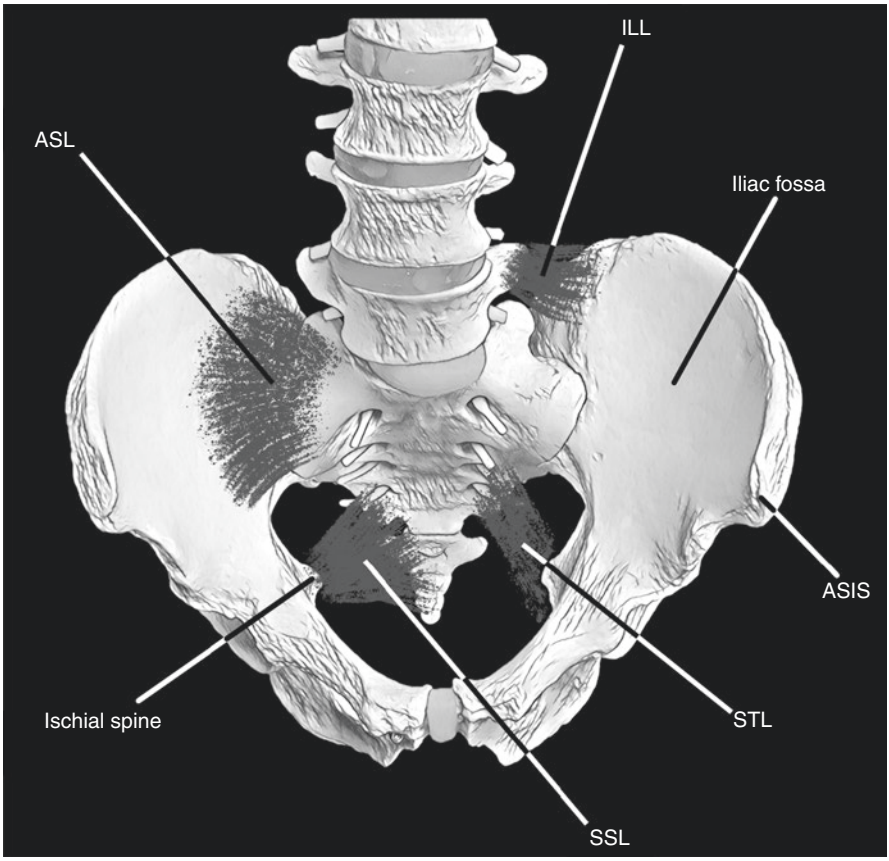

Fig. 11.4 Pelvis, ventral view. ASL anterior sacroiliac ligament, ILL iliolumbar ligament, ASIS anterior superior iliac spine, STL sacrotuberous ligament, SSL sacrospinous ligament

The *interosseous sacroiliac ligament* attaches to the iliac tuberosity and spans the upper joint space between the sacral and iliac tuberosities. This ligament is typically only found in the superior aspect of the joint. One of the strongest human ligaments, the thick ISL firmly locks the sacrum to the ilium.

As its name implies, the *posterior sacroiliac ligament* runs across the posterior aspect of the joint (Fig. 11.5) and is comprised of multiple layers and at least two distinct portions. A superior or cranial portion attaches to the lateral dorsal aspect of the sacral ala and to the ridge of the ilium. An inferior or caudal portion attaches laterally to the iliac tuberosity, iliac crest, and PSIS and medially to the lateral sacral crest. The *long posterior sacroiliac ligament* is a thin sheet of fibers extending from the PSIS to the third and fourth sacral tubercles.

The *iliolumbar ligament* runs primarily from the L5 transverse process (less often with additional contribution from some L4) to the sacral ala and iliac crest. The *sacrotuberous ligament* arises from the PSIS and extends to the caudal edge of the sacrum but also has a portion running from the coccyx to the ischial tuberosity. The *sacrospinous ligament* connects the anterolateral aspect of S3/S4 and the coccyx with the ischial spine.

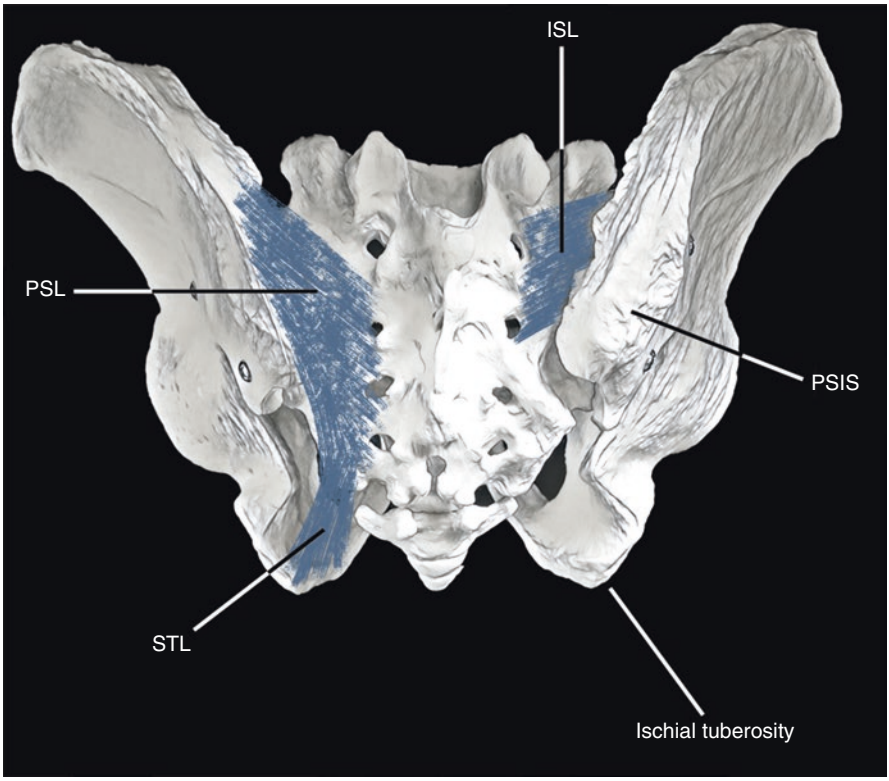

Fig. 11.5 Pelvis, dorsal view. ISL interosseous sacroiliac ligament, PSIS posterior-superior iliac spine, STL sacrotuberous ligament, PSL posterior sacroiliac ligament

Innervation

Numerous studies have attempted to clarify the complex innervation of both the posterior and anterior SIJ (Table 11.1.) Well over a half century ago, Solonen noted dorsal innervation from S1 to S2 and ventral innervation from L3 to S2 as well as from the superior gluteal nerve [2]. The obturator nerve was specifically singled out as not contributing to SIJ innervation, but otherwise a significant degree of variability in the nerve supply was observed. Additionally, it was noted that the right and left joints of a single individual may show significant variance in innervation, a finding which has been confirmed more recently [17]. In other early work, Bradley found nerve filaments in a "plexiform arrangement" on the dorsal sacrum and identified innervation to the SIJ from L5 to S3 [18]. Decades later, Grob reported that the only source of SIJ innervation was from the lateral branches of the S1–S4 dorsal rami and that the ventral aspect of the joint was conspicuously devoid of innervation [9].

Yin et al. also noted that the SIJ was primarily innervated dorsally. In their study, every joint studied contained contribution from S1 to S3, and the course taken by lateral branches from the neuroforamina to the joint complex was often noted to be indirect, meandering, and circuitous. They also found that when considering the dorsal aspect of an individual neural foramen as a clock face, the lateral branches largely exited the foramen between 2 and 6 o'clock on the right and between 6 and 10 o'clock on the left (Fig. 11.6.) [17] This basic finding was later verified by others [19].

McGrath and Zhang studied the long posterior sacroiliac ligament specifically and found primary innervation by S2–S3. Contribution from S4 was less frequently observed, and even rarer still from S1 [20]. Szadek et al. confirmed L4 and L5 rami contributions ventrally [21].

In a cadaveric study of posterior SIJ innervation by Roberts et al., S1/S2 were involved in 100% of studied cases, S3 in 88%, L5 in only 8%, and S4 in only 4%

Table 11.1 SIJ innervation: A review of the literature

Author	L4	L5	S1	S2	S3	S4	Sup. Gluteal
Solonen 1965	V	V	D, V	D, V			V
Bradley [18]		D	D	D	D		
Grob et al. [9]			D	D	D	D	
Yin et al. [17]			D	D	D		
McGrath & Zhang [20]			d	D	D	d	
Szadek et al. [21]	V	V					
Fortin et al., 1999			D	D	D	d	
Roberts et al. [22]		d	D	D	D	d	
Cox & Fortin [19]		D	D	D	D	D	d
Cox et al. [24]	V	v					

V ventral contribution (common), *v* ventral contribution (rare), *D* dorsal contribution (common), *d* dorsal contribution (rare)

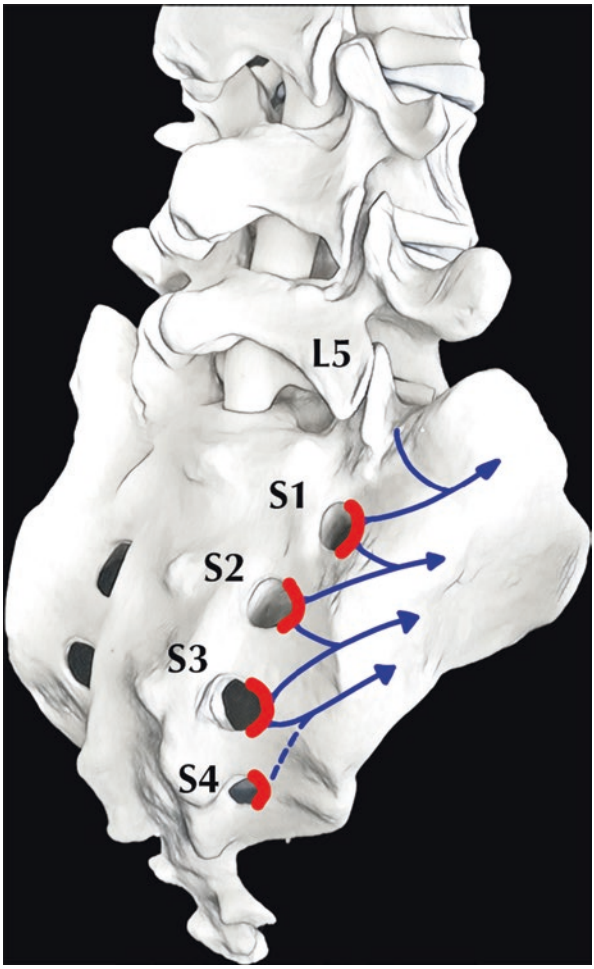

Fig. 11.6 Schematic representation of dorsal sacroiliac joint innervation. Red, likely area of lateral branch exit from neural foramen (i.e., 2–6 o'clock); blue, most common levels of nerve supply; blue (broken), less common supply. S1–S4: sacral neural foramina. L5, primary dorsal ramus of L5

[22]. Cox and Fortin noted involvement of L5–S4 and, occasionally, the superior gluteal nerve. In almost 80% of sacral neuroforamina, more than one exiting lateral branch was noted and often as many as 4; moreover, many of these anastomosed with those of adjacent levels (Fig. 11.6.) In nearly half of their subjects, contribution from the superior gluteal nerve was also documented [19].

The 41st edition of the venerable *Gray's Anatomy* suggests S1, S2, and the superior gluteal nerves as contributors to the SIJ, with possible inclusion of the obturator nerve or lumbosacral trunk [23]. Cox et al., however, studied the anterior innervation of 24 cadaveric SI joints and found no contribution from the obturator nerve or lumbosacral trunk in any specimen; neither was sympathetic input noted. The ventral ramus of L5 was found to supply anterior innervation in 80% of the specimens; L4 in 10%, and both L4 and L5 in the remaining 10%. They did not find direct sacral innervation to the joint [24].

Workup

The clinical presentation of pain in the sacroiliac joint may be varied and does not follow a pathognomonic pattern. Multiple pathologic states of the musculoskeletal system can present with pain that localizes to the sacroiliac joint, and care must be taken to rule out a rheumatologic, inflammatory, or infectious etiology. A thorough history and physical exam are key to rule out other causes of pain in the area and can include lumbar disc or facet disease, malignancy, hip pathology, myofascial syndromes, as well as gastrointestinal, urological, gynecologic, and vascular causes [25] Radiological evidence and laboratory studies may be considered to rule out inflammatory disorders if suspected. Diagnostic SI joint blocks should also be considered as a portion of the workup for SI joint suspected pain.

History

A thorough history is required to accurately begin the workup of suspected sacroiliac joint pain. Primary pathologies leading to sacroiliitis include rheumatoid arthritis, Reiter syndrome, ankylosing spondylitis, and psoriatic arthritis. Secondary etiologies include spinal fusion, scoliosis, and leg length discrepancy [25]. Most often, pain in the sacroiliac joint may be caused by poor biomechanics and functional deficits. The patient may describe the quality of deep, dull aching pain with bouts of sharp exacerbations; symptoms such as burning, paresthesias, electrical sensation, or shooting pain may point more toward a neuropathic etiology of a different origin. Pain referral patterns may help point toward diagnosis. Slipman et al. reported pain referral patterns after positive diagnostic SI joint injections where 94% reported buttock pain, 72% low back pain, and 14% groin pain [26, 27]. Typical historical features are varied and include low back and buttock pain when walking, standing, or sitting, posterior thigh pain, and pain on bending over or backward. Pain is typically described as worse after sitting for prolonged periods and stepping on the affected the side. Getting up from a chair or other sitting to standing transitional activities may exacerbate symptoms. Although these pain referral patterns are typically associated, no evidence of a reference standard is currently accepted in practice to accurately diagnose SI joint pain from history alone [27, 28].

Physical Examination

The clinical examination is integral to help elucidate sacroiliac joint pain and decipher the etiology. Evaluation of gait, assessment of leg-length discrepancy, and routine lumbar spine and lower extremity exam should be administered to ascertain biomechanical and functional deficits and rule out secondary diagnoses [25]. A

thorough exam of the hip should be included as well as routine neurologic and provocative tests of the hip and lumbar spine. Palpation of the SI joint and location of maximal tenderness should be noted. The Fortin finger test has been described as indicative of SI joint pain when the maximum point of tenderness is within 2 cm inferomedial to the posterior superior iliac spine (PSIS) with one finger [25].

Multiple dynamic and provocative tests are described for diagnosing SI joint pain and pathology. No single test has been found to be highly sensitive [29]. Commonly performed motion tests include the standing flexion test, with less common but described are the Gillet test and sitting flexion test. Provocative tests include the compression test, Patrick (FABERE) test, Gaenslen's test, gapping test, and the sheer test.

The standing flexion test (Figs. 11.7 and 11.8) measures relative motion of the sacroiliac joint with respect to lumbar-pelvic motion. The patient is asked to stand up while the examiner places a thumb on each inferior aspect of the PSIS. The patient is asked to bend forward. Both PSIS should move in tandem; if one moves superiorly and anteriorly to the other, this side is restricted [30].

Provocative tests are more commonly employed to elucidate the source of pain. The compression test is performed with the patient in a lateral decubitus position.

Fig. 11.7 Standing flexion test

Fig. 11.8 Standing flexion test

The examiner then places medial pressure on the anterior superior iliac spine (ASIS) from a position behind the patient with arms extended. A positive test would reveal pain elicited in the ipsilateral SI joint or gluteal region [30].

The Patrick/FABERE (flexion, abduction, external rotation, extension) test (Fig. 11.9) is commonly utilized in the exam of the lumbar spine and lower extremities. The patient is laid supine on the table, and the knee is flexed, and the ipsilateral foot is placed on the opposite knee. This motion extends the ipsilateral hip joint. Further gentle pressure is placed on the flexed knee, and the examiner's other hand places gentle pressure on the opposite ASIS. Pain generated in the ipsilateral low back is likely due to SI joint pathology [30].

Gaenslen's test (Fig. 11.10) has had limited research to draw major conclusions as to the presence of SI joint sources of pain but has been traditionally employed. The patient's ipsilateral hip is hyperextended by the examiner carefully off the side of the exam table. The opposite hand is then placed on the contralateral ASIS with gentle downward motion to assist fixating the lumbar spine against the exam table. This motion creates a rotating force through the axis of the SI joint. Pain in the ipsilateral SI joint is considered a positive test [30].

The sheer test (Fig. 11.11) has had conflicting results in sensitivity and specificity [30]. The patient is placed in the prone position, while the examiner places cranially directed pressure on the sacrum at the coccyx. Each lower extremity is then

Fig. 11.9 FABER test

extended at the hip with caudally directed traction by the examiner; the test is positive if patients' pain is reproduced [30].

Data has been lacking overall for any one of these single tests, among other less common tests, as being highly sensitive [29, 31], and overall validity of these traditional tests even when coupled with history may not exist in the diagnosis of SI joint pain [32]. Dreyfuss et al. studied 12 diagnostic tests and found none to be reliable in diagnosing SI joint pain [29], although this has been criticized for having a high threshold for pain reduction (90%) when compared to a diagnostic block. Other studies have shown that when three or more clinical tests described above combined with a more modest reduction in pain threshold for a diagnostic block have high predictive value [32–34].

Radiological Evidence

Computed tomography (CT) scans, x-ray studies, magnetic resonance imaging (MRI), and radionuclide bone scans have all been utilized to aid in the diagnosis of SI joint pain. In general imaging of the SI joint should be considered when the underlying diagnosis of sacroiliitis from a spondyloarthropathy, septic sacroiliitis,

Fig. 11.10 Gaenslen's test

metastatic disease, sarcoidosis, or metabolic disorders is suspected to be the etiology of the pain [35]. In cases of trauma and inflammatory disorders, bone erosion, joint space irregularities, sclerosis, and ankylosis can be visualized on CT and x-ray [27]. However there are no studies that associate x-ray abnormalities with absence or presence of SI joint pain and a diagnostic block and CT scan with minimal association [27].

MRI findings of bone marrow edema, joint erosions, and fat erosions may be present in cases of sacroiliac pain and may be associated with the presence of inflammatory disorders such as ankylosing spondylitis. These findings have similar prevalence in the asymptomatic population and nonspecific low back pain [27, 36]. MRI should usually be considered when ruling out other sources of pain or in conjunction with laboratory testing and rheumatologic referral for spondyloarthropathy and staging for biologics. MRI has been shown to diagnose sacroiliitis earlier than plain radiography [37].

Radionuclide bone scans have shown low sensitivity and high specificity in the diagnosis of SI joint pain [27]. It is not recommended due to the high levels of radiation exposure, however may be considered in cases where diagnostic injection is not possible, or for metastatic disease and stress fracture detection [25].

Fig. 11.11 The sheer test

Diagnostic Intra-articular Injection

Diagnostic intra-articular SI joint injection can be considered as part of the clinical workup prior to further therapeutic treatment for its positive predictive value. The diagnostic block has been used as a reference standard in numerous studies for aiding the diagnosis of SI joint pain, but there is currently no accepted "gold standard" [32–34]. Diagnostic injection should be performed with the aid of imaging and is commonly performed with fluoroscopic guidance. Intra-articular injections without radiologic guidance have been found to be intra-articular in only 22% of patients [38]. The degree of response to injection is debated, but a successful injection is generally accepted as confirmation of a SI joint dysfunction diagnosis [32]. When SI joint pain is the working diagnosis, a single diagnostic block may have a wide variability in positive response, 29–63% of the time, but when two blocks are performed, this decreases to 10–33% [28]. It has been suggested therefore that not all pain emanating from the SI region is from an intra-articular source but may be related to ligamentous and other extra-articular sources such as the posterior sacroiliac ligament [27]. The posterior sacroiliac ligament has been implicated as a pain generator itself, and some preliminary evidence exists for positive diagnostic

blockade of the ligament with sacral lateral branch blocks. One may consider this in the workup if SI source of pain is still suspected in the case of a negative diagnostic intra-articular block [39].

Procedural Technique

Abbreviations

AP	Anterior-posterior
Lat	Lateral
SLBB	Sacral lateral branch block
LBN	Lateral branch nerve
RFA	Radiofrequency ablation
SIJ	Sacroiliac joint
PSFA	Posterior sacral foramina

Introduction

SIJ radiofrequency ablation is a minimally invasive, safe, and effective therapeutic modality when performed by a skilled clinician, utilizing image guidance and following recommended safety precautions. Some commonly used synonyms for ablation are "neurotomy," "denervation," and "lesion," which will be used interchangeably in this section. A recent meta-analysis comparing the efficacy of different radiofrequency techniques (thermal, pulsed, and cooled) found that all three techniques resulted in reduction of pain for up to 12 months compared to baseline [56]. Various techniques will be explored to some degree in this chapter.

Background for Sacral Block Technique

Intra-articular sacroiliac joint injections have been the reference standard for diagnosis and treatment of SIJ complex pain. However, intra-articular steroid injections typically have demonstrated only short-term pain relief [51], inferior to the durability of relief afforded by SLB RFA [50]. As we begin to better understand the segmental innervation of this joint, an alternative method to diagnose and treat SIJ-related pain has emerged with an abundance of evidence-based support.

Described fluoroscopy angles for sacral imaging and radiographic target needle locations vary widely in the literature. To our knowledge, the only study that presents a validated technique for lateral branch blocks was performed by Dreyfuss et al. The authors postulated that administering a small volume of local anesthetic to the sacral lateral branches by a multi-site, multi-depth approach would

anesthetize the intra-articular portion of the SIJ superior to a single-site, single-depth approach. This multi-site, multi-depth technique takes into account the variable topography of the sacrum. In the same study, dye injections, using this approach followed by cadaveric dissection demonstrated a 91% accuracy in staining the S1–S3 lateral branch nerves [40].

Background for Sacral RFA Technique

Historically, there has been a great deal of need for optimization of techniques to treat SIJ dysfunction. Due to variable anatomy (*as previously described in this chapter*), there is no standard approach to denervation of the sacroiliac joint. Primary radioablative methods for SIJ RFA are termed "standard" (or conventional) therapy, in which the active tip of an insulated cannula is placed adjacent to a neural target, causing a small area of tissue coagulation and thus creating a lesion of the target nerve [42], and cooled RF, in which internally cooled probes distribute ionic heat further away from the electrode's active tip, projecting distally and reaching larger lesion volumes than conventional thermal RF [54]. Further subsets are monopolar RF, utilizing a single needle to create a lesion, and bipolar RF techniques. In bipolar techniques, typically, the needles are placed parallel to each other, and in RF, the current flows between two needles. Advantages of cooled RF and bipolar RF include creation of a large-volume lesion [22, 50].

Overview of Sacral Sensory Innervation

As previously reviewed in this chapter, cadaveric studies have indicated variability in the anatomical distribution of the sensory innervation of the SIJ [19, 22]. Sacral lateral branch nerves commonly reside 0–2 mm superficial to the dorsal sacral plate and demonstrate tremendous variability and unpredictability of their exit points from the sacral neural foramina, with cadaveric anatomic locations spanning up to 120 degrees [19] (Fig. 11.12). The sensory segmental innervation of the posterior sacroiliac joint, including dorsal and ventral contributions, is not entirely understood in the literature [17, 19, 45–47]. The uncertainty of our understanding of the precise innervation is evidenced by the wide range of RFA techniques and reported radiofrequency (RF) probe positions [19].

Though the precise spinal levels have not been entirely defined, segmental innervation that may be safely accessed for therapeutic RF is primarily achieved from the posterior primary rami to the sacral lateral branches of the S1–S2, with contributions from L5 and S3 [19, 22]. A number of retrospective and prospective studies have suggested that radiofrequency ablation of these nerves can provide durable pain relief and improvement in quality of life for patients with SIJ-mediated pain [16, 17, 41, 48, 51–53].

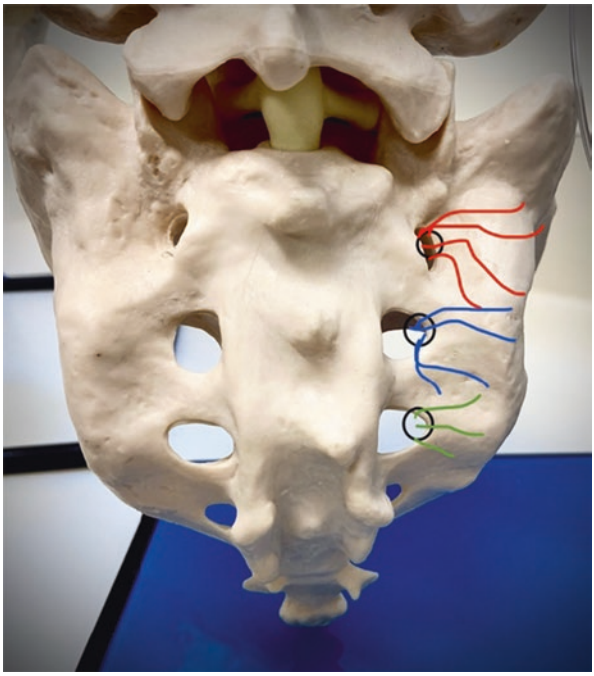

Fig. 11.12 Variable trajectory of the lateral branch nerves as they course through the posterior sacral foramina. Dorsal foramina are outlined in black

Indications

Treatment for sacroiliac joint dysfunction is usually nonoperative and focuses on restoration of normal joint motion. However, in patients who have failed 4 to 6 weeks of conservative management including a comprehensive physical rehabilitation program, local icing, mobilization of the joint, bracing, and nonsteroidal anti-inflammatory medication trials, an SIJ injection or lateral branch block can provide both diagnostic and therapeutic information about the primary pain generator [43, 44]. Not unlike radiofrequency ablation of the lumbar medial branch nerves, which has largely supplanted intra-articular facet joint injections for facet-mediated pain, sacral or lateral branch radiofrequency ablation has been shown to be superior to sacroiliac joint injections for durability of pain relief [51]. For patients who receive only temporary relief from intra-articular injections or a single set of diagnostic lateral branch blocks with a small volume of local anesthetic, radiofrequency neurotomy may provide longer-lasting and more effective pain relief. Interestingly, the percent pain relief from these diagnostic injections has not clearly demonstrated predictability for pain relief with radiofrequency neurotomy [42]. Nonetheless, in the SLBB paradigm, many insurance payors ask for specific diagnostic blocks and specific results following these blocks prior to approval of SIJ RFA.

Contraindications

- Absolute
  - Absence of informed consent
  - Local Infection
  - Hypersensitivity or allergic reaction to agents
  - Local malignancy
- Relative
  - Cardiac disease
  - Uncontrolled diabetes mellitus
  - Systemic infection
  - Bleeding diathesis
  - Full anticoagulation
  - Pregnancy

Informed Consent

Patients must be fully informed of the nature of the procedure and potential risks including bleeding complications, infection, and local tissue injury.

Patient Education

Patients should understand the expectations regarding postoperative discomfort, modification of activity levels, and any work restrictions prior to the procedure.

Sedation

Generally, no sedation is required for either SLBBs or RFA. If the patient is particularly apprehensive about the procedure, short-acting IV sedative medications can be administered.

Patient Preparation

Optional bowel prep – clear liquids and a suppository. Bowel shadows can affect visualization of fluoroscopic targets.

Patient Positioning for Sacral Procedures

Position the patient prone on the examination table with a pillow under the abdomen to allow gravity to lower the hips and reduce the curvature of the sacrum.

C-Arm Positioning for Sacral Procedures

As with all image-guided procedures, proper c-arm image intensifier positioning is key. There is tremendous anatomic variability in morphology among sacra (Fig. 11.13). The authors recommend beginning with a fluoroscopic scout view in the lateral position to assess the degree of curvature of the sacrum. This element of perioperative planning will aid in determining the optimal degree of cephalad-caudal inclination of the image intensifier required to visualize each target and save time and unnecessary struggle. Then, reposition the image intensifier to an AP view to visualize identifiable bony landmarks in the trajectory view. Cooled RF and conventional RF typically differ in the fluoroscopic trajectory view, with the former utilizing a coaxial approach (Fig. 11.21) and the latter utilizing a cephalad trajectory with a skin entry point significantly inferior to the radiographic target (Fig. 11.22). This will be described in more detail later in this section.

In a normally curved sacrum, a cephalic inclination of the C-arm will flatten the superior endplate of S1 and will open the view of the S1 neural foramen below the pedicle. Visualization of "Charley's lines" can aid in identifying the radiographic target (Fig. 11.14). The junction of "Charley's lines" with the PSFA indicates the lateral foraminal border. The smaller lucency, which is the dorsal PSFA, is visualized in the superior lateral quadrant of the foramen. Tilt the image intensifier oblique 5 degrees ipsilateral or contralateral to optimize visualization of the foramen. Commonly, a neutral angle is required for S2, and a slightly caudal tilt (3–5 degrees) is required for S3.

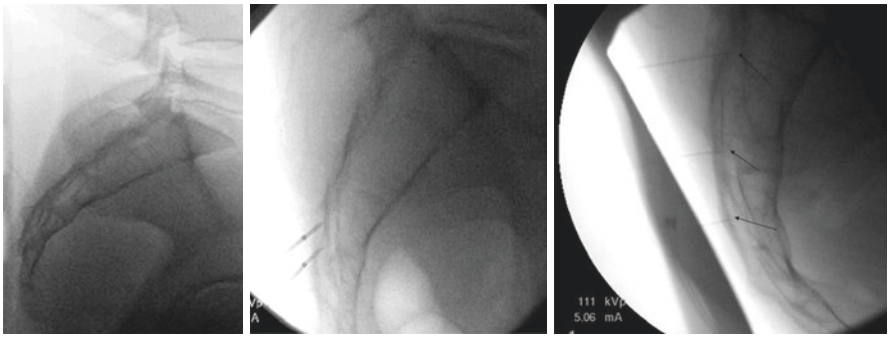

Fig. 11.13 Variable morphology of sacral kyphosis. Scout lateral images such as the figures shown can aid in planning fluoroscopic angles in the trajectory view

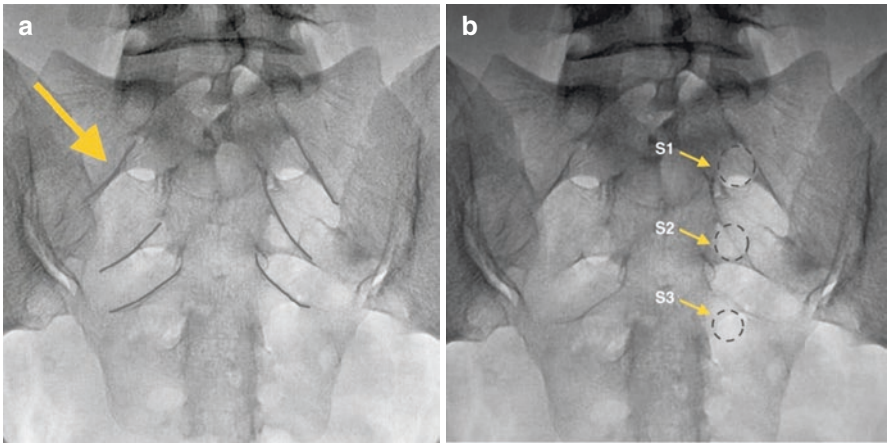

Fig. 11.14 (**a**) Identification of bony landmarks. "Charley's lines" are produced by the inferior surface of the sacral costal element and the lateral border of the posterior foramen. Charley's lines aid in identifying the dorsal foramen at each sacral level. (**b**) Dorsal sacral foramina of S1, S2, and S3 (dotted lines) appear below Charley's lines

C-Arm Positioning

There are a variety of approaches and techniques that have been utilized for denervation of the sacroiliac joints. Using a conventional (or traditional) approach, the fluoroscopic angle is inclined in a (extreme) caudal tilt so that the active tip of the needles comes to lie in the plane with the sacrum. This approach may be performed with a monopolar or bipolar technique as visualized in Fig. 11.15. On the other hand, the cooled RF technique is performed with an AP image intensifier angulation, most similar to traditional SLBBs. Traditional targets for radiofrequency techniques of the SIJ are the L4 medial branch-optional, L5 dorsal ramus, and the lateral branches of S1, S2, and S3 after they exit posteriorly through the corresponding neural foramina *(as previously described)* (Fig. 11.16).

Description of L5 Dorsal Ramus Block Technique

The SLBB paradigm should include a diagnostic block of the L5 dorsal ramus, for which the technique is the same as the precursor to lumbar RFA. This diagnostic technique is well described and validated throughout the literature [52, 53] and is included here for completeness. The target point for the L5 dorsal ramus is the notch between the base of the superior articular process and the sacral ala (Fig. 11.17). Optimal visualization is achieved upon squaring off the superior endplate of S1 and utilizing an oblique angle of the image intensifier from 0°to 10° ipsilaterally, noting

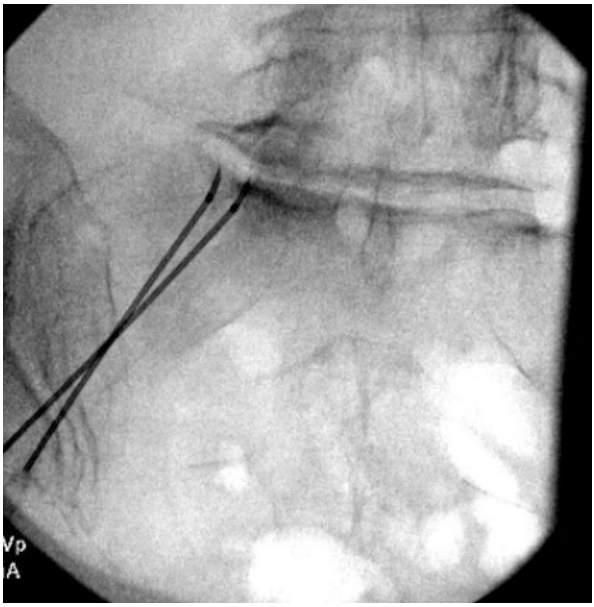

Fig. 11.15 Anterior-posterior view demonstrating a bipolar needle technique, placement at the L5 dorsal ramus

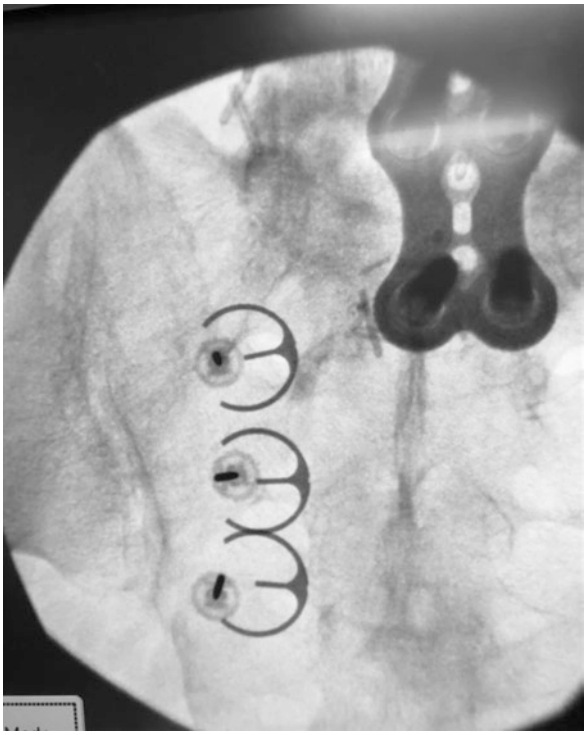

Fig. 11.16 Anterior-posterior view demonstrating cooled RF needle placement; lateral border of the PSFA of S1, S2, and S3

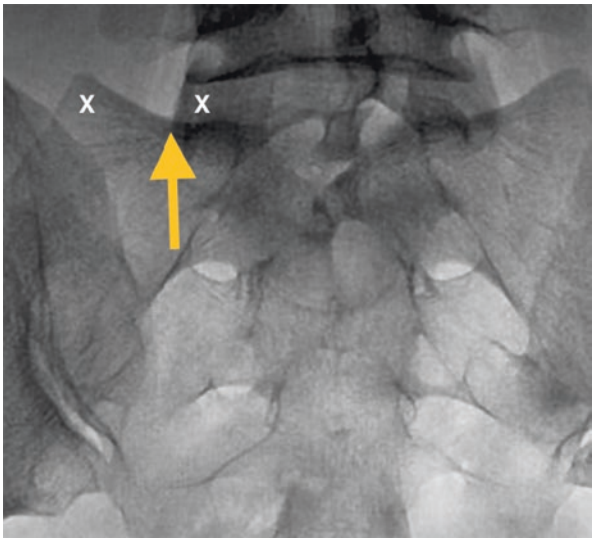

Fig. 11.17 Anterior-posterior view demonstrating the radiographic target of the L5 dorsal ramus (yellow arrow) between the base of the superior articular process and the sacral ala (X's)

that anatomic variations may require adjustment of the fluoroscopic angle within the ranges described. *Injection of local anesthetic 0.5–1 mL is acceptable (cite ISIS book above paragraph).*

Description of Sacral Lateral Branch Block Technique

Multi-site, multi-depth technique is the only validated technique for SLBBs. As previously described, the sacral nerve trajectories are far less predictable of their locations and depths compared to lumbar MBBs. SLBBs should be performed approximately 8–10 mm lateral to the posterior NF of the sacrum at multiple sites and multiple depths [40]. In the lateral view, the needles much reach the sacral plate (Fig. 11.18). Administer a small volume of local anesthetic (0.2–1 cc) over each nerve at multiple sites, typically 2–3 sites per level at S1, S2, and S3. Images demonstrating the multi-site, multi-depth technique are well described by Dreyfuss and included in Reference [40].

Description of L5 RFA

C-arm positioning: Line up endplate of S1. The target is the notch between sacral ala and the lateral border of the S1 SAP (Fig. 11.19a,b). On the lateral projection, the probe should not extend beyond the midline of the S1 SAP to avoid nerve root lesioning. In the cooled RF technique, the lesion projects ventrally, and a slightly

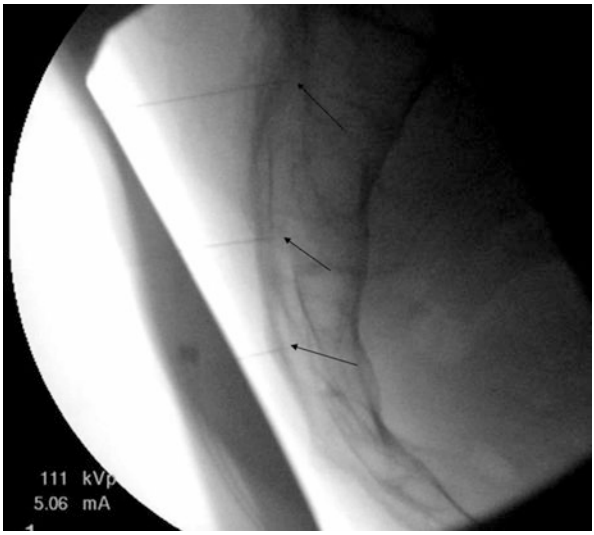

Fig. 11.18 Lateral view of sacral blocks at S1, S2, and S3

more dorsal needle position is advised (Fig. 11.19c,d). An optional second lesion may be performed more dorsally and medially. There is no clear evidence to suggest a second lesion confers additional benefit. The L5 dorsal ramus is differentiated from other lumbar levels by the angle typically used for entry and trajectory toward the target. At L5, the iliac crest may interfere with the typical oblique positioning for lumbar medial branch targets. In these cases, a slight oblique angulation of 5 to 10° is optimal to reach the target nerve.

Description of Sacral Lateral Branch RFA Technique

Many techniques for cooled RF and conventional RF are described throughout the literature. It is noted that Stout's 2018 study suggested expanding the target size from the commonly accepted cooled RF clock-face algorithm in order to successfully lesion all SLB nerves and reduce the percentage of nerves missed with the current approach. This recommended technique is well described with images in the publication in *Pain Medicine* [55], and is not discussed in this chapter.

There are multiple described techniques for applying local anesthetic pre-procedure. It is necessary to anesthetize the skin at the needle entry site. Optionally, local anesthetic may be applied by caudal epidural access. For large-gauge RF needles, such as those used for cooled RF, an 18-gauge introducer needle can help penetrate the skin. Especially when first learning to perform the procedure, it is helpful to use a 22- or 25-gauge finder needle to identify targets and determine depth. Additionally, if caudal anesthesia is being applied, injected dye will create a "Christmas tree" pattern epidurogram that may delineate the sacral foramina fluoroscopically and improve visualization of the neuroforamen and, thus, the associated radiographic targets. A measuring tool called an Epsilon aids in identifying the optimal distance (7–10 mm) from the lateral border of the PSFA to the LBN's lesion site (Fig. 11.20).

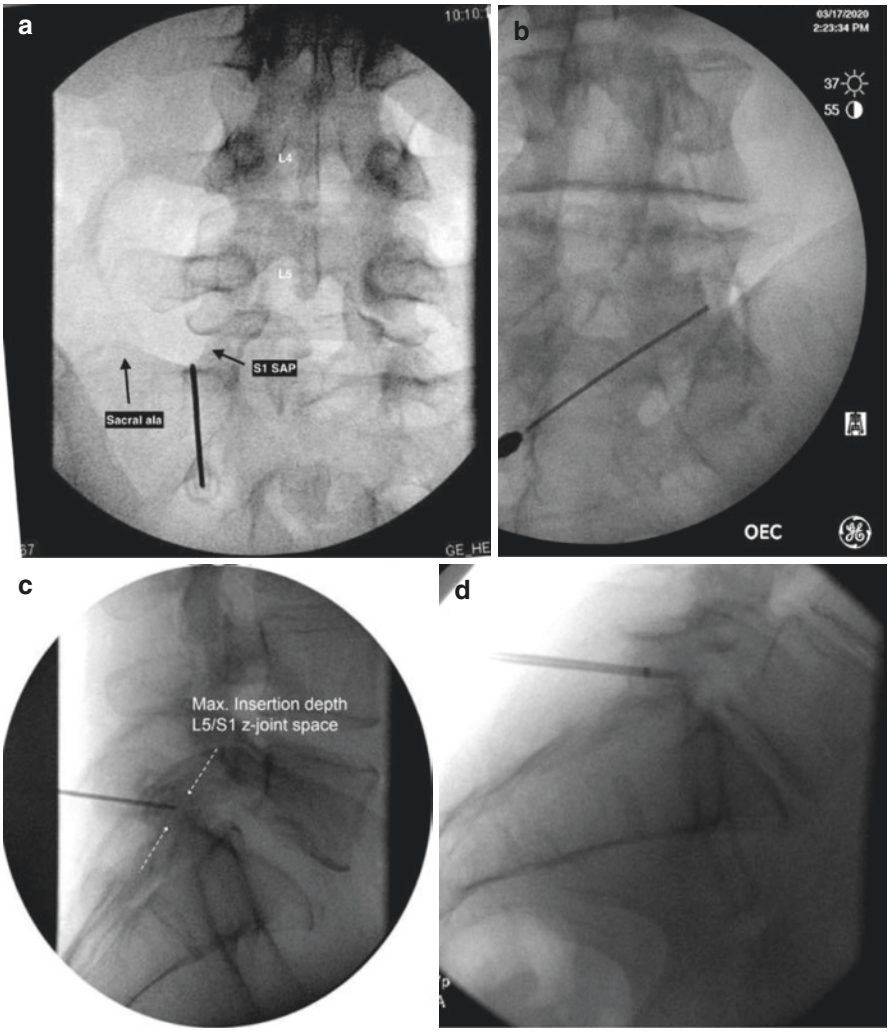

Fig. 11.19 (**a**) Anterior-posterior view demonstrating the L5 dorsal ramus needle placement at the notch between sacral ala and the lateral border of the S1 SAP. (**b**) Contralateral oblique view demonstrating L5 dorsal ramus needle placement. This is an optional confirmatory view. (**c**) Lateral fluoroscopic image of RF needle placement at the L5 dorsal ramus demonstrating optimal positioning dorsal to the midpoint of L5/S1 facet joint. Fig. 8.4 More ventral positioning of the needle risks inadvertent lesioning of the L5 nerve root leading to cutaneous dysesthesia and inadvertent entry into the epidural space. The needle placement in (**d**) is too ventral for cooled RF but optimal for conventional RF (**d**). (Courtesy of Zachary McCormick, MD)

Using a clock face paradigm, lesion locations that have been described for cooled RF needle placement are shown in Table 11.2.

C-arm image intensifier positioning differs significantly between two commonly accepted techniques, cooled RF and conventional RF. In the cooled RF approach, a coaxial needle trajectory and gentle guidance of the radiofrequency cannula toward

the bony landmarks under intermittent fluoroscopy is recommended. In the conventional approach, it is critical that the electrode be placed parallel to the course of the nerve. This approach typically requires a cephalad trajectory with a skin entry point significantly inferior to the radiographic target. Gently guide the needle so that the active tip is in plane with the sacrum (Fig. 11.22). The technique is similar for conventional monopolar and bipolar needle placement. Once os has been reached, a lateral fluoroscopic image can verify posterior placement of the needles and confirm there has not been inadvertent epidural entry. When the introducer needle tip reaches os, removing the stilet will leave the introducer in place 2–3 mm posterior to the bony elements (Fig. 11.23). Local anesthetic 0.5–1 cc volume is typically deposited prior to the neurotomy. Avoid lesioning directly over the bone, which may create significant discomfort for the patient. Place probes at the positions on Table 11.2 at each site, depending on the number of probes available (Fig. 11.21). A spinal needle can be inserted at the middle of the entry position to inject a modest amount of local

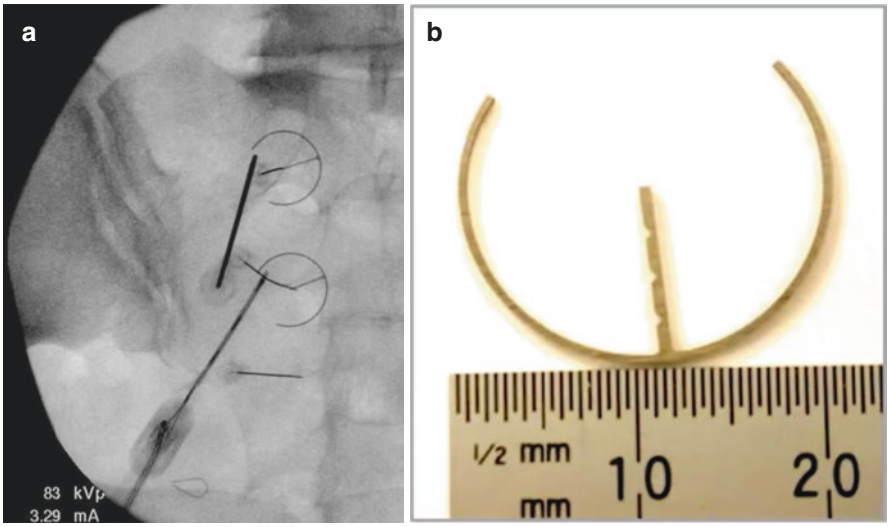

Fig. 11.20 (**a**) Epsilon placement at the optimal position with the central spoke at the lateral border of the PSFA. The two larger-gauge RF needles are shown at S1 and S2, 9:30 position. The three smaller-gauge spinal needles are shown contacting the central spoke of the Epsilon at the lateral border of the foramina of S1, S2, and S3. (**b**) An Epsilon is designed to localize the optimal target sites for RF lesioning 8–10 mm lateral to the sacral foraminal border

Table 11.2 Cooled RF sacral lesion locations along a clock face

	Right side	Left side
S1	2:30, 4:00, 5:30	9:30, 8:00, 6:30
S2, S3	2:30, 4:00	9:30, 8:00

Modified with permission from Avanos COOLIEF

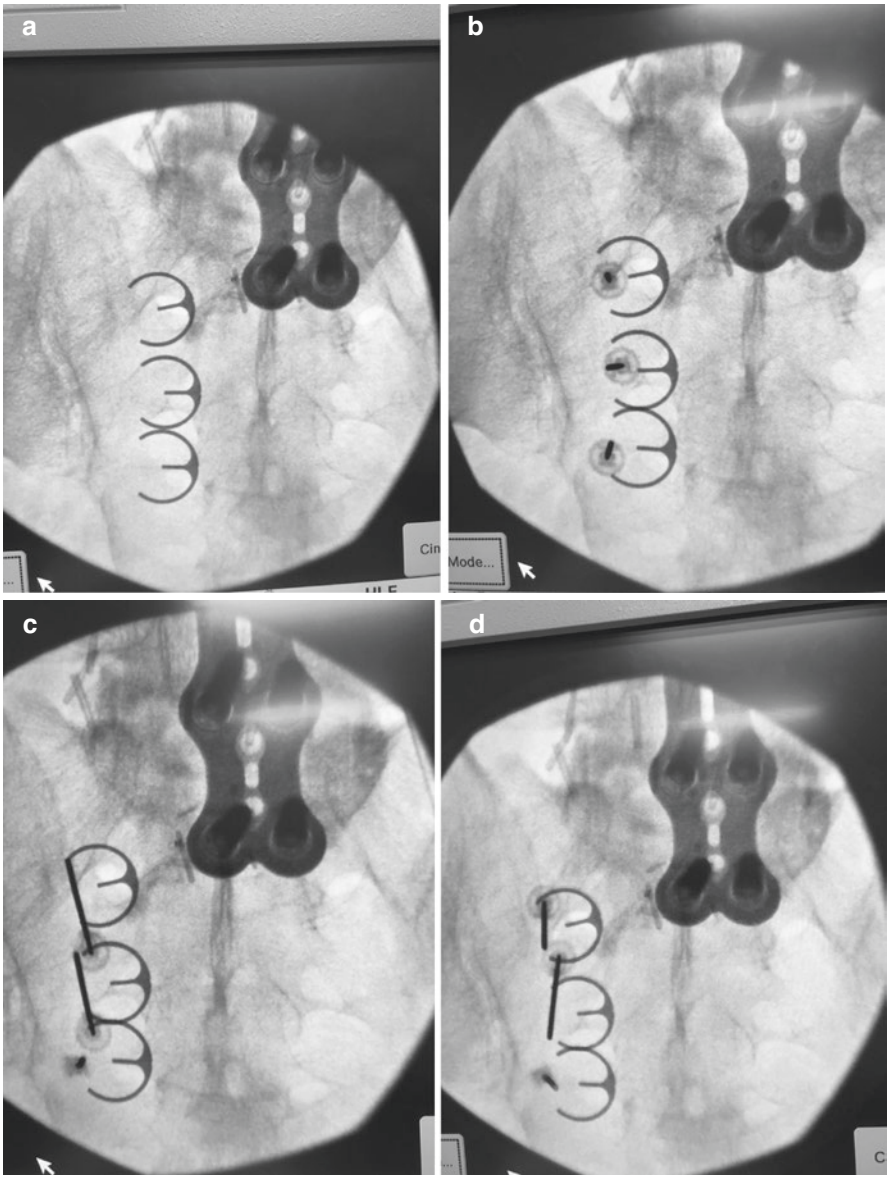

Fig. 11.21 AP and lateral views of cooled RF needles at their radiographic targets using an Epsilon. (**a**) Epsilon placement at the left S1, S2, and S3 SLBs with center spoke placed at the lateral border of the PSFA. (**b**) S1 and S2 needle tips positioned approximately 8–10 mm from the center of the Epsilon, at 9:30. (**c**) Coaxial needle trajectory with S1, S2, and S3 needle tips positioned at 8:00. (**d**) S1 and S2 needle positioned at 6:30. (**e**) Lateral view of needle tips positioned over the sacral plate at S1, S2, and S3. S1 and S2 are placed slightly shallow but adequate for cooled RF since the lesion projects ventrally. (**f**) Note the 2–3 mm gap from os when the electrodes are placed

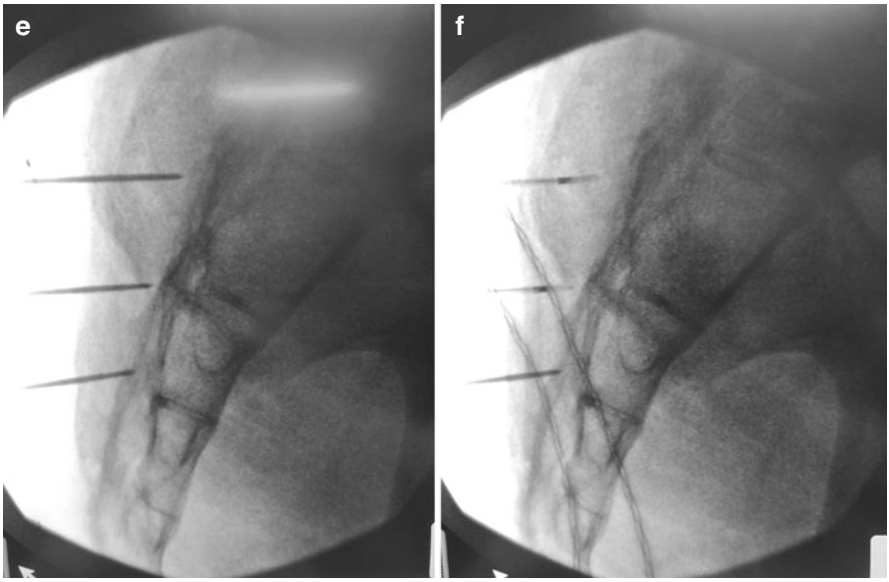

Fig. 11.21 (continued)

anesthetic at 0.5 cc which will spread to all three lesion sites. This technique improves time to anesthesia and may reduce total procedural time. Confirm placement of adequate depth on a lateral fluoroscopic view to ensure there is no epidural placement. Placement of the probe and active electrode will fill the gap to os, and the lesion will protrude ventrally toward the sacral plate to the target nerves. After the needle positions are confirmed radiographically, sensory and motor stimulations are performed at each level as a safety precaution. Appropriate needle proximity to each nerve is confirmed by the presence of paresthesias in the lumbar (for L5) or sacral region (S1-S3) at < or = to 0.5 V at 50 Hz and presence of a multifidus muscle twitch upon stimulation of L5 at < or = 2 V at 2 Hz. Given the multi-site and multi-depth variability of the lateral branch nerves, lesioning at multiple locations lateral and posterior to the neural foramen is recommended to ensure optimal and complete lesioning of neural elements. Figures 11.21 and 11.22 demonstrate optimal needle positioning at the predictable locations of the SLBBs as they exit the PSFA utilizing the accepted cooled RF placement and the bipolar "Palisades" placement, respectively.

Techniques to improve fluoroscopic visualization of sacral foramina
Consider prescribing a bowel prep
Identify Charley's lines
Perioperative planning: Utilize a lateral projection to identify kyphosis of the sacrumUse an Epsilon to predictably localize the LBNs

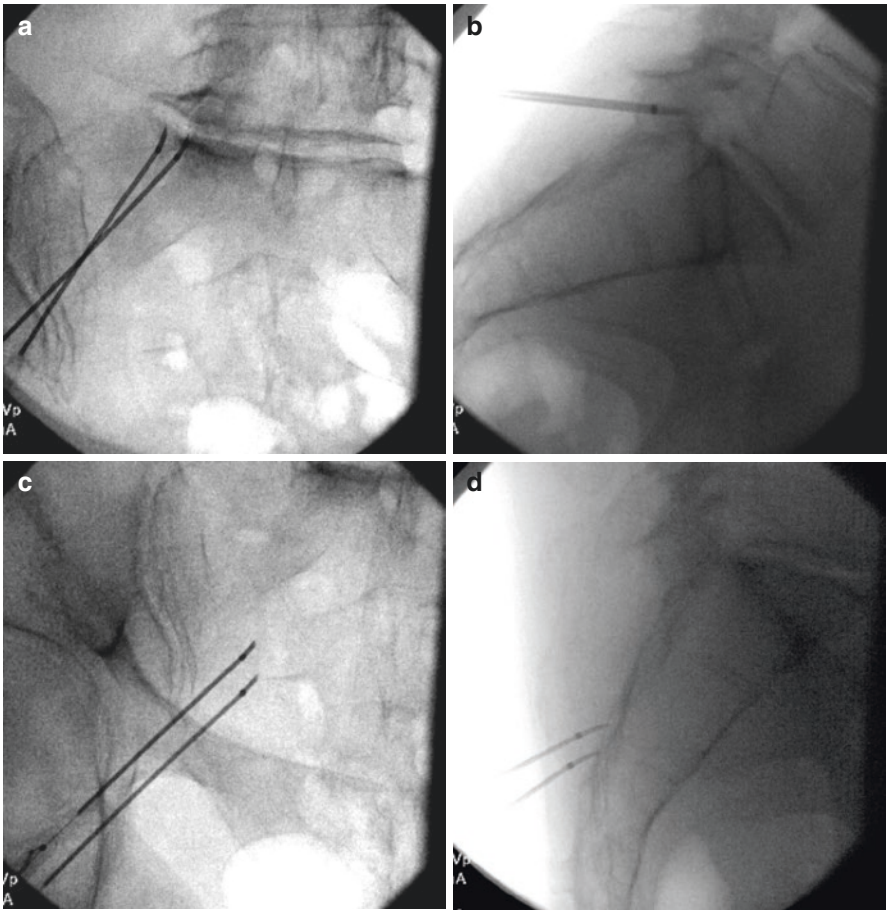

Fig. 11.22 AP and lateral views of bipolar RF radiographic targets. (**a**, **b**) AP/lat at L5. In 12.1, note the needle tips beyond the center of the L5/S1 facet. This is acceptable for conventional RF, but too ventral for cooled RF. (**c**, **d**) AP/lat at S2. In 12.1 and 12.3, note the caudal tilt utilized so that the needles come to lie in plane with the sacrum

Safety precautions
Aseptic technique
Avoid lesioning ventral to the dorsal ramus to minimize risk of neuralgias/cutaneous dysesthesias
Minimum safe probe distance from the foramen is >1 x the radius of the RF lesion
Perform sensory and motor stimulation of each nerve. Place hand on the lower extremity during motor stimulation to ensure no muscular contraction below the sacrum
Ensure a grounding pad has been correctly placed in full contact with a large area of the skin remote from the lesion site

Other Techniques

There are a variety of conventional RFA techniques that are well described in the literature. These include monopolar, periforaminal bipolar, Palisade, Nimbus Continuum, and PSN Lateral Crest. These techniques are extensively described in Shannon's publication comparing SIJ RFA techniques [49]. For comparison, expected RF lesions from two approaches are included below. The latter three create a "strip" lesion of varying degrees along the lateral posterior aspect of the sacral foramina (Fig. 11.23).

Considerations of RF Lesion

Many of the modern radiofrequency generators can be set to automatically lesion at set temperatures and time frames. Optimal lesion set temperature and time frames have not been clearly defined in the literature. For conventional radiofrequency ablation, the set temperature is traditionally 80–85 degrees Celsius for 60 to 90 seconds, with a total of three cycles at S1 and S2. Typically, there are one or two 60- to 90-second cycles at L5 and two cycles at S3. For monopolar RF, usually a single skin entry per NF will suffice. Withdrawing the cannula back to the superficial soft tissue and redirecting to the additional sites is recommended and creates less discomfort for the patient. Local anesthetic 1–2 cc is infiltrated over the nerve prior to the lesion. A grounding pad must be placed prior to commencement of RF lesioning which is included in a conventional RFA kit (Fig. 11.24).

Using a cooled RF generator, impedances should range between 100 and 500 ohms. Pre-lesion motor testing will reveal no response. Local anesthetic is injected. Set RF lesion temp 60° for 2.5 min at each lesion site. Internal temperature will reach 80 ° C while surrounding tissue is internally cooled. Then reposition the same

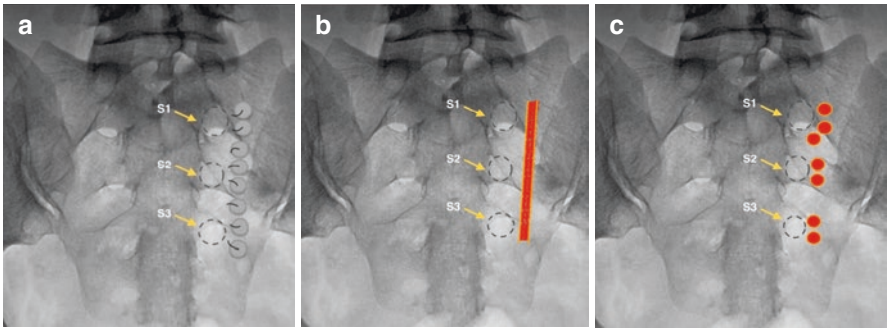

Fig. 11.23 AP view of the PLFA (dotted circles). (**a**) RF needles adjacent to the PLFA at S1–S3 create a "strip" lesion as shown in (**b**). (**c**) Expected sacral lesion locations with cooled RF needle placement

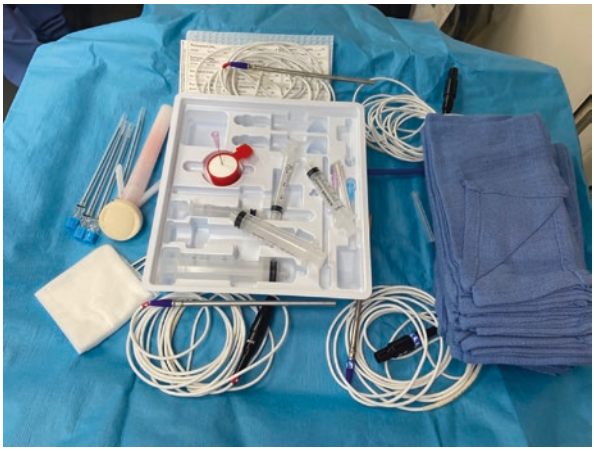

Fig. 11.24 A mayo stand set up with conventional RF probes

needle superior, create a lesion, and then reposition to the inferior position, to achieve lesioning at all recommended sites.

Complications

Typical complications of sacroiliac joint radiofrequency ablation include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect.

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Chapter 12
Hip

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Anatomy

The hip joint is comprised of a complex diarthrodial "ball and socket" articulation that connects the femur and pelvis and provides stability and multiplanar mobility. The joint consists of more than 20 muscles, osseous and ligamentous structures, and their accompanying neurovascular bundles that span the joint. The hip's static stability is supported by its bony configuration and soft tissue attachments, particularly within the anterior hip capsule.

Innervation

The mechanisms with which peripheral joints are able to produce pain require three discrete systems of innervation: afferent nerves from the joint capsule, intraosseous innervation, and cutaneous afferents from the overlying skin providing kinesthetic sensation [1, 2]. Studies have shown that the acetabular labrum is richly populated

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_12

with Vater-Pacini, Golgi-Mazzoni, Ruffini, and Krause corpuscles more frequent in the anterosuperior and posterosuperior part of the labrum. The articular portion of the labrum contains the vast majority of these sensory nerve endings and has implications for denervation targets for percutaneous approaches. These corpuscles observed are receptors of deep sensation, pressure, and temperature, and, thus, the labrum may function to provide proprioceptive input while also leading to a prominent source of hip pain. Anatomic studies have reported that the capsule is poorly innervated anterosuperiorly, and called this internervous plane the "safe zone" of the capsule, where the anterior aspect of the hip joint capsule has the highest number of sensory nerve endings [3].

Pain generation from the hip originates from the joint capsule, and these sensory nerves are referred to as articular nerves or articular branches. The innervation of the capsule is rich and complex receiving contributions from articular branches of the femoral, obturator, and accessory obturator nerve, nerve to the quadratus femoris, superior gluteal, as well as the sciatic and inferior gluteal nerves [4].

Pre-procedure planning coinciding with an anatomic understanding of sensory afferent innervation from the hip joint can ensure proper procedural technique and optimal outcomes after radiofrequency denervation. Table 12.1 describes information comprised from anatomic studies of hip innervation obtained from landmark cadaveric dissection studies [5–7].

Anterior Hip Innervation

Given the rich sensory innervation to the anterior hip capsule, it presents a common target for radiofrequency denervation. The anterior capsule of the hip joint is best organized and divided into four quadrants: superolateral (SL), inferolateral (IL), superomedial (SM), and inferomedial (IM). Generally, the SL and IL quadrants are

Table 12.1 Innervation of the quadrants in the anterior capsule [2]

	Superolateral	Superomedial	Inferolateral	Inferomedial
Femoral high nerves	++++	+++	+++	++
Femoral low nerves	+	+	++	+
Obturator high nerves			+	+++
Obturator low nerves			++	++
Accessory obturator nerve		++		+++
Innervation of the quadrants in the posterior capsule				
Nerve to quadratus femoris	Medial, superior, and inferior			
Sciatic nerve	Lateral, medial (unclear)			
Superior gluteal nerve	Lateral			
Inferior gluteal nerve	Inferior (unclear)			

"+" refers to the presence of nerves in relation to the quadrant of the capsule. The number of "+" simply refers to the predominance of the nerve supply

innervated by the articular branches of the femoral nerve (FN) and the SM and IM quadrants by the obturator and accessory obturator nerves (ON) (Fig. 12.1).

Superolateral and Inferolateral Quadrants

The SL/IL quadrants are classified as superior or inferior in their relation to the inguinal ligament. The high femoral branches arise distal to the lateral border of the psoas muscle and travel within iliacus deep to the inguinal ligament before innervating the capsule. These nerves have also been found to supply the SM quadrant and sparingly innervate the IM quadrant. This anatomic variation of articular nerve innervation may also explain the referred pain pattern from the hip going to the anterior knee in many patients [8–10].

The inferior femoral nerve branches are less abundant and dive into the iliopsoas to supply the capsule directly or course inferiorly recurring to innervate all quadrants of the anterior hip joint capsule with the highest representation in the inferolateral quadrant. They may innervate the capsule exclusively or help provide mixed sensory and motor innervation.

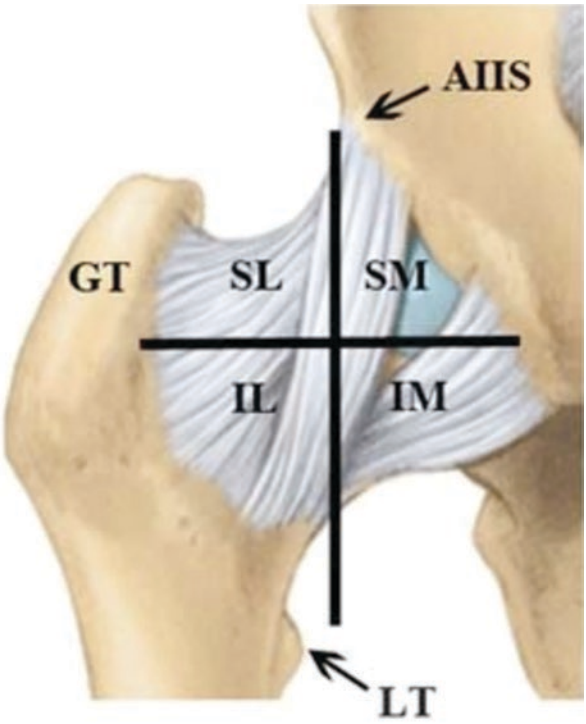


Fig. 12.1 Quadrants of the anterior hip capsule: superolateral (SL), superomedial (SM), inferolateral (IL), and inferomedial (IM). GT indicates greater trochanter; LT, lesser tubercle. Anterior view. Reproduced with permission from Philip Peng Educational Series [11]

Superomedial and Inferomedial Quadrants

Articular branches of the ON innervate the superomedial region of the hip joint capsule and the pubofemoral ligament. The ON articular branches are categorized as high when these originate proximal to or within the obturator canal and low when these arise from the posterior branch of ON. Most high branches are single branches supplying consistently the inferomedial quadrant, while low branches can either travel exclusively or form a fine plexus supplying both the inferior medial and inferolateral portions of the anterior hip capsule. The accessory obturator nerve (AON) is found to innervate the medial capsule with high frequency (54%), and it is present as a single nerve formed by the branches from the lumbar plexus which courses deep to the psoas before supplying the inferomedial quadrant and occasionally the superomedial quadrant.

Posterior Hip Innervation

The posterior hip capsule is considered to be an area of minimal innervation and, thus, a less likely target for hip radiofrequency denervation. The posterior capsular is innervated by the sciatic nerve, nerve to quadratus femoris, and superior and inferior gluteal nerves. The articular branches arising from these nerves either are short or enter the muscle early on in their course, and therefore, attempting to ablate these nerves would pose a risk of motor weakness. Furthermore, the vascular supply to the hip joint is mostly from the posterior circulation of the epiphysis. Pre-procedural planning and consideration would have to be taken if one were to target the nerves supplying the posterior capsular region for patient safety.

Posteromedial Hip: Sciatic Nerve and the Nerve to the Quadratus Femoris

The posteromedial, superior, and inferior regions of the hip joint capsule are innervated by the sciatic nerve and the articular branch of the nerve to the quadratus femoris. The nerve to the quadratus femoris is a branch from the sacral plexus. After exiting the greater sciatic foramen, it descends on the ischium anterior to the sciatic nerve and provides articular branches to the posterior hip joint capsule. The superior and middle branches travel upward along the acetabular rim to supply the posterior joint capsule, while inferior branches run directly along the obturator externus where they supply the posteroinferior region joint capsule and the ischiofemoral ligament. The pattern of innervation of the hip joint from the sciatic nerve remains controversial and unclear.

Posteromedial Hip: Superior Gluteal Nerve

The superior gluteal nerve originates directly from the sacral plexus. Articular branches arise from its branches to gluteus minimus muscle and the tensor fascia lata. These small branches accompany blood vessels and innervate posterolateral part of the hip joint capsule.

Posteroinferior Hip: Inferior Gluteal Nerve or Obturator Nerve

There is no clear description in the existing literature or cadaveric studies regarding the precise location of the articular branches of the inferior gluteal nerve or branches of the obturator nerve supplying this part of the hip joint capsule [12–14].

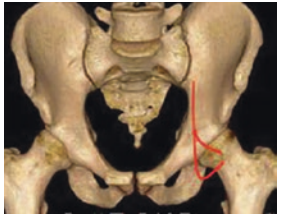
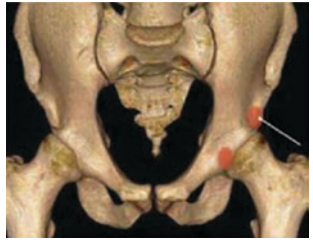
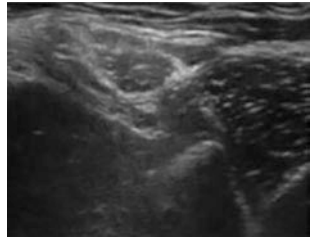
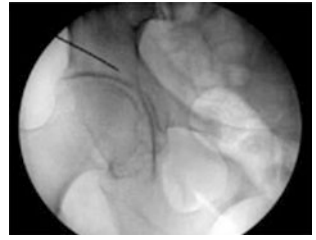
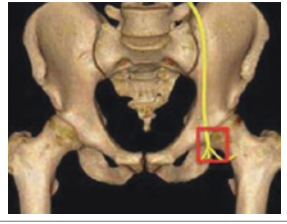
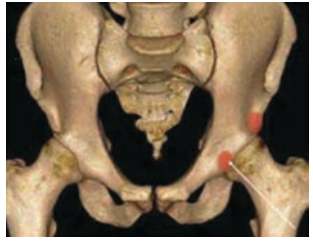
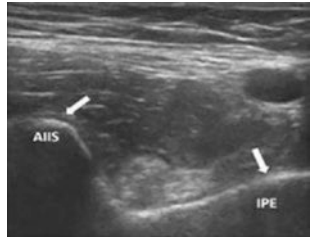
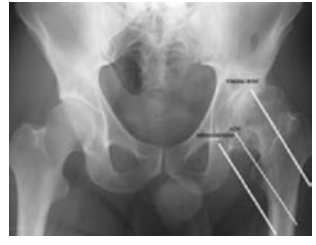
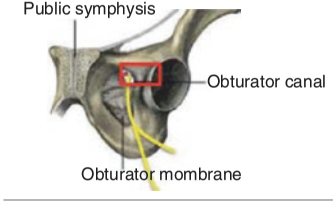
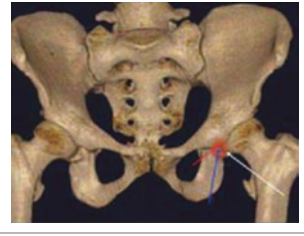
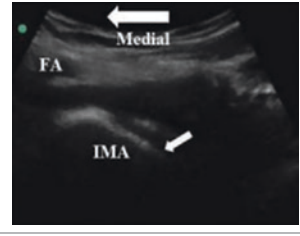
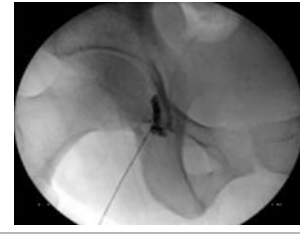
Anatomic Targets for Hip Radiofrequency Ablation

The anatomical targets for hip radiofrequency neurolysis have evolved over the past 30 years due to enhancements in safety. It is commonly postulated that referred hip pain to medial thigh and groin pain may be relieved by denervation of the articular branches of the obturator nerve, whereas lateral thigh and trochanteric pain can be relieved by ablating the articular branches of the femoral nerve. Gluteal pain can be relieved by denervation of the articular branches of the posterior hip joint (i.e., nerve to the quadratus femoris, superior and inferior gluteal nerves, sciatic nerve) (Table 12.2).

Clinical Workup of the Hip-Related Pain Patient

"Hip joint pain" is a generalized term used by most clinicians when documenting clinical examination findings. While the clinical presentation of hip joint pain is varied, the most common clinical symptoms include pain in the groin, buttocks, proximal thigh, and over the greater trochanter. "Hip pain" can emanate from several sources. Often what the patient thinks is the hip is not the hip joint and may be referring to the superior iliac crest area, or as distal as the mid-femur; therefore, it is important to delineate the location of pain. Hip-related pain is divided into *intra-articular* vs *extra-articular generators*. Intra-articular causes of hip pain include labral tears, chondromalacia, degenerative changes, intra-articular bone injury, ligamentum teres rupture, inflammatory arthritis, and synovial proliferative disorders; extra-articular causes include tendinopathy, bursitis, iliotibial band syndrome,

Table 12.2 Radiofrequency targets for the hip joint. **A.** Targets for articular nerves innervating the anterior capsule of the hip joint. The red rectangle in the pelvis skeleton shows the area of interest for RF lesioning [2]

Nerve	Anatomy	Ultrasound	Fluoroscopy
Femoral nerve 			
Accessory obturator nerve 			
Obturator nerve 			

AIIS anterior inferior iliac spine; *AON* accessory obturator nerve; *ASIS* anterior-superior iliac spine; *FH* femoral head; *FA* femoral artery; *GT* greater trochanter; *IMA* inferomedial acetabulum (tear drop); *IPE* iliopubic eminence; *IL* inferolateral; *IM* inferomedial; *LT* lesser trochanter; *SL* superolateral; *SM* superomedial

*The technique described in this table is one of several approaches. In this chapter, we describe a different approach that potentially reduces risk of neurovascular injury

muscle injury, pubalgia, sacroiliac joint dysfunction/sacroiliitis, piriformis syndrome, and lumbar spine-related issues including stenosis with neurogenic claudication or radiculopathy and vertebral compression fracture [15]. The purpose of the history and physical examination is to narrow down the differential diagnosis.

Obtaining a history should include a history of when the pain started, how the pain transpired, the locations of pain, what causes the pain to increase and decrease, characteristics of the pain, any history of trauma, previous surgery, cancer, steroid use, autoimmune disorders, sickle cell anemia, and/or infections [16].

The physical examination of the hip joint, like any major joint, follows inspection, palpation, range of motion testing, neurovascular testing, strength testing, and special tests/maneuvers. When performing *inspection*, one should monitor how a patient sits, how they walk to and from the clinic room, and their overall disposition. Certain positions may be favored to alleviate pain in the hip joint such as slouching toward the unaffected hip, or using a slightly flexed position for the hip while standing. *Palpation* can be useful for determining extra-articular sources of pain such as greater trochanteric bursitis, ischial tuberosity bursitis, pubic symphysis, sacroiliac joint dysfunction, or specific focal bony issues in the ilium, ischium, or lumbosacral spine. *Range of motion* and *neurovascular and strength testing* are typically not compromised unless pain is a limiting factor. Special maneuvers or tests include the FADIR/FADDIR test, Patrick or FABER test, log rolling, forced hip flexion, Thomas test, Ober's test, Stinchfield resisted hip flexion test, and the Trendelenburg test [17].

Imaging studies can be helpful in aiding diagnosis for hip pathologies. However, imaging alone should not be used for diagnosis. It is paramount to support the patient's symptoms with the imaging findings.

As with any painful condition, an evidence-based diagnosis is paramount when choosing the best evidence-based treatment option for the patient, especially when taking into account medical comorbidities, functional ability, and the patient's goals and expectations.

Current nonsurgical options for chronic hip pain include various oral analgesics such as NSAIDs, acetaminophen, corticosteroids, muscle relaxants, and, to a lesser degree, opioids. However, these therapies each come with their own deleterious effects. Corticosteroids are associated with cartilage loss, and NSAIDs have shown marked effects of increasing blood pressure in hypertensive patients including the under-appreciated symptoms such as gastroesophageal reflux disease, renal disease, and increased risk of adverse cardiovascular events [18]. The SPACE trial demonstrated that opioids were not superior to treatment with acetaminophen or NSAIDs for hip or knee-related pain [19]. Opioids also carry a risk of opioid-induced hyperalgesia [20]. Should the patient fail a defined period of physical inactivity with or without an oral analgesic regimen, a course of physical rehabilitation is typically prescribed for a 4–6-week period. While intra-articular injections with glucocorticoid, viscosupplementation, and regenerative treatments have shown some success, radiofrequency neurotomy is proving to be an effective nonsurgical option [21].

Diagnostic and Prognostic Workup for Hip Radiofrequency Neurolysis

Historical Considerations

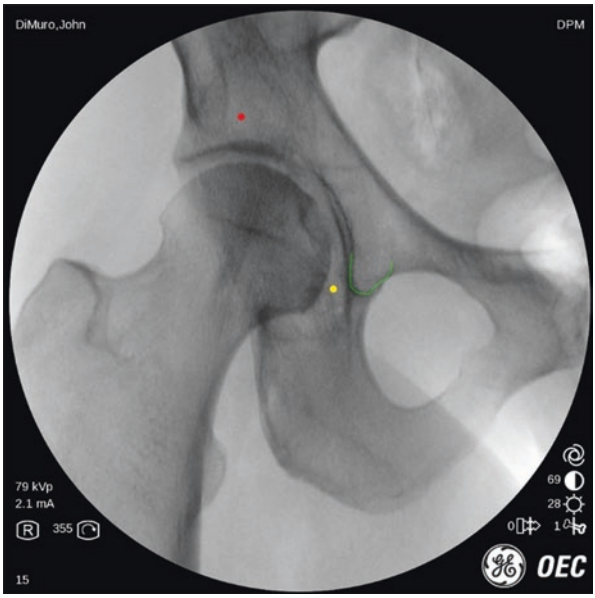
There have been several approaches described in the literature since the 1990s to neurolyze the acetabular branch nerves—branches of the femoral and obturator nerves [22, 23]. As seen in Table 12.2, some approaches involve coming from a lateral to medial approach to get to the two target zones. The primary concern has been that the needle trajectory must pass perilously close to the neurovascular bundle of the thigh. The approach described in this chapter allows for simple needle placement with minimal, if any, concern over inadvertent neurovascular bundle trauma.

In regard to the femoral articular sensory branch nerves, the target site is at the 12 o'clock position along the acetabular ridge when viewed in a PA projection. Typically, there is little concern over inadvertent puncture of the neurovascular bundle; however, it is important to map the femoral artery and vein. The primary geographic anatomical concerns are the anatomical structures adjacent to the inguinal ligament as well as inadvertent puncture of the hip capsule itself. The approach described here will minimize exposure to these areas during introducer placement.

Technique

The technique described in this chapter was implemented in 2014 to address concerns regarding neurovascular injury. Previous research by Locher et al [26] had described the anatomical considerations and dangers in attempting RFA of the obturator and femoral accessory branches as well as the "matrix of lesions required to adequately coagulate the articular branches" (of the obturator nerve). The potential solution was to use a novel technology that provided a larger lesion using a 17 ga introducer. At issue was the large-gauge introducer through a high-risk anatomical area using previously described approaches which could lead to femoral artery puncture and/or shearing. The technique for ablation described here is the same as for prognostic blockade.

Hip Joint Denervation: Targets for Ablation



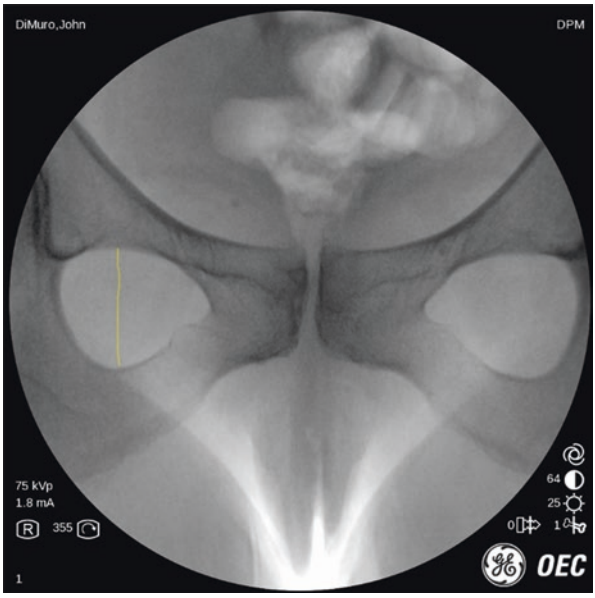
The red dot denotes the anatomical location of the femoral accessory branches. The yellow dot denotes the location of the obturator accessory branches. The green outline demarcates the important internal frame of reference for the incisura.

Preparation

Position the patient in a supine position with approximately 10–15 degrees of abduction. Palpate the femoral artery and map it out along the anteromedial thigh from the inguinal crease to approximately 6 inches distally. If it is difficult to palpate, or the patient is obese, one can use ultrasound to map out the femoral artery. Prep the patient from the umbilicus through the ipsilateral knee with a sterile drape over the contralateral leg and underneath the hip to be ablated.

Step 1: Find Your Best PA Image

A true PA of the pelvis is obtained to the greatest extent possible. The pubic symphysis should be visualized so as to optimize the "superior to inferior" distance within the joint space. Additionally, the obturator foramina should be symmetrical with similar appearing windows.

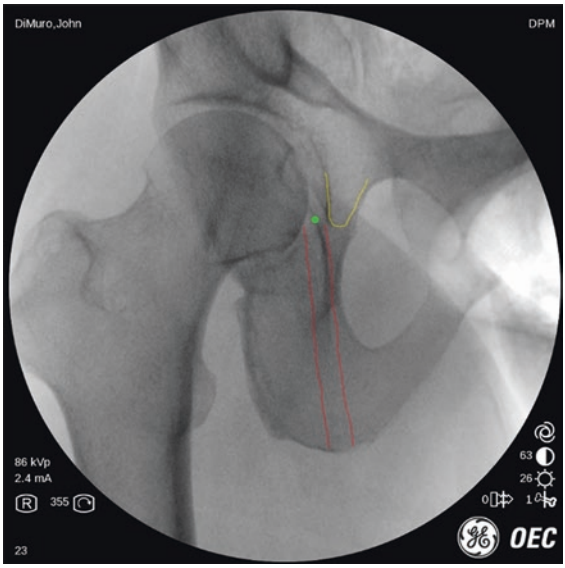


Step 2: Optimizing Visualization of the Obturator Foramen on the Affected Side and Elongating the Ischial Tuberosity

You will simultaneously be elongating the ischial tuberosity which will serve as a "runway" for the introducer (it will appear slightly shorter in the fluoroscopic image but longer in reality). At this point, the x-ray tube will ultimately come into contact with the operating table.

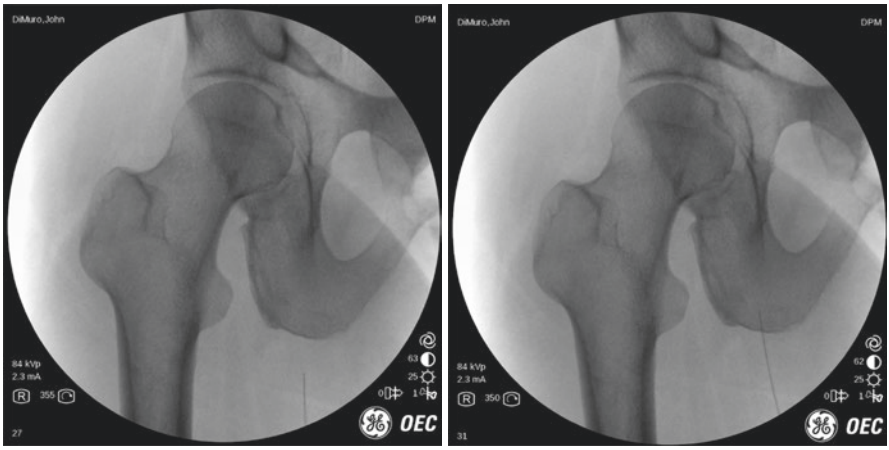
Step 3: Closing the Distance/Visualizing Your Approach

In order to make sure that there is ample introducer length to the target and to provide some "working room" for the fluoroscopic unit, "tilt proximal" 5–10 degrees. This should also help you more clearly delineate the incisura. You should now clearly be able to visualize the pathway from the distal aspect of the ischial tuberosity along the runway of the ischial tuberosity to the target just lateral to the incisura.



Step 4: Anesthetize the Approach

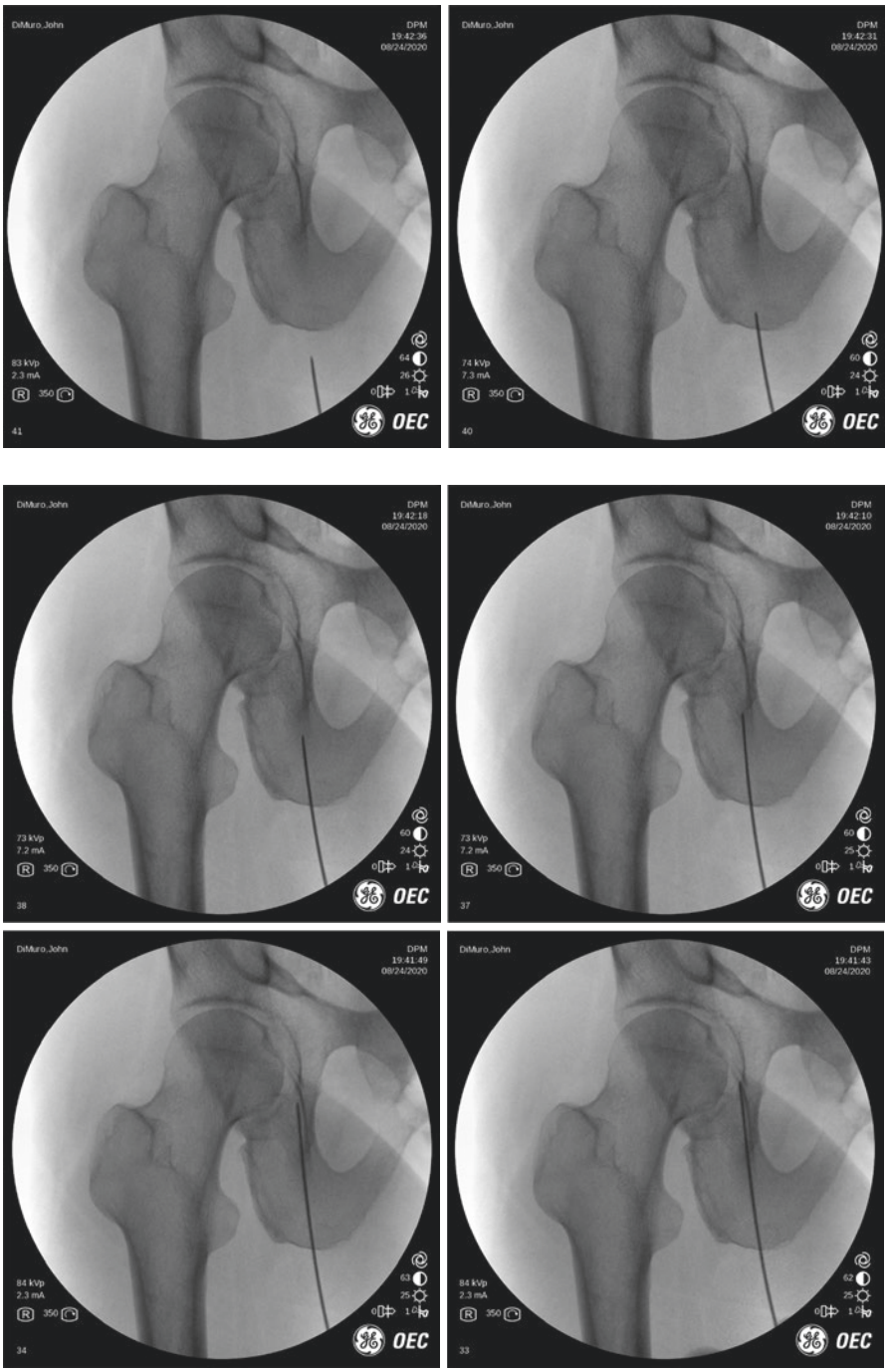
Inject local anesthetic with at least a 25-gauge, 3.5″ spinal needle beginning approximately 1 cm distal to the most distal aspect of the ischial tuberosity in a trajectory toward the most proximal aspect of the ischial tuberosity. This trajectory is actually going to be along an incline, and the dorsal aspect of the hand/fingers of the interventionalist will actually rest on the sterile operating table.

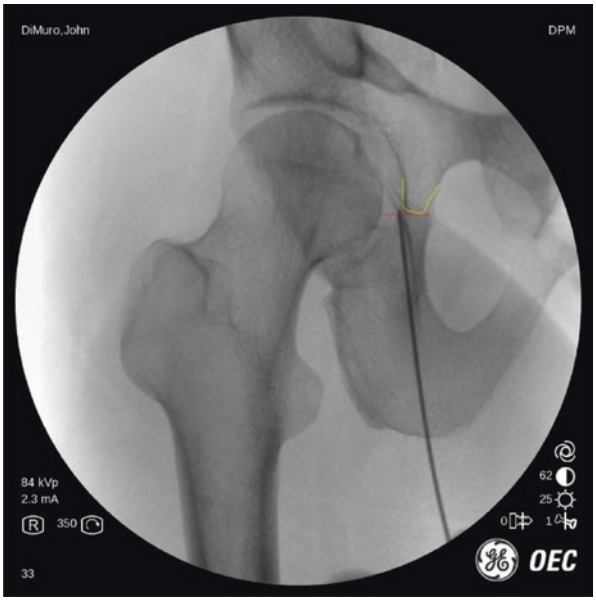


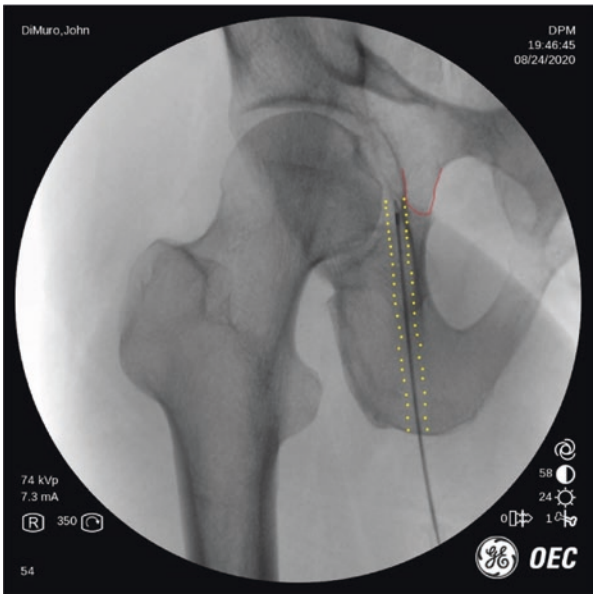
Step 5: Insertion of Introducer

The percutaneous introduction is made medial to the mapped femoral artery with a start distal to the ischial tuberosity. This can range from 10 to 20 cm distal to the inguinal crease and depends on the habitus of the patient. While it is common to

teach the method of "walking up" the ischial tuberosity toward the target lateral to the incisura, it is recommended that individuals strive to touch os just distal to the incisura. If it has not been touched by the time of the incisura, the needle would need to be retracted and trajectory changed to a "steeper" angle.



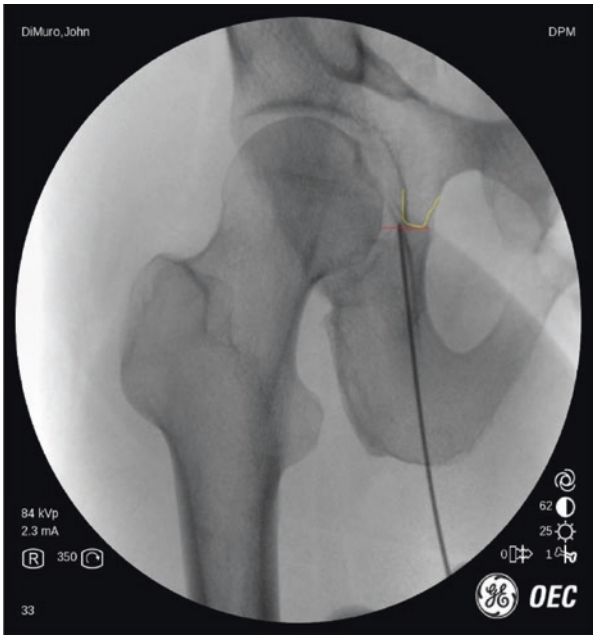




Internal reference: obturator probe final w markings 22

Step 6: Placement at Lesioning Site

The distal tip of the introducer should lie midway between an imaginary horizontal line extending from the most inferior aspect of the incisura to the medial-most aspect of the head of the femur.

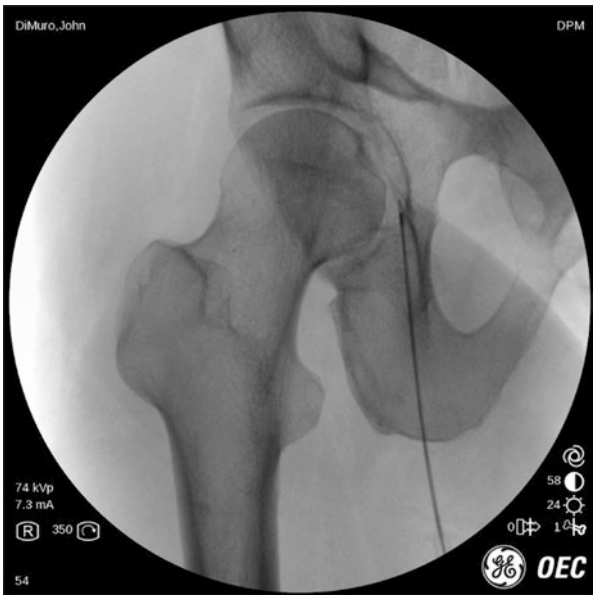


The distal tip of the introducer should lie superficially suspended above the periosteum so that a gentle upward pressure on the proximal aspect of the introducer needle should verify subtle supra-periosteal placement.

Step 7: Probe Insertion

Due to the needle length required to reach the target safely utilizing this technique, the introducer should be held in place with one hand throughout the remainder of the procedure when it has reached the target site so as to minimize the chance for introducer migration. The stylet should be removed and the probe inserted. The tip of the probe should be maintained at the midline at the intersection with the previously mentioned horizontal line extending from the inferior aspect of the incisura to the medial-most aspect of the femoral head. Motor stimulation at 2 Hz should be conducted to verify that no rhythmic twitch is appreciated. If a rhythmic twitch is noted during stimulation, this would be reason for repositioning. When no verifiable

twitch is appreciated, the fluoroscopic image should be saved and moved from the left screen to the right screen of the fluoroscopy unit. At this point, the probe can be removed, and local anesthetic, typically 1 ml of lidocaine 1–2%, can be injected prior to lesioning. Lesioning should always be performed while maintaining and ensuring placement manually.



Step 8: Probe and Introducer Removal

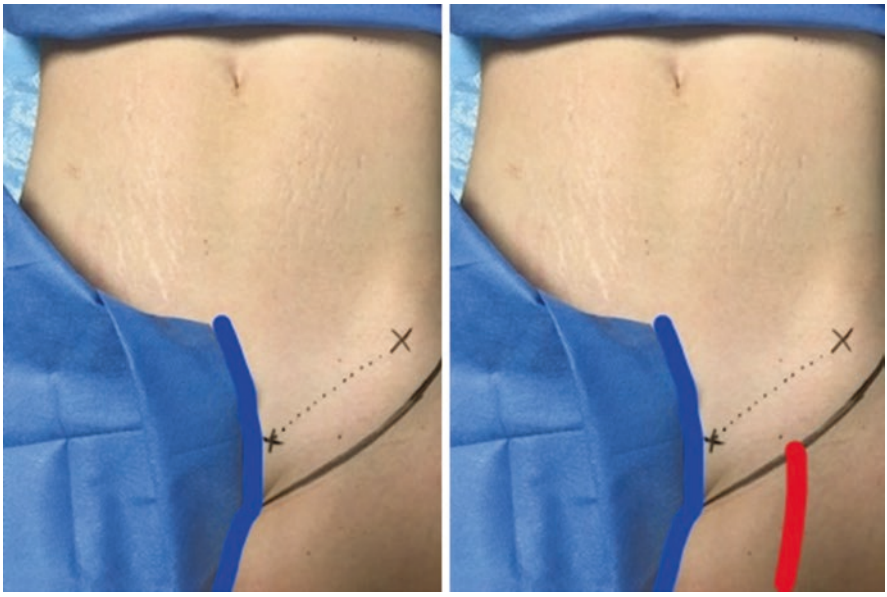
At the conclusion of lesioning, a second lesion may be created just inferior to the initial lesion by a distance equal to the tip of the probe. Then both the introducer and probe may be removed simultaneously as one unit. Apply manual pressure with sterile gauze to the insertion site to help stop any bleeding if needed.

Fluoroscopic Setup for the Femoral Articular Sensory Branch RFA

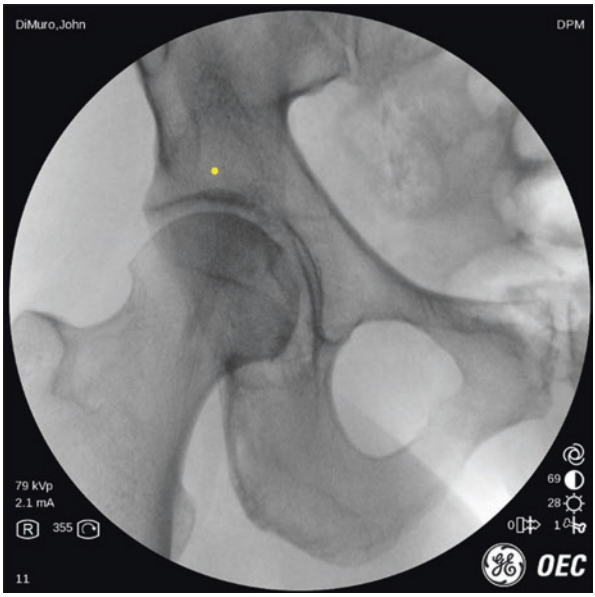
Prior to initiating fluoroscopic visualization, the following anatomical landmarks should be demarcated with a sterile marking pen:

1. The femoral crease
2. The inguinal canal
3. The neurovascular bundle

Clearly identifying these landmarks will keep the interventionalist from straying into vital anatomical structures including not only the contents of the inguinal canal but the bladder, bowel, and reproductive organs.



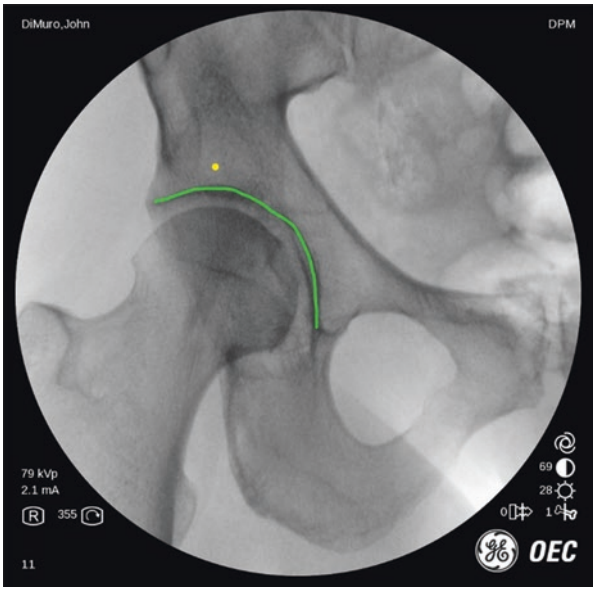
Step 3: Note the Target at the 12 o'clock Position



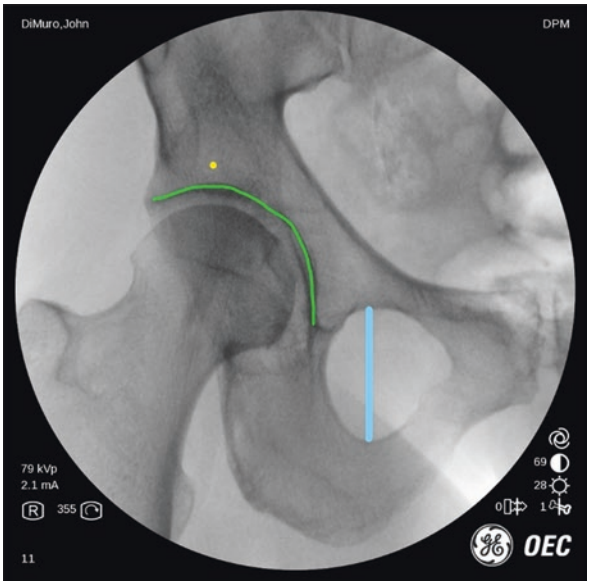
Author Internal Ref: Femoral Image 3.1

Step 4: Optimizing Visualization of the Obturator Foramen on the Affected Side and Observing the Acetabular Ridge at the 12 o'clock Position

From your optimized PA image, initiate "distal tilt" until a maximal volume of the obturator foramen is appreciated. While previously we were elongating the ischial tuberosity for ablation of the obturator articular sensory branches, we are now creating a safe trajectory toward the 12 o'clock position of the acetabular ridge. At this point, the x-ray tube will ultimately come into contact with the operating table.



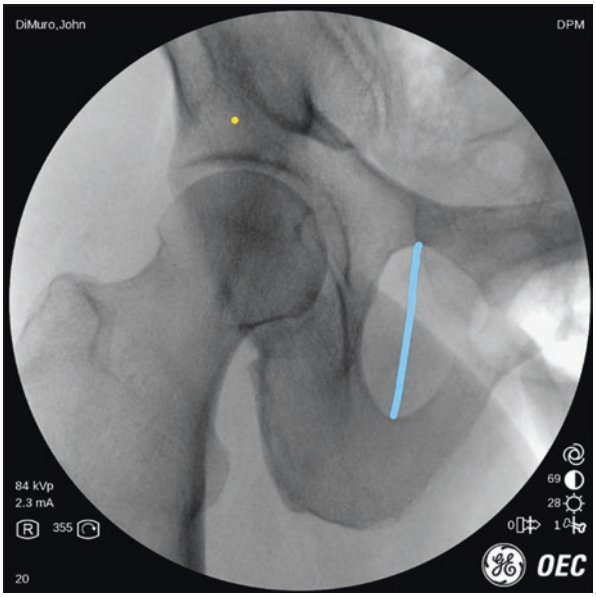
Author Internal Ref: Inked Femoral Image 3.3



Author Internal Ref: Femoral Image 3.5

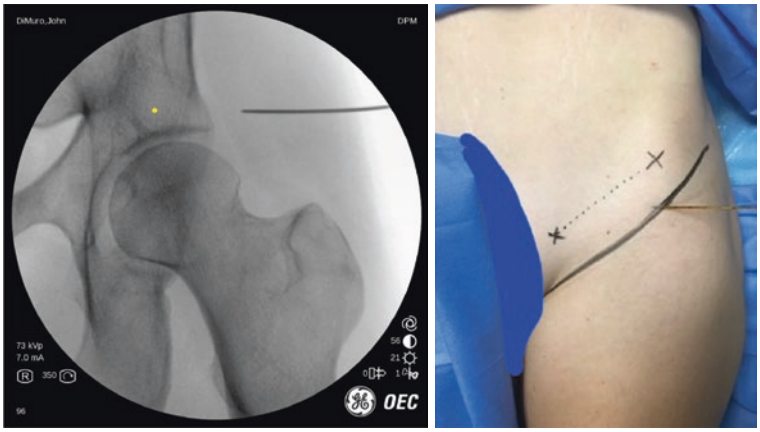
Step 3: Closing the Distance

In order to make sure that there is ample introducer length to the target and to provide some "working room" for the fluoroscopic unit, "tilt proximal" 5–10 degrees. This should also help you more clearly delineate the target 12 o'clock position. Place the target lesion site in the middle of the right half of your fluoroscopy screen.



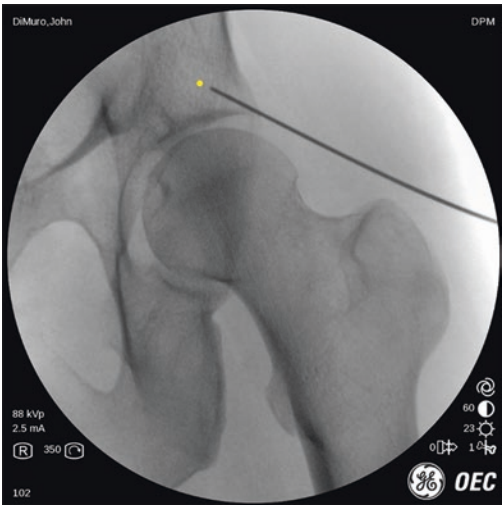
Step 4: Determining Your Trajectory, Part I

Optimal lesioning position is to have the probe tip oriented in a superomedial manner at the target. To best ensure this safe trajectory, first lay the introducer in a horizontal trajectory from lateral to medial over the skin with the distal tip at the 12 o'clock target site.



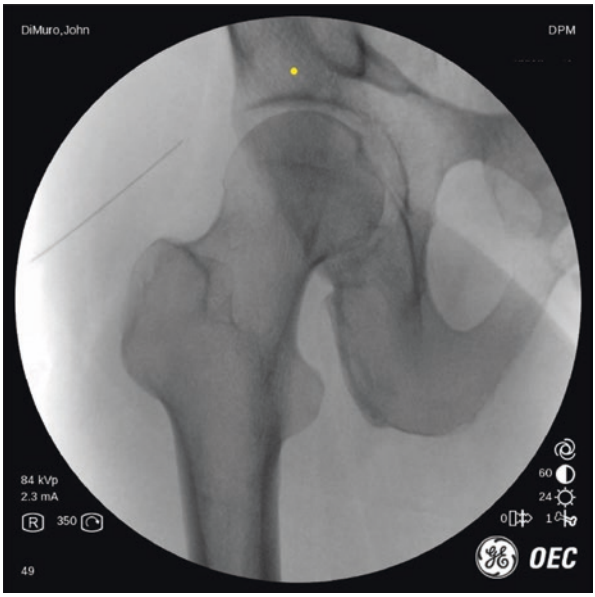
Step 5: Determining Your Trajectory, Part II

Withdraw the introducer back along this horizontal until it is inferior to the previously demarcated femoral crease. Now, walk the introducer inferomedially along the femoral crease approximately 2 cm. This trajectory will allow you to pass the introducer to the target without violating the hip capsule and remaining below the contents of the inguinal canal. The idea is to never have the introducer enter the skin superior to the femoral crease, where the peritoneal contents exist, to ensure safety during the approach.

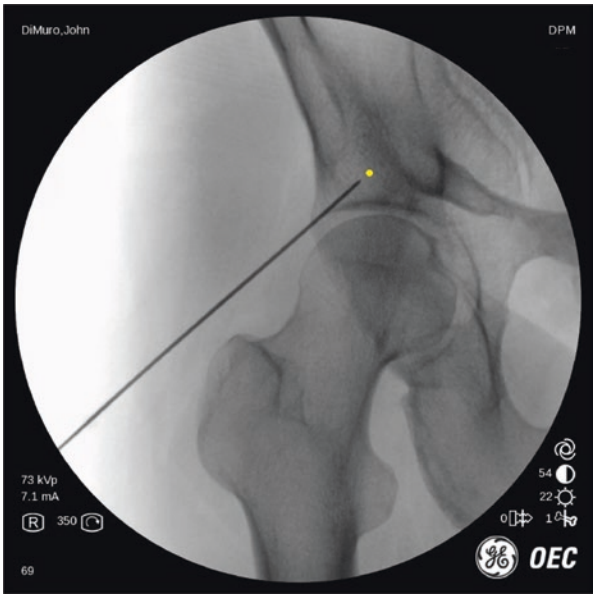


Step 6: Anesthetize the Approach/Place the Introducer

Using a 25-gauge, 3.5″ spinal needle, begin to anesthetize the track toward the 12 o'clock position at the acetabulum. The goal is to touchdown with the local needle at the target. Then, place the introducer through the previously anesthetized tissue until it is superficially suspended above the 12 o'clock position. The needle projection needs to be superomedial and not medial as there is distal projection during lesioning. Once again, gentle upward pressure on the proximal aspect of the introducer should allow the interventionalist to note contact with periosteum via tactile feedback. Care should be taken to again make the *first attempt the only attempt* in order to minimize injury.



Internal Ref: Femoral Local image 31



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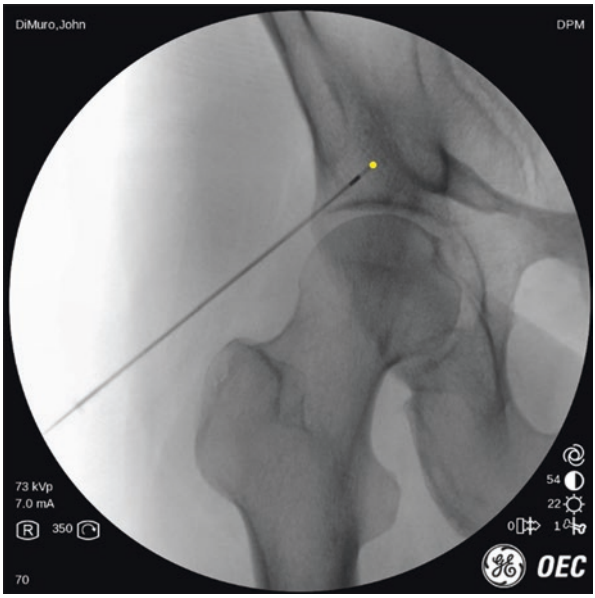
Step 7: Probe Insertion

The stylet should be removed and the probe placed. Confirm suspension over the periosteum with gentle upward pressure at the proximal aspect of the introducer. Percutaneous nerve stimulation should be conducted to verify that no rhythmic twitch is appreciated. When no verifiable twitch is appreciated, the fluoroscopic image should be saved and moved from the left screen to the right screen of the fluoroscopy unit. At this point, the probe can be removed while manually stabilizing the introducer, and local anesthetic can be injected prior to probe replacement and subsequent lesioning. Lesioning should always be performed while maintaining and ensuring placement manually.



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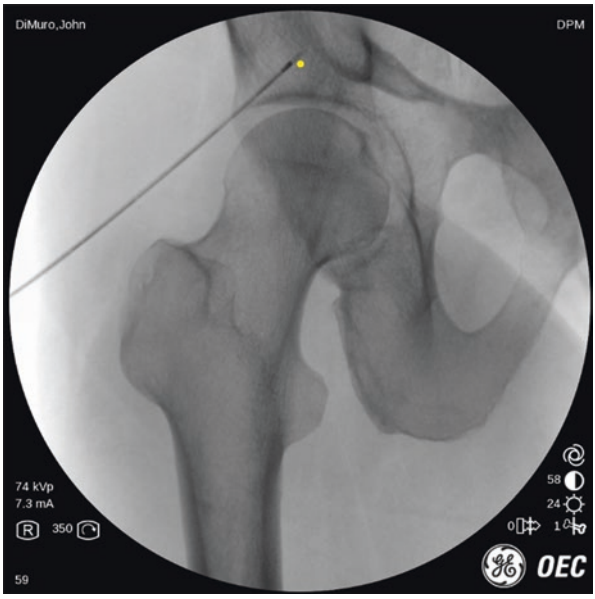
Step 8: Probe and Introducer Removal

At the conclusion of lesioning, a second lesion may be created in a more superior trajectory to the initial lesion by a distance equal to the tip of the probe.



Then both the introducer and probe may be removed simultaneously as one unit. Apply manual pressure with sterile gauze to the insertion site to help stop any bleeding if needed. At the conclusion of the procedure, sterile bandages should be applied and standard post-radiofrequency ablation written instructions provided to the patient.

This novel approach to both the femoral and obturator articular sensory branches will allow even the inexperienced interventionalist to safely perform the procedure with minimal or no changes in fluoroscopic orientation required.

Potential Complications

Although rare, there have been reported complications associated with hip radiofrequency ablation for hip pain. There have been reports of inguinal hematoma formation using an anterior approach for RF of the articular branches of the obturator nerve [24]. There has also been reported loss of cutaneous sensation in the distribution of the obturator nerve and femoral nerve following RF [19, 22, 26]. There is no current reported incidence of infection with the use of sterile precautions during the procedure.

Long-Term Outcomes

There is currently sparse data in the literature for long-term outcomes following RF of the hip. According to Chye et al., pulsed RF of the obturator and femoral nerve provided greater improvement in Visual Analog Scale (VAS), Oxford Hip Scores (OHS), and a reduction in pain medication consumption at 3 months when compared to conservative treatment [25]. There is a need for further data collection to substantiate long-term outcomes.

Complications

Typical complications of hip radiofrequency ablation include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect.

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Chapter 13
Knee

Leonardo Kapural, James Deering, and Amela Minerali

Applied Anatomy

The innervation of the knee joint capsule is complex, with contributions from up to 13 nerves (Figs. 13.1 and 13.2) [1]. These distal branches are derived from the femoral, saphenous, tibial, common peroneal, and obturator nerves. The key to successful genicular RFA is positioning the radiofrequency probes such that they may accurately target even the most distal branches of the genicular complex and avoid any unwanted sensory and/or motor impairment after ablation [2].

In a detailed cadaveric study, Tran et al. [1] concluded that the anterior knee joint capsule is invariably innervated by articular branches of the nerve to the vastus medialis (NVM), nerve to the vastus intermedius (NVI), nerve to the vastus lateralis (NVL), common fibular nerve (CFN), and recurrent fibular nerve (RFN) (Figs. 13.1 and 13.2), in addition to the superior lateral (SLGN), superior medial (SMGN), inferior lateral (ILGN), and inferior medial genicular nerves (IMGN) [1]. This nerve complex was divided further into four quadrants: superolateral (NVL, NVI, SLGN, and CFN), inferolateral (ILGN and RFN), superomedial (NVM, NVI, and SMGN), and inferomedial (IMGN and IPBSN). The majority of these branches are found just superficial to the periosteum, thus necessitating precise needle placement in close proximity to the femur and tibia. Notable exceptions to this are the NVL and NVM, which Tran et al. found to be 0.97 +/− 0.27 cm and 0.71 +/− 0.28 cm from the periosteum of the femur, respectively [1].

In another cadaveric study [3], the posterior knee joint capsule innervation was found to be derived from the posterior division of the obturator nerve, sciatic nerve, common fibular nerve, and tibial nerve [3]. No contribution was found from the

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_13

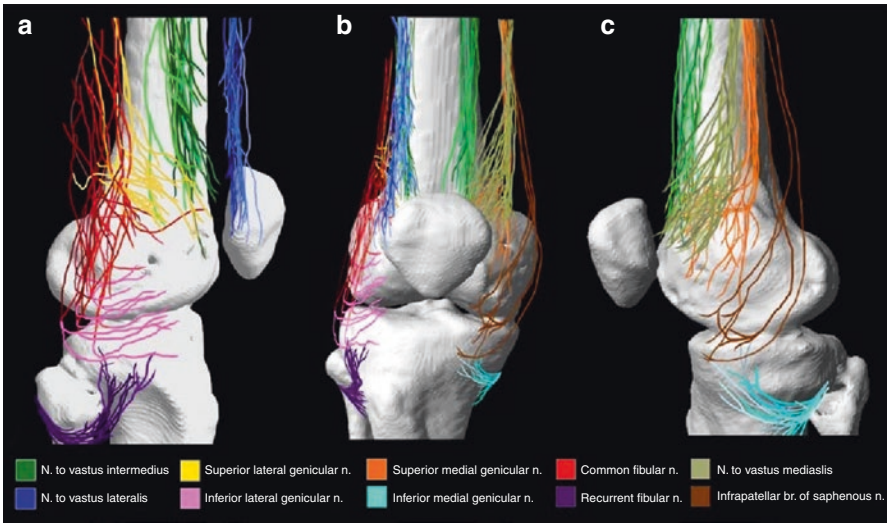

Fig. 13.1 Knee innervation frequency map as originally described by Tran et al. [1]. (**a**) Lateral view shows neural mapping from 15 cadavers in superior lateral knee area and more consistent location of the recurrent fibular nerve inferolaterally. (**b**) Anterior view illustrating more consistent location of the inferior medial geniculate nerve, recurrent fibular nerve, and nerves to vastus lateralis and intermedius. (**c**) Medial view of the joint suggesting more posterior location of superior medial geniculate nerve. (Borrowed with permission from: Tran et al. [1])

anterior division of the obturator nerve, and the majority of anatomic studies to date have been in agreement on this point ([4–6]; Fig. 13.2). One important anatomic landmark that was identified in this study was the femoral condyle. This was the point at which terminal branches of the obturator nerve (100% of specimens), common fibular nerve (53% of specimens), and sciatic nerve (20% of specimens) were found at the level of the lateral femoral condyle. This was also the point at which the terminal branches of the tibial nerve were found at the level of the superior border of the medial femoral condyle (100% of specimens) [3] (Fig. 13.2).

A thorough understanding of the anatomy of knee joint capsule innervation provides the basis for performing successful needle placement during genicular nerve complex radiofrequency ablation. Fonkoue L. et al. [7, 8] applied information gained from multiple anatomic studies to provide a new information regarding placement of radiofrequency needle. By examining the spread of methylene blue via needles that were placed using fluoroscopy, new insights were gained regarding proper needle placement for denervation of the knee [7, 8]. After injecting methylene blue, a physical dissection of the cadavers and an examination of whether or not the desired nerve target was dyed blue served as confirmation of accuracy in needle placement. Perhaps the most significant contribution of the study was the understanding that the placement of the needle for ablation of the superior lateral and superior medial genicular nerves is significantly more posterior than previously described [2.7]. In order to properly target the SMGN, the location of the needle tip

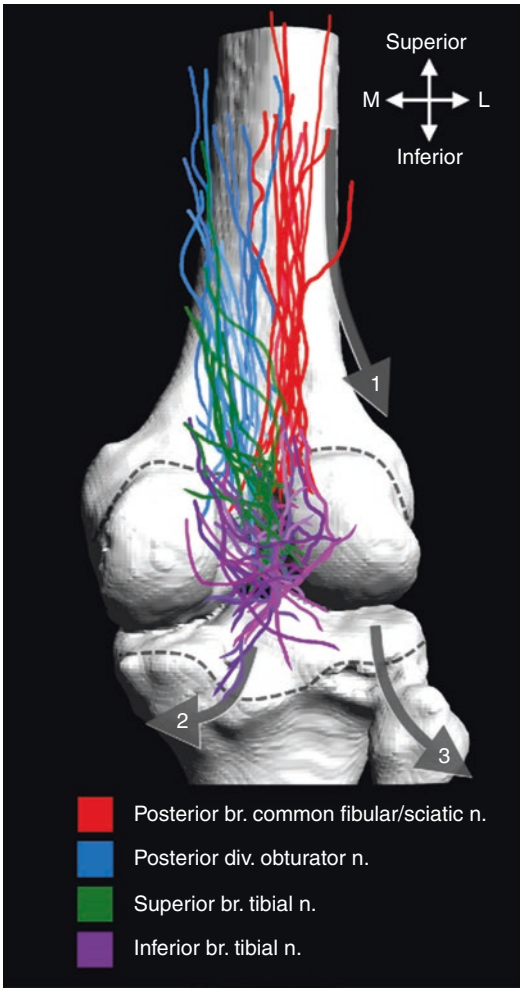

Fig. 13.2 Innervation map of posterior aspect of the knee joint. Mix of motor and sensory fibers precludes an effective block/radiofrequency ablation without risk for motor weakness. (Borrowed with permission from: Tran et al. [3])

should be a few millimeters anterior to the adductor tubercle, which is found at the posterior edge of the confluence of the femoral shaft and medial condyle (see Fig. 13.3) [7]. The appropriate endpoint for the needle tip targeting the SLGN is at the junction between the posterior cortex of the femoral shaft and the superior edge of the lateral condyle (see Fig. 13.3c and d) [7]. This is contrary to the former common practice of targeting the middle of the femoral shaft as a depth target for the placement of the SMGN and SLGN directed needles [2.9–11]. However, the needle target for the ablation of the IMGN was unaltered as a result of recent studies, and the recommendation remains to place the tip of the needle at the junction between the tibial shaft and medial condyle at a depth that correlates with the midpoint of the tibial shaft [7]. Traditionally, RFA of the ILGN has been avoided due to its close proximity to its parent nerve, the CFN. Fonkoue et al. proposed a novel technique in

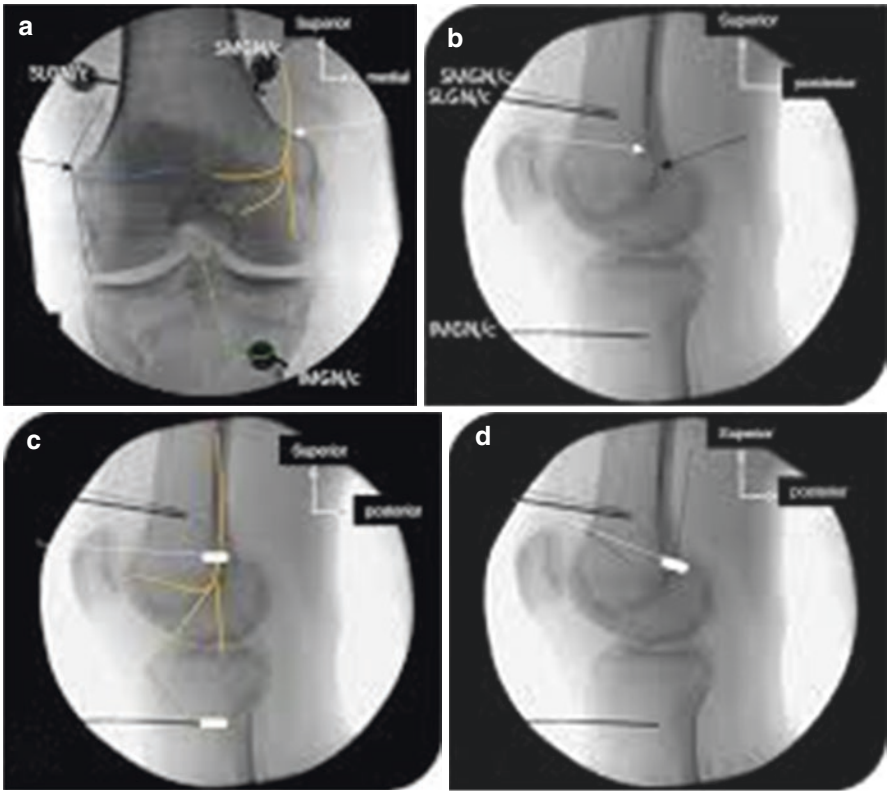

Fig. 13.3 Anterior-posterior (**a**) and lateral views (**b**, **c**, **d**) of the radiofrequency needle placement and proximity of the targeted sensory knee innervation. Please see above text for description. More posterior RF needle active tip was suggested in order to achieve proper denervation. (Borrowed with permission from: Fonkoue, et al. [7])

which the ILGN may be targeted safely in its distal trajectory before it enters the knee joint capsule [7, 8], but this has yet to enter the mainstream as a common clinical practice.

Workup

Ideal candidates for genicular RFA are patients who meet the following criteria: (1) have chronic knee pain secondary to osteoarthritis; (2) have been deemed to be an unsuitable candidate for knee replacement surgery due to co-morbidities or would prefer to avoid a knee replacement; and (3) conservative treatment options have

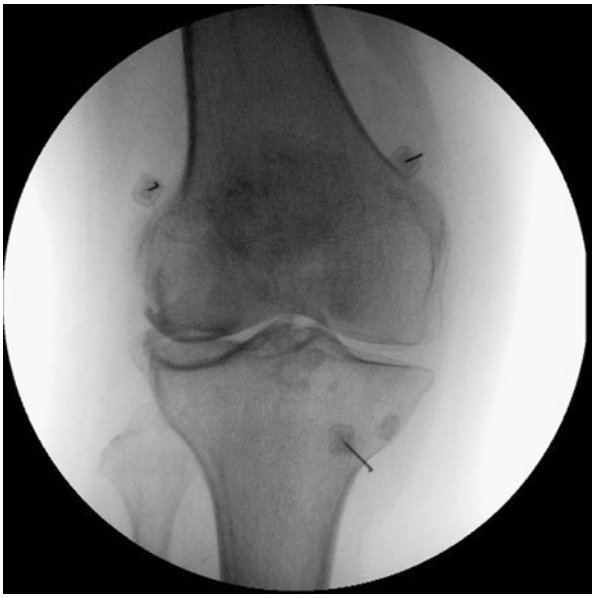

Fig. 13.4 Fluoroscopic anterior-posterior view of the knee joint during diagnostic geniculate nerve block procedure. Used are 25 G 3.5 inches spinal needles to facilitate the placement, and delivered was up to 1 cc of local anesthetic

failed. Traditionally, conservative treatment options include medical management using oral analgesics, physical therapy, and intra-articular steroid and/or visco-supplementation injection.

Patients being considered for RFA are often required to first undergo at least one diagnostic nerve block utilizing local anesthetic (Fig. 13.4). The traditional thought is that if the patient obtains more than 50% pain relief for the 6 hours following the diagnostic nerve blocks, then they should proceed with radiofrequency ablation. Although commonly utilized as a prognostic indicator, the practice of using genicular nerve blocks as such has been called into question. A recent prospective and randomized control trial examined whether or not the use of genicular nerve blocks was predictive of greater than 50% pain relief 6 months after patients had received cooled radiofrequency ablation of their genicular nerves [9]. It was concluded that if a 50% reduction in pain level was used as the threshold for moving forward with CRFA after undergoing diagnostic nerve blocks, then the nerve blocks did not have a significant impact on efficacy 6 months after patients received cooled RFA. However, if the threshold for selection was increased from at least 50% to at least 90% pain relief, there may be a larger subset of patients that experience successful CRFA results [9, 10]. This correlates with a case study by Reddy et al. that followed four patients who had 80% improvement in pain after diagnostic genicular nerve blocks. In this study, all four patients subsequently experienced greater than 90% improvement in pain 6 months after RFA and greater than 80% pain relief at the 12-month follow-up [11].

Technique (Diagnostic Block/RFA)

Despite some controversy surrounding the predictive value of diagnostic genicular nerve blocks [9], it is commonplace for these to be performed prior to proceeding with genicular RFA. The patient is first placed in supine position on the fluoroscopy table, and the desired knee is draped and prepped in a sterile fashion using a Betadine and/or chlorhexidine solution. Utilizing an anteroposterior fluoroscopic view (if most common fluoroscopic guidance is used; Fig. 13.4), one needle is then placed on either side of the femoral shaft as it meets the epicondyles, and a third needle is placed on the periosteum of the shaft of the tibia where it meets the medial epicondyle. After the periosteum has been contacted with all three needles, a true lateral view of the targeted knee is obtained. It must be ensured that the epicondyles are properly aligned without any overlap of the medial and lateral epicondyles on fluoroscopy in order to confirm a true lateral view and, thus, an accurate placement of the needle. The two superior needles targeting the SLGN and SMGN are advanced in close proximity to the femur until the needle tips are just a few millimeters away from the posterior edge of the femur [7.8]. The inferior needle targeting the IMGN is then advanced in close proximity to the tibia until it reaches the midpoint of the shaft of the tibia. The volume of local anesthetic injected should be kept to a minimum (0.5–1 mL) in order to maximize specificity of the diagnostic nerve blocks. A nerve block is generally thought of as successful if the patient obtains greater than 50% pain relief for the expected duration of action of the local anesthetic used. However, it may be prudent to utilize a higher threshold of 80% pain relief to improve prognostic utility [9–11].

Radiofrequency ablation of the genicular nerve complex can be performed in a similar fashion to the diagnostic nerve blocks described above (Figs. 13.3,13.4, and 13.5). Traditionally, the procedure has been performed under fluoroscopic guidance. The patient is placed in supine position on the fluoroscopy table, and the desired knee is draped and prepped in a sterile fashion using a Betadine and/or chlorhexidine solution. The skin and underlying soft tissues are then anesthetized with 1% lidocaine. Utilizing an anteroposterior fluoroscopic view, one RF needle is placed on either side of the femoral shaft as it meets the epicondyles, and a third needle is placed on the periosteum of the shaft of the tibia where it meets the medial epicondyle. After the periosteum has been contacted with all three needles, a true lateral view of the targeted knee is obtained. Sensory stimulation is performed at 50 Hz up with a threshold of less than 0.6 V to detect a proper reproduction of knee pain [2]. Motor stimulation is then performed at 2 Hz up to 2.0 V, and the extremity is observed for muscle contraction to reduce the likelihood of damaging any motor nerve fibers with the RFA. Next, each cannula is injected with 1–2 mL of 2% lidocaine prior to initiating lesioning. Once each site has been adequately anesthetized, the RF generator is activated, and the temperature is raised to 80° C for 90 seconds if traditional RF is being utilized or to 60° C (probe temperature 60° C; surrounding tissue temperature 80° C) for 150 seconds if cooled RF is being utilized. The authors complete the procedure by injecting 2–3 mL of 0.25% bupivacaine through each

cannula as they are withdrawn. Finally, hemostasis is achieved, and sterile bandages are placed.

In addition to the fluoroscopically guided procedure described above, alternative techniques have been proposed that involve the use of ultrasound as opposed to fluoroscopy [12]. Lash et al. cite several advantages of utilizing ultrasound versus fluoroscopy, including a lack of radiation exposure, improved precision of needle placement, and a potentially improved access to the procedure, given the prevalence of ultrasound machines versus C-arms. Perhaps most notably, ultrasound enables the operator to identify and avoid arterial structures surrounding the joint capsule. Lash et al. (Fig. 13.5) targeted the SMGN, SLGN, IMGN, and the suprapatellar genicular nerve in the following fashion: The patient was placed in supine position with the knee elevated to create 25–30° of flexion. The knee was then prepped and draped in a sterile fashion and a high-frequency, linear ultrasound probe was utilized to identify the four targets described.

The SMGN was found by orienting the ultrasound transducer coronally over the medial joint line and moving cephalad to the metaphyseal/diaphyseal junction. The genicular artery is visualized near the periosteum. The ultrasound probe is then rotated to an axial orientation, and the genicular artery/nerve in tandem are seen in short axis. The skin is anesthetized with 1% lidocaine, and the RF cannula is advanced from the anterior to the posterior using an in-plane technique. The desired endpoint described is either the genicular nerve or 50% depth of the femur if unable to visualize the nerve. The SLGN was targeted in an identical fashion after starting with the ultrasound probe being oriented coronally over the lateral joint line, rather than medial joint line [12]. While Lash et al. reported good outcomes with this technique, it is notable that 50% depth of the femur has fallen out of favor as a target, given the improvement in anatomic understanding provided by recent cadaveric studies [3, 7, 8, 12].

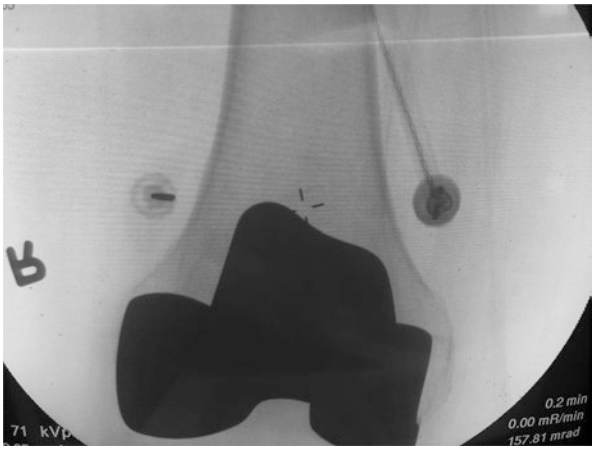

Fig. 13.5 Anterior-posterior view of the knee during CRFA with properly positioned CRF probes. Outcomes of RFA for chronic post-arthroplasty knee pain are similar to outcomes achieved in patients with chronic osteoarthritis

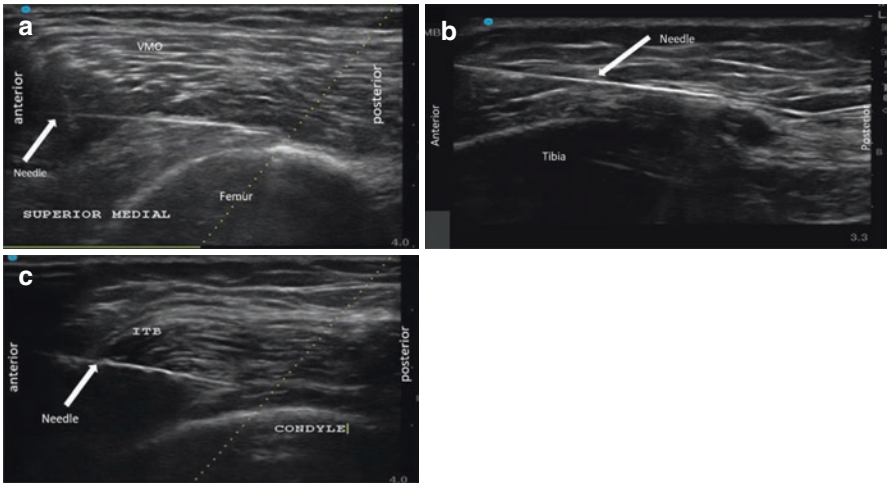

Fig. 13.6 (**a**) Superior medial geniculate nerve block. Introducer is positioned near genicular nerve/artery or close to metaphyseal/diaphyseal junction. *VMO* vastus medialis oblique. (Taken with permission from: Lash, et al. [12]). (**b**) Inferior medial geniculate nerve denervation. See text for details. (Taken with permission from Lash, et al. [12]). (**c**) Superior lateral geniculate nerve denervation. See details in the text. ITB=Illio-tibial band. (Taken with permission from Lash et al. [12])

The IMGN was targeted by placing the ultrasound probe over the medial joint line in a coronal orientation and moving caudal to the metaphyseal/diaphyseal junction. The genicular artery was identified, and the transducer was rotated to an axial orientation. The genicular artery/nerve was then identified in short axis and served as the target while advancing the RF cannula in-plane with the ultrasound beam. If the genicular artery/nerve was poorly visualized, then the desired endpoint was 50% the depth of the tibia [12] (Fig. 13.6).

In order to target the suprapatellar genicular nerve, the ultrasound probe was placed 5 cm proximal to the superior pole of the patella in a sagittal orientation, and the quadriceps tendon, prefemoral fat pad, and femur were identified. The transducer was turned 90° to visualize the femur in short axis. After anesthetizing the skin with 1% lidocaine, the RF cannula was inserted in plane to the tideline of the femur/quadriceps tendon just superficial to the periosteum [12].

After each RF probe was inserted, motor stimulation was performed at 2 Hz up to 1–2 V to rule out any motor activity. The introducers were then injected with local anesthetic, and CRFA lesioning was performed at 60° C (probe temperature) for 150 seconds [12].

Potential Complications

Genicular RFA is generally thought of as a safe procedure with minimal risk of complication. However, despite a low rate of reported complications, there have been incidents of adverse outcomes following the procedure. While obtaining

consent for the procedure, it is prudent to inform the patient of the possibility of bleeding, infection, and/or injury to surrounding structures, as all three of these complications have been described in the literature.

The genicular nerve branches targeted by RFA are found in close proximity to the genicular arteries, which are derived from the popliteal artery. This anatomic relationship makes vascular injury leading to pseudoaneurysm, arteriovenous fistula, and/or hemarthrosis a real concern [13]. The downstream impact of these vascular complications can be severe, potentially leading to osteonecrosis of the patella and ultimately patellar fractures [14, 15]. While this has not yet been described as a result of genicular RFA, it has been reported as a result of knee arthroplasty or arthroscopy, and the theoretical concern exists.

There have also been case series reporting of large periarticular hematomas and hemarthrosis following cooled radiofrequency ablation [16]. Two of the three described cases involved patients taking various anticoagulants. The anticoagulants were held prior to the procedure in accordance with the American Society of Regional Anesthesia Guidelines for deep peripheral nerve blocks [17]. However, two patients had self-limited hematomas. The third patient in the case series developed hemarthrosis and ultimately underwent total knee arthroplasty [16]. A separate case report described a hematoma along the anteromedial aspect of the distal femoral diaphysis found 4 days after cooled RFA had been performed on a patient [18]. The patient described was not maintained on any anticoagulants and did not report any bleeding disorders. The hematoma resolved with symptomatic management.

Additionally, there has been one case report of third-degree skin burn resulting from conventional radiofrequency ablation of the IMGN [19]. The authors of this case report noted some skin erythema overlying the site of their IMGN cannula, but no skin blanching or breakdown. The patient was found to have an 8-millimeter lesion with a central eschar at the 5-week follow-up visit, but the lesion was healed by week 7 post-procedure, and the patient did not require any intervention as a result of the burn.

There has been one report of septic arthritis following genicular RFA [20]. Although the authors of this case report maintained strict aseptic technique, their patient presented to the emergency room approximately 24 hours post-procedure with increased pain and a sense of "fullness" in the joint. The diagnosis of septic arthritis was confirmed with a CT scan demonstrating a large effusion and an aspiration of the knee joint, which yielded a purulent fluid that ultimately grew methicillin-resistant *Staphylococcus aureus*. The authors postulated that they had inadvertently punctured through and through the joint capsule with the placement of their superomedial and/or superolateral RFA probes, thus contaminating the joint space.

Care should also be taken with regard to RFA of the inferior medial genicular nerve, given its proximity to the saphenous nerve. The saphenous nerve provides sensory innervation to the medial aspect of the leg and foot, and therefore damage to the saphenous nerve while targeting the IMGN may theoretically lead to neuralgia or possibly complex regional pain syndrome. There have not been any case reports of this complication as a direct result of genicular RFA at the time of this publication.

Long-Term Outcomes

A genicular RFA treatment is generally thought of as successful if the patient maintains at least 50% pain relief, though other outcomes may also be considered, such as patient satisfaction or functional improvement. RFA has been found to provide superior results to intra-articular corticosteroid injection with regard to VAS scores, percentage of perceived pain relief, and function [21–24]. This has also been found to be true in comparison with intra-articular injection of hyaluronic acid [25]. With the growing body of literature regarding genicular RFA, the durability of this treatment option has been well established [26–31].

The original outcomes that were measured by Choi et al. in their landmark study describing genicular RFA in 2011 were VAS pain scores and the percent of pain relieved at 1 week, 4 weeks, and 12 weeks post-procedure. They reported that 59%, 65%, and 59% of patients at 1 week, 4 weeks, and 12 weeks post-RFA, respectively, reported greater than 50% pain relief [2].

Many recent studies have examined the longer-term outcomes of genicular RFA. In a retrospective chart review and follow-up in 2017, it was concluded that a majority of patients experienced greater than 50% pain relief at the 6-month post-procedure mark [26]. These results were confirmed by a prospective, randomized, controlled trial that involved 60 patients. Half of the patients underwent traditional genicular RFA, and the other half received conventional analgesics only, which included paracetamol, diclofenac sodium, and physiotherapy. It was concluded that patients who underwent RFA had a statistically significant decrease in VAS (Visual Analogue Scale) scores, WOMAC (Western Ontario McMaster Universities OA index) scores, and patient satisfaction, which is measured via the Likert Scale at 6 months post-procedure [24]. A large retrospective study that included data from 183 patients who underwent cooled RFA found that the patients had a mean duration of greater than 50% pain relief of 12.5 months (range 0–35 months). Notably, this study did not find a significant difference in CRFA outcomes between patients that had total knee arthroplasty (TKA) and had ongoing knee pain versus those that had never had knee surgery, indicating that CRFA is a viable option for patients whether or not they have had TKA [31].

There is now data demonstrating the efficacy of genicular CRFA (Fig. 13.7) may extend to up to 24 months. A prospective, multicenter, randomized, crossover trial presented data demonstrated that 65% of CRFA patients that maintained pain reduction greater than 50% at 12-months post-procedure. Patients were allowed to cross over to the CRFA group if they had unsatisfactory results from an intra-articular steroid injection, and these patients were found to have a statistically significant improvement in pain and functional capacity ($p < 0.0001$) [21–23]. In an extension of this study, the authors evaluated 25 patients 18 months after CRFA treatment and 18 patients 24 months after CRFA treatment [21–23]. At 18 months, the mean NRS score was 3.1 +/− 2.7, with 12 out of 25 patients reporting greater than 50% pain relief. At 24 months, the mean NRS score was 3.6 +/− 2.8, with 11 out of 18 patients reporting greater than 50% pain relief. The authors also reported a maintenance of

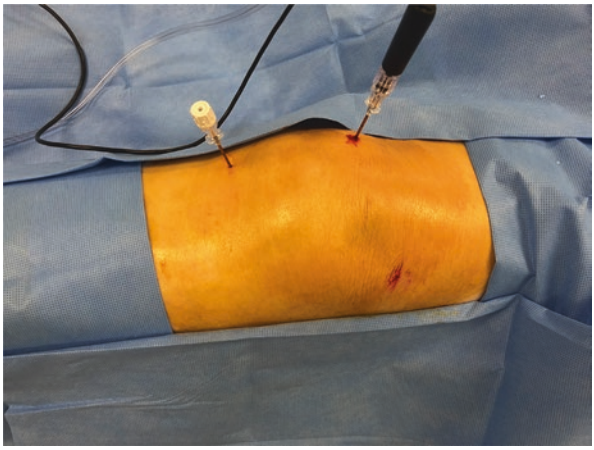

Fig. 13.7 Photograph or CRFA introducer and electrode placement. While CRFA electrode is in place via introducer at medial superior geniculate nerves location, inferior medial introducer positioning is being completed in order to mover RF electrode to next position

a significant improvement in the Oxford Knee Score at both 18 and 24 months post-CRFA, indicating an improvement in function [23].

With regard to ultrasound-guided genicular CRFA, the data is limited. Lash et al. collected data retrospectively via telephone on 22 patients (33 procedures accounting for some bilateral) and reported that 82% of the contacted patients reported an improvement in pain ranging from 50 to 100%. The mean time elapsed since the ultrasound-guided CRFA was performed was 306 days, with a range of 162–519 days [12].

Conclusions and Future Directions

Genicular radiofrequency ablation has been proven to be a safe, effective treatment option for the multitude of patients that suffer from chronic knee pain related to osteoarthritis, and cooled radiofrequency ablation has been shown to have particularly durable effects [21–23, 25]. It has also been demonstrated that after initial improvement has waned, repeat CRFA leads to similar levels of pain relief, extending the efficacy of the treatment indefinitely [31]. This durability may be attributed to the larger lesion size obtained by CRFA (Fig. 13.7) versus the conventional RFA, resulting in the improved likelihood of ablating the desired neural target [10, 32, 33]. However, further prospective investigation is warranted to support this theoretical advantage.

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Chapter 14
Shoulder

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Anatomy

Chronic shoulder pain is a common musculoskeletal complaint resulting in functional disability, reduced rehabilitation potential, and significant healthcare burden [1, 2, 3]. Key muscles include supraspinatus, infraspinatus, teres minor, and subscapularis, better known as the rotator cuff complex. Innervation of the shoulder joint comprises of the suprascapular nerve, the axillary nerve, and the lateral pectoral nerve. Presentation can consist of acute, subacute, or chronic onset, and a variety of conditions may contribute to shoulder pain. Common etiologies of chronic shoulder disorders include suprascapular neuropathy, glenohumeral and acromioclavicular joint pathologies, rotator cuff syndrome, and adhesive capsulitis [3].

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_14

Innervation

Nerve supply to the shoulder joint primarily consists of suprascapular nerve, the axillary nerve, and the lateral pectoral nerve, which supplies the posterosuperior, posteroinferior, and anterosuperior aspects of the joint capsule, respectively [4]. The suprascapular nerve travels laterally from the spinoglenoid notch toward the glenohumeral joint capsule posteriorly, innervating almost 70% of the shoulder joint [1, 5]. Meanwhile, the articular branches of the axillary nerve course circumferentially from the quadrangular space to the posterolateral humerus, to provide the nerve supply to the inferior aspect of the posterior shoulder joint [4, 5]. The articular branches of the lateral pectoral nerve run alongside the acromial branches of the thoracoacromial blood vessels over the superior portion of the coracoid process, innervating the anterior joint capsule [1, 4].

Etiologies and Associated Pathologies

Shoulder pain can ensue from a magnitude of conditions involving the shoulder and its surrounding structures, but common etiologies include suprascapular neuropathy, glenohumeral and acromioclavicular joint pathologies, rotator cuff syndrome, and adhesive capsulitis [3].

Suprascapular Neuropathy

The suprascapular nerve travels inferiorly and laterally as it approaches the lateral border of the scapula; this tortuous path makes the nerve particularly susceptible to injury as it passes through the suprascapular and the spinoglenoid notches [6, 7]. Suprascapular neuropathy can result from a hypertrophied or ossified transverse scapular ligament, affecting both the supraspinatus and infraspinatus muscles. The most common cause for nerve injury at the spinoglenoid notch is attributed to a paralabral cyst from a labral injury, resulting in infraspinatus muscle atrophy [8]. Sometimes, if a rotator cuff tear is large enough, it may result in suprascapular neuropathy as the nerve is compressed under the medial belly of the rotator cuff complex [9, 10].

Glenohumeral Joint and Instability

The glenohumeral joint consists of the humerus and glenoid fossa, labrum, capsule, glenohumeral ligaments, static shoulder stabilizers, and dynamic shoulder stabilizers. It is a shallow ball-and-socket joint that allows significant mobility, although, at

the expense of stability. As a result, the glenohumeral joint necessitates both static and dynamic restraints to ensure proper stability and function. Static and dynamic stabilizers allow for shoulder joint congruity during overhead motions [6]. The rotator cuff muscles and the scapular stabilizers assist in preservation of the shoulder joint in midrange movement [6, 11].

The glenoid labrum is a dense fibrocartilaginous tissue that surrounds the glenoid bone and further augments shoulder stability by increasing the height and depth of the glenoid fossa [12, 13] The labrum increases the superior-inferior diameter of the glenoid by 75% and increases the anterior-posterior diameter by 50%, allowing for increased contact of the humeral head with the glenoid fossa and further joint stability [14]. The glenohumeral ligaments, long head of the triceps tendon, and the long head of the biceps tendon attach to the labrum, creating a fibrous cavity over the joint and enhancing shoulder stability [15]. It prevents anterior and posterior dislocation of the humeral head [6, 7, 11]. The glenohumeral capsule originates from the labrum and encapsulates the head of the humerus. The capsule attaches to the neck of the humerus, and it thickens anteriorly to form the glenohumeral ligaments [7, 11].

The glenohumeral ligaments attach to the glenoid to stabilize the shoulder joint and prevent translation of the humeral head from the glenoid cavity [14]. These ligaments consist of the superior, middle, and inferior glenohumeral ligaments. The anterior and posterior bands of the inferior glenohumeral ligament are the primary static stabilizers of the shoulder when the arm is placed in a functional (abducted) position [7, 11]. These two bands along with the axillary pouch consist of the inferior glenohumeral ligament, the thickest of all glenohumeral ligaments [7].

Instability of the glenohumeral joint can be caused by traumatic or atraumatic injuries. Traumatic injury is attributed to glenohumeral dislocation due to either an anterior or posterior disruption, resulting in a unidirectional instability [16]. While anterior dislocations occur secondary to a fall on an outstretched, externally rotated, and abducted arm, posterior dislocations are associated with a fall on the forward flexed and adducted arm [6]. The most common type of traumatic unidirectional instability is traumatic anterior dislocation [11]. Atraumatic etiology is related to congenital capsular laxity or repetitive overuse injuries resulting in microtrauma [7, 11]. Multidirectional instability is often seen with bilateral shoulder symptoms.

Acromioclavicular Joint and Sprain

The acromioclavicular (AC) joint, a diarthrodial joint that is localized between the clavicle laterally and the acromion medially, is enclosed by a fibrous capsule and reinforced by ligaments [17]. The trapezoid and conoid ligaments originate at the coracoid process of the scapular and attach to the clavicle, whereas the coracoacromial ligament begins at the coracoid process of the scapula but inserts at the acromion [17, 18].

Injuries to the AC joint can be due to trauma as well as with repetitive overhead or throwing activities. AC joint complex sprains are graded from I to VI depending on the degree of sprain complex disruption [6]. These occur more commonly in males in their 20s as a result of direct trauma to the acromion or due to a fall.

Rotator Cuff Complex and Correlative Pathology

The rotator cuff muscles comprise of the supraspinatus, subscapularis, infraspinatus, and teres minor. This complex allows for the humeral head to lie within the glenoid cavity. These muscles work together to oppose the actions of the deltoid muscle, which elevates the humeral head, by limiting superior translation of the humeral head when the arm is abducted [7, 19]. These muscle forces play a pivotal role as the force couple concept consists of an imbalance of the external rotators and internal rotators (ER/IR ratio), which can increase the incidence of chronic shoulder pain [7].

Injuries to this complex can result from overt microtrauma, recurrent microtrauma, and outlet impingement between the greater tuberosity of the humerus and the acromion [20]. This condition can also be associated with a fibroblastic hyperplasia, leading to rotator cuff tendinosis which most frequently occurs in the supraspinatus tendon [6]. Furthermore, there is some correlation with anatomic shape of the acromion and incidence of rotator cuff tears, in which there is a higher occurrence of tears with a curved or hooked appearance [20]. While primary etiologies of rotator cuff pathology include a hooked or curved acromion shape and a thick coracoacromial ligament, secondary causes are associated with scapular dyskinesia and glenohumeral joint instabilities [21, 22]. Patients often complain of anterior or lateral pain with overhead activities or worsening of pain during sleep. Overtime, rotator cuff tendinopathy and tears can progress into adhesive capsulitis due to prolonged disuse secondary to pain [6, 11].

Adhesive Capsulitis

Adhesive capsulitis, or frozen shoulder, is a painful condition resulting in limitation of range of motion despite normal imaging [23, 24]. It affects almost 2–5% of the population, and females appear to be more affected, with increased incidence after the fourth decade of life [24, 25]. This condition is progressive with a duration of approximately 2 years and occurs through various stages including the painful stage, the freezing stage, and the resolution stage [23, 24]. Etiologies of primary origin appear to be mainly idiopathic, but there are numerous secondary etiologies to adhesive capsulitis including diabetes, prolonged immobilization of the shoulder, hypothyroidism, and autoimmune disease [6, 11].

Workup

Shoulder pain is one of the most common musculoskeletal complaints reported; the incidence of which rises with age and affects anywhere from between 4.7 and 46.7% of adults. [30] While nociceptive pain is often thought of as the primary mediator of large joint and musculoskeletal pain, we now know that there is also a neuropathic component, especially in chronic pain syndromes [32]. The suprascapular nerve provides sensory innervation to the posterior shoulder and glenohumeral joint, the axillary nerve innervates the lateral shoulder and inferior portion of the glenohumeral joint, and the lateral pectoral nerve innerves the anterior shoulder and the anterosuperior quadrant of the glenohumeral joint. [31, 37].

The mechanism of action of neuropathic pain in osteoarthritis is proposed to be via the release of inflammatory mediators, resulting in the activation of peripheral nociceptors innervating the joint (i.e., synovial capsule, periosteum, ligaments, etc.), leading to peripheral sensitization, and subsequent upstream hypersensitization of the central nervous system [29]. The nerves surrounding the shoulder joint can be injured in various mechanisms, resulting in shoulder pain. Trauma, more specifically from fracture (i.e., scapular or humeral fracture) or surgery, is a common cause of nerve (suprascapular and axillary, respectively) injury at the shoulder. Direct nerve compression may also cause shoulder pain, and etiologies include tumor, cyst, or entrapment syndromes, such as the suprascapular nerve becoming entrapped at the suprascapular/spinoglenoid notch in the setting of calcification or adhesion to the transverse scapular ligament or engorged vasculature or inflammatory changes due repetitive microtrauma or a narrow notch. Dynamic compression of the peripheral nerves of the shoulder, specifically the supraspinatous, can occur with repetitive overhead throwing sports such as volleyball. Finally, a stretch injury, for example, from shoulder dislocation or a rotator cuff tear, may also result in neuronal stretch injury. [28].

A study by Albritton et al. (2003) underscored the significance of rotator cuff injuries in suprascapular neuropathy, citing medial retraction of the supraspinatous rotator cuff muscle for placing increased tension on the suprascapular nerve as it passes through the suprascapular notch, thus resulting in neuropathic pain and possibly weakness [26]. By the time that corrective surgery has been performed at the shoulder, peripheral sensitization from chronic inflammatory changes may often have already occurred, leading to chronic shoulder pain despite intervention. Excessive distalization or lateralization of the humerus after reverse total shoulder arthroplasty has been shown to be associated with neurological deficit, specifically of the axillary nerve [34]. Buildup of postsurgical scar tissue can result in neurapraxia, and intraoperative surgical sacrifice may result in axonotmesis or neurotmesis and possible neuroma formation. A Canadian study with 115 patients by Razmjou et al. in 2018 found that approximately 4% of patients who underwent shoulder arthroplasty complained of neuropathic pain (defined by the Leeds assessment of neuropathic symptoms and signs scale), which was associated with greater pain, greater depression, and more disability [36]. A Dutch study with 538 subjects found

that at 1–2 years postoperatively, 22% of patients had persistent shoulder pain, and 13% of that was presumed to be secondary to neuropathic mediated pain [27]. A study by Karasugi et al. in 2016 found that nearly 10.9% of patients with rotator cuff tears have neuropathic-mediated pain as defined by the painDETECT questionnaire (PDQ) [33].

The presentation of shoulder pain can be thought of as acute, subacute, and chronic. Neuropathic pain may be associated with burning, tingling, numbness, allodynia, dysesthesias, electrical sensations, and altered temperature sensation. A patient with suprascapular neuoropathy typically presents with dull achy nonspecific posterior shoulder pain, possibly radiating to the neck or shoulder, and often associated with one of the clinical vignettes above. Of note, pain of the shoulder is typically accompanied by functional impairments in range of motion and may lead to eventual muscular atrophy or adhesive capsulitis if left untreated [SOURCE].

Examination

The suprascapular nerve stretch test described by Lafosse may be used to reproduce the patients posterior shoulder pain in suprascapular neuropathy, thus confirming the diagnosis. The examiner stands behind the patient, the patient rotates the cervical spine to the contralateral side while the examiner applies gentle anterior to posterior pressure on the head, and with the other hand, the examiner provides anterior to posterior pressure on the affected shoulder, placing a stretch on the suprascapular nerve [35]. If there is motor involvement due to entrapment of the suprascapular nerve, an entrapment of the nerve at the suprascapular notch will result in both weakness of the supraspinatous and infraspinatous, while entrapment at the spinoglenoid notch results only in infraspinatous weakness. Weakness of the supraspinatous may be seen with a positive empty can or Jobe's test. Infraspinatous weakness may be tested by resisted external rotation of the shoulder with the elbow at the side. Motor involvement of the axillary nerve will result in weakness in primarily shoulder abduction. Of note, there does not have to be motor involvement of the affected nerve for there to be a painful neuropathy. Tenderness to palpation may be elicited at the suprascapular or spinoglenoid notch as the suprascapular nerve transgresses these points of entrapment. Similarly, tenderness to palpation may occur at the quadrangular space or posterior humeral neck with entrapment of the axillary nerve.

Diagnostics

In terms of diagnostic studies, magnetic resonance imaging and ultrasound can be used to diagnose compressive lesions as well as identify muscle atrophy. A nerve conduction study (NCS) can identify changes such as decreased conduction velocity and decreased amplitude indicative of nerve damage, while electromyography

(EMG) testing can demonstrate acuity of nerve damage; positive sharp waves, fibrillations, and fasciculations represent acute nerve damage, while increases in duration, amplitude, and polyphasics represent chronic nerve damage. Together, a NCS/EMG study has typically been thought of as the gold standard for diagnosis of mononeuropathy at the shoulder.

Treatment

Conservative treatments for shoulder pain include relative rest, modalities such as ice and heat, physical and occupational therapy, and medication management with nonsteroidal anti-inflammatories. If the above treatments are not successful, an intra-articular injection of steroid is typically attempted. Other interventional treatments include regenerative medicine injections, peripheral nerve stimulation, neurolysis, and surgery. Peripheral neurolysis may be performed chemically, surgically, and via thermal ablation. For the purposes of this chapter, we discuss thermal radiofrequency ablation techniques for the treatment of chronic shoulder pain.

While physical exam can be helpful in the diagnosis of mononeuropathic pain at the shoulder, an image-guided diagnostic injection with a small volume of local anesthetic is the gold standard for diagnosis and to see if a patient will be a responder to neurolysis. Using either ultrasound, fluoroscopy, or a combination of both, a needle is guided to the target nerve under direct image guidance, and 0.5–1 cc of local anesthetic is injected surrounding the target nerve. Injections which result in significant pain relief, defined as 50–80% improvement, for the duration of the local anesthetic, are considered successful diagnostic blocks. This diagnostic block may be repeated for confirmation.

After a successful block, thermal radiofrequency ablation is performed to impart long-term treatment. The type of thermal ablation (conventional radiofrequency ablation, pulsed radiofrequency ablation, or cryoablation) utilized is dependent on access, insurance reimbursement, and comorbidities. Of particular importance, the peripheral nerves of shoulder are mixed sensory and motor nerves, and thus significant ablation to the nerve may result in motor weakness. Duration of lesion, temperature, and preexisting functional capacity of the shoulder be taken into account when performing neurolysis at the shoulder.

Technique

RFA of the shoulder joint has been determined to be a safe and efficacious treatment [38]. Early diagnostic blocks and RFA focused primarily on the suprascapular nerve [39]. Blockade of the suprascapular nerve is a treatment that is both used for acute and chronic pain therapies as it innervates approximately 70% of the shoulder [40]. The nerve originates from the superior trunk of the brachial plexus, including C5–C6.

It receives sensory information from the acromioclavicular joint, the posterior and superior capsule of the glenohumeral joint, the subacromial bursa, and the coracoclavicular ligament [41]. Complete ablation of the main suprascapular nerve can be an option for patients with severe chronic pain who maintain limited functional use of the shoulder [42]. The remainder of the sensory innervation is achieved through the axillary and lateral pectoral nerve [43]. The identification of articular branches of these nerves paved way for the possibility of additional future targets [44].

Blockage of the Suprascapular Nerve

The suprascapular nerve block can be performed without imaging based on anatomical landmarks, with ultrasound guidance, or with fluoroscopic guidance. Please note, appropriate sterile technique should be used for every procedure outlined.

The patient is typically seated or prone with the anatomical landmarks noted. These include the spine of the scapula, the acromion, the clavicle, and the acromioclavicular joint. The injector should locate the suprascapular notch and then insert the needle at the floor of the supraspinatus fossa. Administration of local anesthetic of the choice of the physician should be done at the site.

To perform the injection under ultrasound guidance, the ultrasound transducer is placed in a transverse plane at the base of the spine of the scapula [45]. The transducer is then moved in a cephalad direction to identify the suprascapular fossa and then moved laterally to locate the suprascapular notch where the nerve can be visualized beneath the transverse scapular ligament [46].

Under fluoroscopic guidance, patients are placed prone on the table with the affected arm flexed at the elbow and then internally rotated and flexed at the shoulder. The image intensified is then rotated in a craniocaudal and mediolateral direction until the "u-shaped" suprascapular notch is identified. Then, approximately 1 cc of contrast is administered followed by administration of the physician's preferred anesthetic agent [47] (Fig. 14.1).

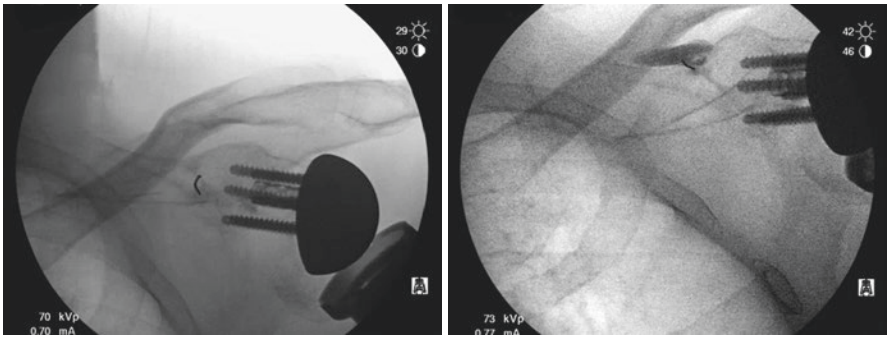

Fig. 14.1 Flouoroscopic-guided suprascapular nerve block

Blockade of the Axillary and Lateral Pectoral Nerve

In a cadaveric study, mapping was performed to determine the location of the sensory terminal branches of the axillary and lateral pectoral nerves. To allow access to the articular branches of the axillary nerve, the patient should be placed in a prone position and the affected arm rotated internally with the palm positioned posteriorly [48].

Then, using an AP image of the image intensifier, rotate the machine in approximately 15-degree obliquity toward the affected side and then caudally 15 degrees. Center the image intensified over the head of the humerus. The needle should be placed at the most inferior and lateral border of the greater tubercle. Blockade of this area may produce weakness in the deltoid, teres minor, and triceps muscles. It is important to not move beyond the anterior portion of the greater tubercle.

In order to access the LPN, the patient must be flipped supine. A PA view is obtained, and then the image intensified is oblique 15 degrees toward the affected side and then cephalic 15 degrees. The target location of the LPN under fluoroscopy is the midpoint of the coracoid process.

There are three types of radiofrequency ablation that are used for treatment of the shoulder, including conventional RFA, pulsed RFA, and cooled RFA. In conventional RFA and pulsed RFA, most data has been shown that treatment of the suprascapular nerve is the most common treatment with data indicating up to 6 months of relief [49]. However, Eckman et al.'s mapping of novel targets as indicated above for terminal sensory branches of the axillary and lateral pectoral nerve had led to additional targets being utilized for all types of RF, including cooled.

Complications

Typical complications of shoulder radiofrequency ablation include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect. Less common complications may include motor weakness and vascular injury.

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Part III
Other Indications and the Future of RFA

Chapter 15
Peripheral Nerve Radiofrequency Ablation

Eric Lee, Dennis G. Patterson, Nomen Azeem, and Timothy R. Deer

Introduction

Radiofrequency ablation is a stalwart in the interventional pain physician's treatment algorithm. The basic science and mechanism of action as well as lesion shape and size are elucidated elsewhere in this textbook. From the first treatments with radiofrequency therapy to treat trigeminal neuralgia by Kirschner in 1931 to commonplace utilization of the therapy today, the wide variety of pathophysiological states that can cause pain is nearly as varied as the number of major sensory nerves in the body. Given the fact that in theory, any nerve that can safely be accessed percutaneously is potentially a target for radiofrequency ablation, this chapter has highlighted several peripheral nerves that are amenable to such therapy. It further focuses on patient selection and the procedural technique as well. For purposes of clarity, it should be noted these procedures are performed after a successful diagnostic block which helps conform the intended target will treat the patient's pain.

Multiple imaging modalities such as ultrasound and fluoroscopy help guide the physician in targeting the desired nerve safely and effectively. These modalities, however, are not a substitute for excellent anatomical acumen, and an understanding of the risk of any interventional procedure entails.

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_15

Occipital Nerve Radiofrequency Ablation

Anatomy

The occipital nerves originate from the dorsal rami of C2 and C3 spinal nerves. These comprise of three major occipital branches: greater occipital nerve (GON), the lesser occipital nerve (LON), and the third occipital nerve (TON). The GON innervates the skin of the back of the scalp up to the vertex of the skull, the ear, and the skin just superior to the parotid gland. The LON innervates the scalp in the lateral region of the head and the cranial surface of the ear. The TON also innervates the facet joint between the C2 and C3 spinal nerves and a portion of the semispinalis capitis muscle.

The GON becomes subcutaneous inferior to the superior nuchal line and above the aponeurotic sling, between the trapezius and sternocleidomastoid. This is the most common site for occipital nerve compression [1]. To a lesser extent, the TON and the LON may be involved which are located in the subcutaneous layer medially and laterally to the GON, respectively.

Workup

Occipital neuralgia is associated with symptoms of dysesthesias and/or allodynia in the distribution of the occipital nerve often associated with tenderness over the nerve or trigger points to the posterior scalp. Pain is most commonly unilateral but may involve both sides. In the presence of these symptoms, temporary alleviation of pain with local anesthetic block may aid in diagnosis [2]. Diagnostic workup may include imaging of both the brain and cervical spine. Common sources of headaches including migraine, tension headache, cluster headache, and cervicogenic headache should be ruled out. Other possible causes of headaches and neck pain should be eliminated prior to diagnosis of occipital neuralgia, including C2 radiculopathy, cervical facet pain, greater auricular neuralgia, hemicrania continua, giant cell arteritis, tumor, or pseudotumor cerebri.

Technique

Traditionally, occipital nerve blocks were performed without image guidance for needle placement, based solely on anatomical landmarks. The GON is most often located one-third the distance from the external occipital protuberance and the mastoid process. The nerve can be found by palpation of the occipital artery and is typically located just medial to the artery. Anatomic variations in some patients result in

the GON occasionally being located lateral to the occipital artery. The LON is localized along the same line as that of the GON, two-thirds the distance lateral from the external occipital protuberance. Recent literature has typically favored the use of image-guided techniques [3]. Fluoroscopy has been used to assist in more accurate identification of anatomical landmarks for both nerve blocks and radiofrequency ablation. This is particularly the case with TON blocks and radiofrequency ablation, which are performed in the lateral fluoroscopic view (as with medial branch blocks) in the upper cervical spine [3–5]. When performing radiofrequency ablation, parallel needle placement with the facet surface is recommended to ensure optimal ablation surface area. Ultrasound has more recently described in visualization of the occipital nerve branches and surrounding vasculature when performing diagnostic block or radiofrequency ablation.

Complications

Complications of occipital nerve radiofrequency ablation include infection, bleeding, lightheadedness, vertigo, numbness or dysesthesias, and increased pain at the procedural site [7–9].

Long-Term Outcomes

Studies have shown efficacy of both continuous radiofrequency ablation and pulsed radiofrequency ablation within the range of 6 months to 12 months [4–9], though there is no consensus to which has greater efficacy.

Intercostal Nerve Radiofrequency Ablation

Anatomy

Intercostal neuralgia is a painful disorder which is characterized by sharp, often intense, shooting and burning pain radiating back to front, along the distribution of an intercostal nerve. Intercostal neuralgia is commonly seen in patients with chronic chest wall pain after thoracotomy, postsurgical pain, idiopathic nerve entrapment, traumatic or iatrogenic neuromas, or as a result of herpes zoster infection [10]. The intercostal nerves emerge from the anterior rami of the thoracic spinal nerves from T1 to T11. The anterior ramus of the twelfth thoracic nerve lies in the abdomen as the subcostal nerve. Each intercostal nerve lies between the posterior intercostal

membrane and the parietal pleura. The nerves travel with the intercostal vessels in the costal groove of the ribs between the internal and innermost intercostal muscle layers. Near their origin, the intercostal nerves send a posterior branch to the paraspinal muscles and the overlying skin, and communicant rami to the sympathetic trunk adjacent to the vertebral column. The first six intercostal nerves then innervate the intercostal muscles, the cutaneous territory on the side of the thoracic wall, and the thoracic pleura, eventually ending as the anterior cutaneous branches supplying the skin near the midline of the chest. After supplying branches to the intercostal muscles, abdominal peritoneum, and skin, the lower intercostal nerves leave their intercostal spaces anteriorly to innervate the anterior abdominal wall, the rectus abdominis muscle, and the overlying skin.

Workup

Intercostal neuralgia is typically a clinical diagnosis made by physical examination. Examination findings may include sharp and focal pain involving the ribs, reproduction of pain with palpation, and increased pain with inspiration. Imaging and blood work should be performed to ensure that there is no underlying pathology within the thoracic cavity. A recent history of trauma or infection may precede intercostal neuralgia. Diagnostic blocks should be performed prior to radiofrequency ablation to confirm the diagnosis of intercostal neuralgia and correctly identifying the specific intercostal nerve(s) involved.

Technique

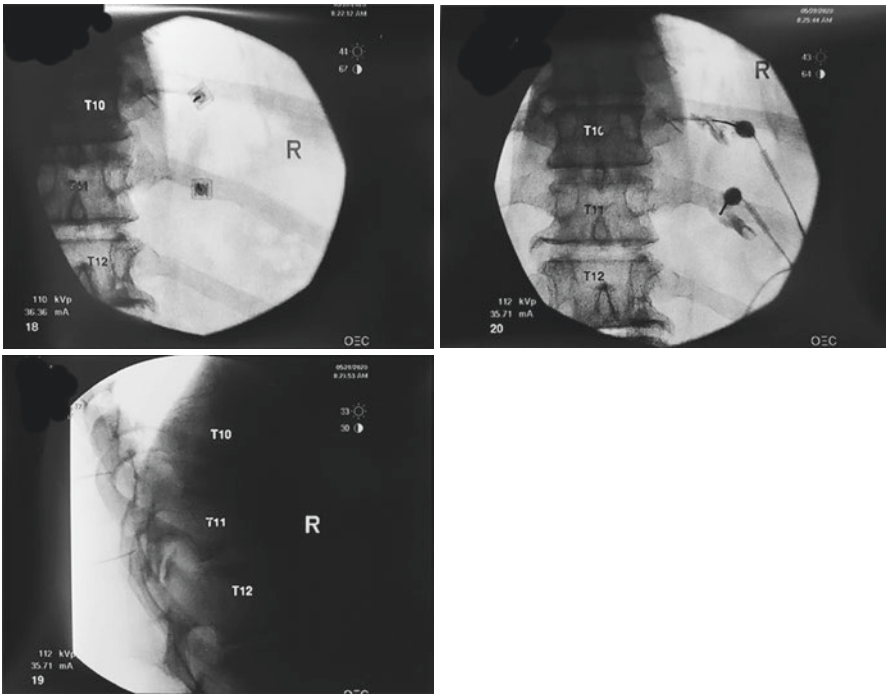
Intercostal nerve radiofrequency ablation is performed with the patient in prone position. The radiofrequency needle and probe are positioned under the inferior border of the intercostal space using imaging guidance. Fluoroscopy and ultrasound have both been utilized to guide and confirm appropriate needle placement [11]. Caution must be taken to ensure the needle does not penetrate the underlying pleura. Typical approach involves utilizing the rib as a guide. The radiofrequency needle is driven toward the inferior border of the rib. Utilizing a step-off technique, the needle tip is advanced into the costal groove. On fluoroscopy, lateral views may assist in appropriate depth of the radiofrequency needle, as well as injecting contrast to avoid the vascular bundle adjacent to the intercostal nerve. On ultrasound, differentiation of the three intercostal muscles layers (innermost, internal and external) can assist in appropriate needle placement. Both efficacies of pulsed radiofrequency ablation and continuous radiofrequency ablation have been documented with ablation times ranging from 60 to 180 seconds although data is mainly limited to retrospective studies and case series [11–14].

Complications

A distinct complication with radiofrequency ablation of the intercostal nerves is pneumothorax, due to the location of the intercostal nerve relative to the pleural space. Damage of the intercostal vessels is another complication as they run along with their respective intercostal nerve. Additional complications include abdominal wall weakness, persistent numbness, or deafferentation effect following ablation.

Long-Term Outcomes

Case series have shown a wide range of relief from intercostal radiofrequency ablation with relief noted after 2 months to over a year [11–14].



Lateral Femoral Cutaneous Radiofrequency Ablation

Anatomy

Meralgia paresthetica (MP) is a term to describe clinical pain symptoms that result from compression or irritation of the lateral femoral cutaneous nerve (LFCN). Symptoms may include numbness, paresthesia, and/or pain. Etiologies of MP include entrapment of the nerve caused by everything from physiological changes in the inguinal area, choice of clothing, and iatrogenic injury during surgery [15, 16].

The lateral femoral cutaneous nerve (LFCN) is a pure sensory nerve that is a derivative of the posterior divisions of the L2 and L3 spinal nerves. Variations in the LFCN's anatomy are common, with seven different points of exit from the pelvis having been observed [15]. The nerve most commonly exits medial to the sartorius muscle, beneath the inguinal ligament (IL), anterior to the ASIS, and then bifurcating into an anterior and posterior divisions. These distal branches provide sensory innervation to the skin of the anterolateral and lateral aspects of the thigh.

Workup

To rule out correctable causes of MP, imaging studies including plain film radiographs, ultrasound (US) of the pelvis, and MRI of pelvis and thigh are typically performed. MRI of the lumbar spine may be considered to rule out lumbar radiculopathy, particularly involving the L2 or L3 nerve roots. Nerve conduction studies may show decreased sensory nerve action potentials and increased latency, with side-to-side amplitude difference on comparison to the healthy nerve. Positive response to diagnostic blocks is often performed prior to consideration of radiofrequency ablation.

Technique

There are a variety of reports on placement of the radiofrequency needle and probe. The anterior superior iliac spine (ASIS) is used as the primary landmark for both ultrasound and fluoroscopy. Cephalad and caudal approaches, both medial of the ASIS, have been described [16–18]. Sensory and motor testing should be used to ensure proper needle placement, particularly reproduction of concordant pain in the thigh with sensory stimulation. Both continuous and pulsed radiofrequency are options. There is no consensus on the timing of radiofrequency ablation with a large range described in the literature.

Complications

Potential complications from radiofrequency ablation of the LFCN may lead to Wallerian degeneration, severe neurodestruction, persistent numbness, or deafferentiation effect. Additionally, ablation of surrounding soft tissue may lead to increased post-procedural pain. As the LFCN is located in the pelvis near the colon, it is critical to observe appropriate needle depth to avoid intestinal perforation.

Long-Term Outcomes

Case reports and series have described improvements of MP symptoms ranging from 6 months to 24 months of pain relief [16–19].

Ilioinguinal/Iliohypogastric Nerves Radiofrequency Ablation

Anatomy

Ilioinguinal and iliohypogastric neuropathy is a rare but painful condition involving the groin and lower pelvis, respectively. Both nerves are mixed nerves with both sensory and motor function. The ilioinguinal and iliohypogastric nerves originate from the T12 and L1 somatic nerves and follow a curvilinear course along the concavity of the ilium. The nerves emerge near the lateral border of the psoas major muscle and travel inferior through the anterior abdominal wall, located anterior to the quadratus lumborum muscle until it reaches the iliac crest. Both nerves then perforate the transverse abdominis muscle. In the anterior abdominal trunk, the nerves travel between the transverse abdominis and the internal oblique muscles [20, 21].

At this point, the iliohypogastric nerve divides into an anterior and a lateral branch. The lateral branch provides cutaneous sensory innervation to the posterolateral gluteal region. The anterior branch pierces the external oblique muscle medial to the anterior superior iliac spine to provide cutaneous sensory innervation to the abdominal skin above the pubis.

The ilioinguinal nerve becomes superficial by passing through the superficial inguinal ring anterior to the spermatic cord. It provides motor innervation to the transverse abdominis and the internal oblique muscles. The nerve also carries sensory information from the anterior surface of the scrotum and root of the penis in males or labia majora and mons pubis in females and the upper anteromedial thigh.

It is often difficult to discriminate between ilioinguinal, iliohypogastric and genitofemoral neuropathies due to their common spinal origin and anatomical proximity in the pelvis. Confounding localization of these nerves is the fact that they may at times anatomically interconnect with each other [21].

Workup

The causes of ilioinguinal and iliohypogastric neuropathy include iatrogenic entrapment (paravertebral, iliac crest, abdominis rectus border, inguinal region), injury during abdominal or pelvic surgeries, trauma, and pregnancy. Diagnosis of the ilioinguinal or iliohypogastric neuralgia is typically a clinical diagnosis based on history, physical examination, and alleviation of pain by diagnostic nerve block to either nerve [20, 21]. Selectively blocking the individual nerves may be difficult due to the proximity of the nerves to each other, but use of low volumes of anesthetic and imaging guidance may allow for an accurate diagnosis. Complete abdominal and pelvic evaluation is essential to rule out non-neuropathic and treatable sources of pain.

Technique

Placement of radiofrequency ablation needle and probe is dependent on whether the clinician intends to target both nerves or one of them selectively. For the ilioinguinal ablation, the radiofrequency needle and probe are typically introduced approximately 2 centimeters medial and 2 centimeters inferior in the plane of muscle toward the anterior superior iliac spine (ASIS). In comparison, the iliohypogastric nerve lies medial to the ilioinguinal nerve. For iliohypogastric ablation, the radiofrequency needle and probe are typically introduced approximately 1 centimeter medial and 1 centimeter inferior in the plane of muscle toward the anterior superior iliac spine (ASIS). Alternatively, literature has described a lateral to medial approach at the level of the ASIS. Intermittent sensory testing is recommended to obtain optimal needle placement. CT scan, ultrasound, and fluoroscopy have been used for image guidance during radiofrequency procedure [22, 23].

Complications

Potential complications from radiofrequency ablation of the ilioinguinal and iliohypogastric nerves include abdominal wall weakness, persistent numbness, or deafferentiation effect. Attention to depth of radiofrequency needle is required to ensure that needle does not enter the peritoneal cavity.

Long-Term Outcomes

There is a limited amount of literature addressing the long-term efficacy for either ilioinguinal and iliohypogastric radiofrequency ablation. One particular study reported duration of pain relief lasting over 1 year [24].

Genitofemoral Nerve Radiofrequency Ablation

Anatomy

Genitofemoral neuralgia is rare condition that is defined as chronic pain distributed along the cutaneous region in the groin and inner thigh innervated by the genitofemoral nerve (GFN). Symptoms vary from paresthesias, burning pain, and hypoalgesia over the region. Walking and hip extension typically exacerbate the pain and parathesias associated with this condition. Genitofemoral neuralgia is predominantly reported as a result of iatrogenic nerve damage occurring during surgeries or as a result of trauma to the inguinal and femoral regions.

The genitofemoral nerve is found in the abdomen. It is a mixed nerve with both sensory and motor function. The genital branch and femoral branch supply sensation to the upper anterior thigh, as well as the skin of the anterior scrotum in males and mons pubis in females. The genital branch has a motor portion that is responsible for the cremasteric reflex, which causes contraction of the cremasteric muscle when the skin of the superior medial part of the thigh is touched. The genitofemoral nerve originates from the upper L1 to L2 segments of the lumbar plexus. It passes downward and pierces the psoas major and emerges from its anterior surface. The nerve then divides into two branches, the genital branch and the femoral branch. Both branches of the nerve then continue downward and medially to the inguinal and femoral canal, respectively.

The genital branch of the genitofemoral nerve then passes through the deep inguinal ring and enters the inguinal canal. In men, the genital branch supplies the cremaster and scrotal skin. In women, the genital branch accompanies the round ligament of the uterus, terminating in and innervating the skin of the mons pubis and labia majora.

The femoral branch of the genitofemoral nerve then passes underneath the inguinal ligament, travelling through the lateral muscular compartment of the femoral canal where it innervates the skin of the upper leg. Passing through the cribriform fascia of the saphenous opening of the fascia lata of the thigh, it then supplies the skin of the upper, anterior, and medial side of thigh.

Workup

Genitofemoral neuropathy can be difficult and elusive to diagnose. The anatomic overlap of the GFN with the inguinal nerve can obscure a definitive diagnosis of genitofemoral neuralgia [25, 26]. A multidisciplinary diagnostic approach is suggested to eliminate diagnostic error [27]. Selective nerve blocks can be used in effort to reduce incidences of misidentifying whether damage to the ilioinguinal or GFNs are the cause of chronic pain. Ilioinguinal nerve blocks are typically done first as GFN blocks are more difficult procedures [28]. If an ilioinguinal nerve block causes relief of the patient's painful symptoms, a diagnosis of ilioinguinal neuralgia

can be established and the proper management implemented. However, if such a nerve block does not provide relief, a block of the L1 and L2 nerve plexus may identify the GFN as the cause of chronic pain [29]. The use of selective nerve blocks as a diagnostic technique is widely supported in the literature [29–33]. While this method significantly helps in determining which nerve is the root cause of pain, it is not effective in all patients. This can be the case in patients who suffer a genitofemoral neuralgia associated with inguinal herniorrhaphies.

Neuropathic pain is the result of impulses that travel proximally from the site of injury to the central nervous system. As a result of this mechanism, nerve blocks should be administered proximal to the site of injury in an effort to block the impulses coming from the distal location [34]. A proximal nerve block is useful in identifying the culpable nerve in inguinal neuropathies. However, the classical anatomical location for administering GFN blocks is just lateral to the pubic tubercle and inferior to the inguinal ligament, which is distal to the deep inguinal ring and the inguinal canal (where inguinal herniorrhaphies are presumed to cause injury) [35]. Proximal to this location, the GFN is retroperitoneal, making an anterior approach difficult in terms of correctly localizing the nerve. Parris et al. [34] proposed a CT-guided trans-psoas approach to blocking the GFN as a diagnostic and potentially therapeutic procedure. The results of their study identified this technique as a safe way to block the GFN effectively and proximal to the site of injury to accurately evaluate the GFN and its responsibility in causing neuropathic pain symptoms.

Technique

Placement of radiofrequency ablation needle and probe is dependent on whether the clinician intends to target the genital or femoral branch of the nerve. For femoral branch ablation, the femoral component of the genitofemoral nerve runs superficially outside the inguinal canal, eventually providing sensation to the anterior superior thigh and groin. The radiofrequency probe should be placed superficial and lateral to the femoral artery, caudal to the inguinal ligament, and approximately a third of the distance from the pubic tubercle to the anterior superior iliac spine. This is typically done under ultrasound guidance. Sensory testing is recommended to evaluate for reproduction of the patients' usual pain. Motor testing should be done to make sure there is no apparent leg movement.

For genital brand ablation, the genital branch is localized by using ultrasound. Ultrasound is used to locate the inferior epigastric vessels under the rectus sheath, and then ultrasound probe is then moved caudally to the point where the inferior epigastric artery connects with the external iliac artery. The ultrasound probe is then moved medially to locate the spermatic cord. After localizing the spermatic cord above the inguinal ligament just lateral to the symphysis pubis, genital retraction of the testis should result in movement of the spermatic cord. Color Doppler is then

used to locate the testicular and vas deferens vessels. The area containing the spermatic cord should then be zoomed in on for better visualization of the genital branch of the genitofemoral nerve. It is typically located lateral to the deferens duct. Gentle compression of the ultrasound probe will obliterate the vessels but not the duct, and the duct should appear as a hypoechoic noncompressible structure. The radiofrequency probe is then placed between the internal and the cremaster fasciae using an in-plane technique. Sensory testing is recommended to evaluate for reproduction of the patients' usual pain. Motor testing should be done to visualize the cremaster muscle contraction.

The medical literal only describes using pulsed radiofrequency ablation when carrying out the procedure for the genitofemoral nerve [36–38].

Complications

Typical complications of radiofrequency ablation include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect.

Long-Term Outcomes

Case reports and series have described improvements of GFN symptoms ranging from 6 weeks to 14 months of pain relief [36–38].

Sural Nerve Radiofrequency Ablation

Anatomy

The sural nerve is a sensory nerve in the calf region (sura) of the lower extremity. Sural neuralgia is a relatively rare condition which is caused by an injury or inflammation of the sural nerve that results in pain. The sural nerve, along with four other nerves, provides sensation to the foot. The sural nerve provides sensation to the lateral posterior corner of the distal lower extremity, lateral foot, and fifth toe. It is made up of branches of the tibial nerve and common peroneal nerve. Specifically it is formed by the medial cutaneous branch from the tibial nerve and the lateral cutaneous branch from the common peroneal nerve. Once formed, the nerve runs down the mid-calf to the ankle and along the skin from the mid-posterior popliteal fossa to just behind to the lateral malleolus and then under the malleolus and forward along the lateral aspect of the foot.

Workup

The superficial course of this nerve makes it susceptible to local and iatrogenic trauma [39]. It is particularly at risk of injury when a posterolateral surgical approach to the ankle is made [40]. A previous clinical study revealed that 21% of patients who were treated with an open reduction and internal fixation (ORIF) after ankle fractures had an associated nerve injury [41]. Sural neuralgia is typically a clinical diagnosis made by thorough history and physical examination. Examination findings include focal pain or lack of sensation along the posterior and lateral portion of the ankle, lateral foot, and fifth today. Sural neuropathy often can be confirmed by electrodiagnostic studies, but such testing can be challenging; plus, it loses its diagnostic capabilities in patients who are older than 60 years old. Blood work should be performed to ensure that there is no underlying peripheral neuropathy that can account for the symptoms. A diagnostic block should be performed prior to radiofrequency ablation to confirm the diagnosis of sural neuralgia.

Technique

The radiofrequency probe should be inserted subcutaneously between the lateral malleolus and the Achilles tendon and advanced 1.5 cm in the caudad direction in the anatomic direction of the sural nerve. Alternatively, ultrasound can be used to identify the sural nerve adjacent to the lesser saphenous vein [42]. Sensory testing is recommended to evaluate for reproduction of patients' usual pain in the distribution of the sural nerve. Motor testing should be done to make sure there is no apparent motor involvement of the foot and ankle. The medical literal only describes using pulsed radiofrequency ablation when carrying out the procedure for the sural nerve.

Complications

Typical complications of radiofrequency ablation include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect.

Long-Term Outcomes

Case reports and series have described improvements of sural neuralgia symptoms ranging from 2 months to 5 months of pain relief [43–45].

Medial Calcaneal Nerve Radiofrequency Ablation

Anatomy

Heel pain associated with plantar fasciitis is one of the most common painful conditions of the foot. It is estimated that more than 2 million people are treated in the United States alone for heel pain associated with plantar fasciitis. In most cases, heel pain associated with plantar fasciitis will respond to conservative care: arch support, shoe modifications, massage, stretching, night splints, physical therapy, anti-inflammatory medications, and steroid injections. When these standard treatments fail, a novel treatment option to consider is radiofrequency ablation of the medial calcaneal nerve.

The *medial calcaneal nerve* is a terminal branch of the tibial nerve. The tibial nerve splints into three terminal nerves inside the tarsal tunnel at the level of medial malleolus: medial calcaneal nerve, medial plantar nerve, and lateral plantar nerve. After the medial calcaneal nerve exits the canal, it courses between the medial surface of the anterior calcaneus and abductor hallucis deep fascia. The medial calcaneal nerve is a sensory nerve that supplies sensation to the skin of the medial heel and sole of the foot.

Workup

Plantar fasciitis is diagnosed based on your medical history and physical examination. Usually, imaging tests are not necessary. X-rays or magnetic resonance imaging (MRI) can be done to rule out bone spurs and/or a stress fracture which can be the cause for the heel pain.

Technique

The radiofrequency probe should be inserted and advanced along the anterior medial aspect of the calcaneus, at the origin of the medial portion of the central band of the planter fascia. This is typically done under fluoroscopic guidance. Sensory stimulation is then performed to ensure that the patient feels vibration in the distribution of their pain. Ideally, the impendence should be less than 0.5 mV which indicates that the radiofrequency probe is very close to the target nerve. Motor stimulation should be done to evaluate for involuntary contraction of the muscles of the foot in a cyclic manner. When stimulation occurs, the probe should be repositioned. The sensory/motor stimulation process should be repeated until sensory stimulation is achieved, but motor stimulation is not. The medical literature describes both thermal and pulsed radiofrequency as being utilized for the procedure.

Complications

Typical complications of radiofrequency ablation include infection, bleeding, numbness or dysesthesias, increased pain at the procedural site, or deafferentiation effect.

Long-Term Outcomes

Retrospective studies and case reports have described improvements of plantar fasciitis symptoms ranging from 3 months to 12 years of pain relief [46–51].

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Chapter 16
Future Indications

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Introduction

Conventional ways to apply radiofrequency ablation (RFA) technology to ablate or modulate painful sources have been made known. In the more than 50 years since the use of RF, various pain-producing components have been used as therapeutic targets, but due to knowledge or technical limitations, RF is not yet used in all pain syndromes. In this chapter, we will analyze the novel, trending, and future utilization of RFA in pain management. Alongside the new indications, the collaborative uses, improved technologies, and safety features of RF in pain medicine will be discussed.

New and Trending Indications of RF in Pain Medicine

This section provides a review of novel and trending RF indications in pain medicine (Table 16.1), which have been less discussed in previous chapters. The main focus is on recent and validated clinical trials, even though the reports are used for

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6_16

Table 16.1 Novel and trending RF indications in pain medicine (each items will be discussed separately in the text)

Region of pain	Specific pain syndrome
Headache pain syndromes	Chronic headaches, migraines, cluster, atypical facial pain, postherpetic neuralgia, head and neck cancer pain, postoperative headaches, post-traumatic headache, Sluder's neuralgia, cervicogenic headaches, tinnitus
Facial pain syndromes	Trigeminal neuralgia (typical-atypical-post-traumatic), glossopharyngeal neuralgia, supraorbital neuralgia, infraorbital neuralgia, facial pain secondary to tumor removal
Temporomandibular	TMD, numb chin syndrome or mental nerve neuropathy
Neck pain syndromes	Cervical facet syndrome, whiplash injuries, chronic cervical radicular pain, brachial plexus injury
Shoulder pain syndromes	Adhesive capsulitis, impingement syndrome of the shoulder, suprascapular neuropathy, rotator cuff arthropathy, chronic shoulder pain after septic arthritis, hemiplegic shoulder pain, chronic shoulder tendonitis
Elbow pain syndromes	Lateral epicondylitis, cubital tunnel syndrome, osteoid osteoma of the elbow
Hand pain syndromes	Median nerve injury
Chest wall pain syndromes	Chest wall pain, thoracic postherpetic neuralgia
Thoracic spine pain syndromes	Spondylolisthesis, spondylosis, thoracic facet syndrome, chronic middle back pain, intercostal neuralgia, post-mastectomy pain syndrome, intercostobrachial neuralgia, cancer-related intercostal neuralgia pain, rib metastasis, work-related injuries in the intercostal nerves, rib fractures or blunt trauma to the chest, sports trauma of the chest
Abdominal and groin pain syndromes	Chronic pancreatitis, acute pancreatitis pain, resistant abdominal pain, abdominal cancer pain, refractory cancer pain, pain in pancreatic cancer, pain in cholangiocarcinoma, functional abdominal pain syndrome, anterior cutaneous nerve entrapment syndrome, abdominal wall endometrioma, abdominal wall metastasis, uterine adenomyosis, loin pain hematuria syndrome
Lumbar spine and sacroiliac joint pain syndromes	Disc herniation and radiculitis, intradiscal PRF for discogenic pain, chronic lumbosacral radicular pain, lumbosacral facet joint pain, spinal stenosis, degenerative spondylolisthesis, breast cancer metastases in the SI joint, post-lumbar surgery syndrome, coccygodynia, ganglion impar
Pelvic and hip pain syndromes	Osteoarthritis of the hip, chronic post-arthroplasty hip pain, persistent right hip pain after septic arthritis, coxarthrosis, lumbosacral facet joint pain
Lower-extremity pain syndromes	Chronic inguinal neuralgia, post-surgery pain: Herniorrhaphy, cesarean section, appendectomy; post-trauma pain, chronic post-surgical orchialgia, sural neuralgia, pudendal neuralgia, recalcitrant neuropathic pelvic pain, meralgia paresthetica
Knee pain syndromes	Subchondral insufficiency fractures of the knee, knee osteoarthritis, previous knee arthroplasty

Table 16.1 (continued)

Region of pain	Specific pain syndrome
Ankle pain syndromes	Acute Achilles tendon injury, Achilles tendinosis, insertional Achilles tendinosis, arthroscopic joint surgeries to remove soft tissue
Foot pain syndromes	Plantar fasciitis, chronic plantar fasciitis pain, metatarsalgia
Specific pain syndromes	Postherpetic neural, phantom limb pain, stump pain, complex regional pain syndrome, chemotherapy-induced peripheral neuropathy, chronic axonal polyneuropathy, ischemic pain, cervicobrachialgia, post-stroke pain, diabetic neuropathic pain, painful bone metastases, metastatic lesion involving brachial plexus, intractable neoplastic plexopathic pain

specific cases. Specifically, almost all of the recent 5-year relevant papers of RF in pain medicine and related ideas are covered here.

Headache Pain Syndromes

Headaches are a major debilitating cause of pain, work loss days, and social compromise. To so many, the cause of the headache is never found; however, to the astute clinician, discovering that certain sensory nerves contribute to the patient's headache allows us to perform an ablation with minimal adverse events. This improves daily function to the point that many patients do not have to be medication dependent.

In general, RF can also be used to treat *chronic headaches*, including *chronic migraines*. When RF ablation for pericranial nerves was used to treat chronic daily headache, the pain was improved in 90.3% of patients, and the mean pain score decreased from 6.6 to 1.9 [1].

PRF stimulation to the greater occipital nerve (GON) is used to control migraines that have not responded to common medications. In a trial, this method was able to reduce pain score from 8 to 3, for at least 3 months [2].

The sphenopalatine ganglion (SPG), also known as the pterygopalatine ganglion, is located in the pterygopalatine fossa. SPG is the largest ganglion outside of the calvarium, containing sympathetic, parasympathetic, and sensory neurons [3]. SPG, due to its special location, is the only ganglion that is accessible externally through the nasal mucosa [4]. By targeting SPG, several headaches can be improved. They include *cluster and migraine headaches, atypical facial pain, and trigeminal neuralgia* [4, 5]. The blockade and ablation of the SPG have also been studied for *postherpetic neuralgia, head and neck cancer pain, and postoperative headaches after endoscopic sinus surgery* [6, 7].

Previously, RF thermocoagulation was used to target SPG. However, cheek numbness and hypoesthesia of the palate were seen in these methods, due to

irreversible damage to the sphenopalatine branch of the maxillary nerve [8]. The pulsed RF application on the SPG has less destructive effects and procedural pain [9, 10].

The most common method to stimulate SPG is the percutaneous infrazygomatic approach, while fluoroscopy and computed tomography are used to guide the needles [11].

PRF-SPG is effective for *atypical facial pain, SPG neuralgia due to herpes zoster, and atypical trigeminal neuralgia*. In the above syndromes, PRF-SPG were applied with the infrazygomatic approach and fluoroscopy guide. The complete pain relief was obtained in 35% of patients, and moderately relieved in 42% of them [8]. By application of SPG- PRF to 30 patients with chronic head and face pain, 21% had complete pain relief, and 65% had moderate pain relief [12].

RF is also used to treat *cluster headaches (CH)*, which are one of the primary headaches. Cluster headaches are presented by severe unilateral pain with recurrent attacks, usually around the orbit. Symptoms of autonomy in the eyes and nose present in the form of flushing, lacrimation, rhinorrhea, and redness of the face [13].

For refractory episodic and chronic cluster headache, PRF may be applied by CT-guided targeting SPG. Effective remission was found in 95% of patients with refractory episodic and 64% of patients with chronic CH [10].

The SG RF stimulation may relieve *postoperative headaches*. In *facial pain secondary to cavernous sinus meningioma removal*, this technique was accompanied by complete pain relief in a 12-month follow-up [14]. Also, in *post-traumatic headache*, SPG stimulation leads to successful pain relief [15].

RF thermocoagulation of the SPG was also used to relieve *Sluder's neuralgia*, which is a rare headache subtype known as contact point headache [16].

Cervicogenic Headaches (CHA)

A secondary headache that originates in the upper cervical spine [17]. Numerous case reports and retrospective studies examined RFA or PRF efficacy in CHA cases resistant to drug therapy [18, 19].

Recently, various targets have been used for CHA, such as bilaterally targeting the DRG of C2 and C3, which has yielded satisfactory results [20], or pulsed RF to the greater occipital nerve and left atlantoaxial joint region which also had positive outcomes [21].

A new method for alleviating CHA is C1–C2 intra-articular joint ablation. An important difference in intra-articular procedure versus RF neurotomy is in their therapeutic goal. In intra-articular joint ablation, pain relief is provided by articular cartilage stimulation or joint capsule innervated by sensory fibers, whereas in RF neurotomy, the RF needle is directed alongside the target, usually the medial nerve branches that supply the facet joints. Using ablation of the C1–C2 joint, at first, a transient increase in pain was observed, but functional improvements were achieved at 3 months [22].

Another interesting indication of the application of PRF of C2 dorsal root ganglion was that it was able to reduce the severity of *tinnitus* [23].

Facial Pain Syndromes

Trigeminal Neuralgia (TN)
Manifests itself with sudden, frequent, transient, sharp to stabbing attacks in the distribution path of one or more branches of the trigeminal nerve [24]. RF can be used in cases of TN resistant to common therapies. In general, the trend of RFA targets has progressed from the intracranial Gasserian ganglion (GG) to the individual branch at the existing foramen under CT guidance, as this method is safer and more selective. The common approach used for this purpose is the percutaneous transforamen ovale (FO), through which the GG is targeted [25, 26].

The percutaneous within-FO RFA of the V3 under CT-guidance was examined. Patients with V3 primary TN were treated with monopole or bipolar RFAs. Both of these extracranial monopolar and bipolar techniques resulted in complete V3 analgesia and pain relief. The bipolar approach was better in cases where the FO diameter is greater than 6 mm [27].

Post-Traumatic Trigeminal Neuropathy (PTTN)
Occurs due to injuries to the peripheral branches of the trigeminal nerve. PTTN patients undergoing PRF of the SCG, under a lateral fluoroscopic approach, had a reduction in pain intensity from 8.82 to 3.94 [28].

Glossopharyngeal Neuralgia (GPN)
Is an uncommon facial pain syndrome, characterized by pain attacks in the sensory distribution of the glossopharyngeal nerve (cranial nerve IX) [29]. Medical therapy is the first-line treatment for GPN [30], but other treatments such as nerve block, microvascular decompression, and rhizotomy have also been investigated.

Percutaneous RF thermocoagulation may successfully treat idiopathic and secondary GPN, but it has some complications, such as dysphagia, dysesthesias, and diminished gag reflex [31]. Therefore, in several studies, PRF has been used in the treatment of GPN, which has had fewer side effects [32, 33]. The long-term outcome of CT-guided pulsed RF in the treatment of idiopathic glossopharyngeal neuralgia was surveyed. Their 1-month effective rate was 93.3%, and long-term recurrence-free survival rates were 54.8% at 120 months postoperatively [34].

As mentioned, fluoroscopy was used as the guide for percutaneous procedures, but skull base anatomy is complex and complicates the work of the guide fluoroscope. This difficulty is exacerbated when an individual trigeminal sub-branch (e.g., V1 or V2) nerve block is targeted.

The classic treatment for GPN is the percutaneous rhizotomy of the glossopharyngeal nerve through the JF via a lateral cervical approach. This method is sometimes associated with damage to the vagus nerve, spinal accessory nerve, and the internal carotid artery.

As a new technique, fluoroscopic C-arm and CT-guided selective RF ablation was performed in the treatment of trigeminal and glossopharyngeal facial pain syndromes. In a 2018 paper, flat-panel C-arm CT guidance was used to block the V3 branch via the FO approach, the V2 branch via FR approach, and the

glossopharyngeal nerve via peripheral styloid process approach. With this method, 18 patients with classical TN, GPN, and atypical facial pain were treated. This method was associated with 100% technical success of needle guidance, especially in areas that were previously difficult to reach, such as foramen rotundum and the styloid process. This accuracy of needle placement reduced side effects and provided a good therapeutic response [35].

Supraorbital Neuralgia

It is an uncommon neuropathy characterized by pain in the region of the supraorbital notch and the medial aspect of the forehead. The supraorbital nerve is a sensory branch of the frontal nerve. Drug therapy and supraorbital nerve block may be somewhat effective. Neurologically damaging procedures (such as RF thermocoagulation), as well as non-destructive procedures (such as PRF), have been used to treat supraorbital neuralgia [36].

The long-term efficacy and safety of ultrasound-guided RF thermocoagulation were evaluated in the treatment of refractory supraorbital neuralgia patients. The cumulative proportion of recurrence-free survival was 96.2% at 12 months and 49.7% at 97 months [37].

Infraorbital Nerve Neuralgia

RF has been used in the treatment of this neuralgia, included via 42 ° C percutaneous nondestructive method, PRF [38]. Recently, high-voltage PRF showed a safe and effective treatment for patients with refractory infraorbital nerve neuralgia [39]. Further, 42 °C PRF combined therapy with 60 ° C CRF was used for those who did not respond to traditional therapy, which was associated with a 72.7% effective rate over 2 years [40].

Temporomandibular (TMD) Disorders

TMD disorders are common medical and dental problems, which are presented by dysfunction of the masticatory muscles and the temporomandibular joints. These patients suffer from severe pain with any opening of the jaw, as well as sound in the TMJ while chewing, and decline in the quality of life.

The analgesic effect of RF waves, with low energy and high frequency, has been proposed recently in TMD patients. The soothing role of RF waves on the TMJ joint is due to diathermy effect, through high-voltage rapid alternating current [41]. RF therapy on TMD patients resulted in pain relief and clinical improvement, even greater than the sonophoresis method in the control group; therefore, RF should be considered as a supportive treatment in TMD [42].

Numb Chin Syndrome, or Mental Nerve Neuropathy

It is a neuropathy or paresthesia associated with altered sensory perception in the mental nerve. In a patient with mental nerve neuropathy after dental extraction, who did not even respond to drugs and nerve block in the mental foramen, RF nerve ablation was performed under fluoroscopic guidance (at 80 degrees Celsius for 90 seconds). The patient was completely satisfied with the procedure, and at

8 months follow-up, near 100% pain relief and quality of life improvements were reported.

Also in a man with a neuropathy like "like a cold sore" after right third molar removal, after 2 years of unsuccessful treatments, he underwent a series of diagnostic right mental nerve blocks with complete success. So he treated with RFA of the right mental nerve, which reported complete pain relief after 6 months [43].

Neck and Brachial Plexus Pain Syndromes

Cervical Facet Syndrome

Various studies have examined the effectiveness of PRF in the treatment of cervical joint pain (atlanto-occipital and cervical facet joints) [44, 45].

In a comparison between intra-articular PRF and intra-articular corticosteroid injection (IA ICI) in the treatment of cervical facet joint pain, similar results were obtained after 6 months [46]. Also, the effect of IA PRF stimulation in atlanto-occipital joint pain was similar to IA CSI [44].

Whiplash Injuries

Refers to a neck injury that occurs due to forceful, rapid back-and-forth movement of the neck. PRF stimulation was applied on the cervical medial branch, for patients with neck pain caused by whiplash injuries. After 1 year of PRF, 64.3% of patients had significant pain relief [47].

Chronic Cervical Radicular Pain

In a 2020 trial, patients with chronic cervical radicular pain who did not respond to transforaminal epidural steroid injections got PRF stimulation under US guidance. The pain was reduced by 63% of patients 6 months later [48]. Also, in patients with cervical radicular pain refractory to monopolar PRF and transforaminal epidural steroid injection, bipolar PRF was applied on their cervical dorsal root ganglion DRG. A 3-month follow-up showed successful treatment in half of the patients [49].

Brachial Plexus Injury

There are reports of RF usage for this, for example, in a complete left brachial plexus injury with cervical root avulsion. This patient complained of neuropathic pain in the forearm and thumb and was also resistant to surgery, rehabilitation, and medication. Ultrasound-guided PRF was performed on the ulnar nerve at the elbow, which reduced pain by 70% on the VAS scale [50].

Shoulder Pain Syndromes

Shoulder pain is a complex condition that can have different pain-producing elements (intra- and extra-articular). Most studies of RF in shoulder pain have been from *adhesive capsulitis or GH osteoarthritis* and targeted the *suprascapular nerve (SSN).*

Several randomized controlled trials have been shown to have good clinical efficacy of PRF for shoulder pain for at least 12 weeks. But the comparison of PRF with other methods (intra-articular corticosteroid and conventional transcutaneous electrical nerve stimulation) should be further investigated [51].

In a study of different patients with diagnoses of *adhesive capsulitis, rotator cuff syndrome*, and *impingement syndrome of the shoulder*, who had more than 50% pain relief after the initial diagnostic block, underwent PRF therapy of the SSN under UG. By 6 months, all indices, including VAS score, shoulder pain, disability index, and flexion, internal rotation, external rotation, and abduction values, had improved significantly [52].

In the treatment of *frozen shoulder* or *adhesive capsulitis*, PRF lesioning of the SSN using ultrasound guidance can also be used. Interestingly, compared to physiotherapy, the effect of PRF was found to be greater in reducing VAS and disability index scores at 12 weeks of follow-up [53].

PRF can also be used in the treatment of *suprascapular neuropathy* (*posterosuperior shoulder pain*). Most previous studies have been on the treatment applied to the nerve trunk under the transverse scapular ligament. In a 2020 report, a patient with *entrapment of the distal SSN in* spinoglenoid notch and suprascapular neuropathy underwent PRF. After decompressing the entrapped SSN in the SGN, PRF was performed on the distal SSN under ultrasound guidance, which was followed by a year of pain relief [54].

Rotator Cuff Arthropathy

In the treatment of patients with partial rotator cuff tears by RF, via targeting the SSN, good pain relief and functional improvement can be achieved for at least 6 months [55].

Interestingly, in a 14-year-old child with 2 years of *chronic shoulder pain after septic arthritis* of the shoulder, PRF on the SSN caused a significant reduction in pain. The therapeutic effects of PRF on pediatric chronic pain can be further investigated [56].

Hemiplegic Shoulder Pain

Is common after stroke and can be treated with RF. Ultrasound-guided SSN PRF for hemiplegic shoulder pain, 6 months after stroke, improved all indicators in 4-week and 16-week follow-up, including shoulder passive range of motion and Disability Assessment Scale [57].

These results were confirmed in another study in 2020 with patients 1 year after stroke. In the ultrasound-guided RF on suprascapular or axillary nerve, compared with RF nerve block, both treatment results were positive, but PRF improved PROM of shoulder abduction and external rotation more than nerve block [58]. The combination therapy of PRF applied to the SSN and physical therapy was successful rather than suprascapular NB and physical therapy [59].

The effectiveness of the SSN in *chronic shoulder pain* was evaluated recently. Patients underwent PRF of the SSN and then got dexamethasone. VAS sharply

decreased and active range of motion was improved. The analgesic effects of PRF and a short-acting corticosteroid lasted up to 24 weeks.

Transcutaneous pulsed RF (TPRF) stimulation can also be used for *chronic shoulder tendonitis*. In a 2019 study, the effects of TPRF were compared versus transcutaneous electrical nerve stimulation (TENS) in patients with chronic shoulder tendonitis. Both modalities improved pain, enjoyment of life, and general activity scores; however, TPRF had a better profile than the TENS [60].

Elbow Pain Syndromes

Lateral Epicondylitis

A painful syndrome that limits the patient's function is usually self-limiting, but some patients require conservative treatment and even surgery. The RF can be effective in treating lateral epicondylitis by targeting the radial nerve. Patients with intractable lateral epicondylitis, not responding well to conservative treatment, underwent ultrasound-guided PRF neuromodulation of the radial nerve. After 12 weeks of follow-up, there was a significant reduction in their pain [61]. Also, 34 patients with symptomatic lateral epicondylitis for more than 6 months, who did not respond to non-surgical treatments, were treated with US-guided percutaneous RF lesioning. At a 6-month follow-up, patients' pain in resting, palpation, and grip were significantly reduced. At the final follow-up, 14 months later, 78% of patients reported pain relief [62].

Another study confirmed the effect of pulsed electromagnetic field therapy for lateral epicondylitis pain, pressure pain threshold, and pain-free grip strength [63]. This method can be an alternative preoperative treatment for recalcitrant lateral epicondylitis.

Cubital Tunnel Syndrome

Is the second most common neuropathy in the upper limb, occurring behind the inner epicondyle of the elbow, due to pressure or stretching of the ulnar nerve. Cubital tunnel syndrome presents with sensory deficits in the ring and small fingers, weakness in the distribution of the ulnar nerve, and neuropathic pain on the medial side of the elbow, forearm, and hand [64]. For the first time in 2019, two patients with cubital tunnel syndrome who were confirmed by electrodiagnostic studies were treated with RF. The PRF was applied to the right ulnar nerve at the medial epicondyle level, under the guidance of ultrasound. One patient experienced complete pain relief, and one patient experienced two-thirds pain relief [65].

Osteoid Osteoma (OO) of the Elbow

RFA can play a role in the treatment of bone tumors, such as *osteoid osteoma*. The low invasiveness of RFA has resulted in excellent functional recovery in the OO of the elbow, compared to surgical procedures [66].

Hand and Wrist Pain Syndromes

Median Nerve

The median nerve injury in the forearm can have serious consequences if left untreated, such as allodynia, hyperalgesia, paresthesia, skin color changes, and atrophy in the right forearm. A patient with median nerve damage, who have all of these symptoms and intractable pain, refer to a neurectomy of the median nerve, which was unsuccessful. Then, ultrasound-guided PRF of the median nerve was performed, which reduced her pain by 80%. So ultrasound-guided PRF may be used for the treatment of refractory neuropathic pain, even to neurectomy [67].

As we know, the treatment of degenerative, inflammatory, and post-traumatic arthritis in the wrist is associated with challenges to maintain wrist mobility and relieve prolonged pain. Interestingly, interrupting its sensory innervation may relieve wrist pain, without impairing motor function or requiring postoperative immobilization and probability of stiffness. Although some studies have shown that this method is ineffective in the wrist with traditional approaches, in a new study in 2020, partial percutaneous wrist denervation was performed using radiofrequency ablation of the posterior and anterior interosseous nerves. One-year follow-up results showed improved grip strength, provided pain relief, and maintained wrist motion [68].

Chest Wall Pain Syndromes

Chest Wall Pain

RF thermocoagulation of the thoracic nerve roots can be effective in short-term pain control in patients with cancer and intractable chest wall pain [69]. In an analysis of 100 patients with intractable chest wall pain who underwent thoracic nerve root RFA, the NRS rate decreased from 7 to 4, after 6 months. The RFA outcome differed depending on what the initial cancer was.

Thoracic Postherpetic Neuralgia

Ultrasound-guided PRF for intercostal nerves (ICN) in combination with pharmacotherapy can be a suitable method for the treatment of postherpetic neuralgia. In a double-blinded trial, patients received two cycles of ultrasound-guided PRF after 2 weeks of pregabalin treatment. The control group received only medication. Patients in the PRF group had a significant reduction in VAS and the need for pregabalin and acetaminophen, and their quality of life significantly was improved [70].

Thoracic Spine Pain Syndromes

RFA has been used for the treatment of various thoracic pain syndromes, such as *spondylolisthesis, thoracic facet syndrome, spondylosis, and chronic middle back pain*. This RF is applied in people who have not responded well to previous treatment, including nerve block, and whose source of pain is known.

Chronic thoracic facet joint pain: PRF on the thoracic medial branch is an effective way to control chronic TFJ pain. RF stimulation was applied in these patients, who received nerve block for upper or mid-back pain but did not respond well. The RF setting was 5 Hz and a 5-millisecond pulsed width for 360 seconds at 45 V. 55% of patients reported successful pain relief after 3 months of PRF.

Intercostal neuralgia: is a pain syndrome characterized by severe, shooting, and burning pain at the site of the intercostal nerve distribution. It is treated with medication, nerve block, and, in refractory cases, cryoablation and RFA [71].

Post-mastectomy pain syndrome (PMPS): is one of the chronic post-surgical pain disorders. The effectiveness of thermal versus super voltage pulsed RF application of stellate ganglion in neuropathic PMPS in cancer patients was compared. The thermal group had a higher percentage of patients with an adequate therapeutic response, functional improvement, and less usage of analgesia [72].

Combination therapy can also be used for *intercostobrachial neuralgia*. For example, for 100 post-mastectomy pain syndrome, pulsed RF and steroid injection were performed. PRF is applied for 120 s twice on T2 and T3 DRGs, and then 1 ml of 4 mg dexamethasone and 1 ml of bupivacaine 0.25% were injected. In a follow-up, the VAS score decreased, and the quality of life improved. 66% of patients recommended this method to other similar patients, which indicated the acceptability of this method [73].

Cryoablation can also be used to treat *post-thoracotomy pain syndrome*. For these patients who were refractory to medical management, CT-guided intercostal nerve cryoablation was performed. 69% experienced significant improvement in an 11-month follow-up. Complications included pneumothorax (8.8%) and pseudohernia (23%) [74].

The common complications in RFA applications of the chest are lung puncture resulting in pneumothorax, headaches, and neuroma formation. Most of these cases occur immediately after surgery [75]. In general, the incidence of complications in this area is reported to be slightly higher than in other areas, which requires the implementation of more accurate technologies and protocols to prevent these complications.

In the chronic *refractory pain due to chest malignancies*, RF was applied. In one group fluoroscopy guidance was done, and in another group, integrated XperCT scan and fluoroscopy guidance were followed. Usage of pregabalin and oxycodone was more reduced in the second group, and functional improvement was more in the second group. Therefore, it was suggested that integrated modality guidance of XperCT scan and fluoroscopy, via suprapedicular inferior transforaminal approach, can be a more effective and safe approach for the treatment of TDRG [76].

PRF can also be used in *cancer-related intercostal neuralgia pain,* which was resistant to initial treatment. In a patient with breast cancer treated by lumpectomy and radiotherapy, as well as an esophageal carcinoma treated with chemotherapy radiation and surgical resection, RF applied by 80 ° C and 180 seconds was associated with relative improvement [77].

Also, in *work-related injuries in the intercostal nerves* where RF was applied, five of six patients became pain-free [75].

Breakthrough pain (BTP) due to rib metastasis was treated with ultrasound-guided RF on intercostal nerves. The pain intensity and frequency decreased in more than half of patients, and their opioid dose was reduced by more than 50% [78].

RF on intercostal nerves can also be used for patients with *rib fractures or blunt trauma to the chest wall*. This method was applied in athletes with *sports trauma of the chest* who complained of intractable neuralgia, which reduced the severity and pain and returned to exercise faster [79].

In a report in 2020, two patients with *blunt thoracic trauma* due to the severity of pain, with difficulties for *ventilation*, successfully underwent RF ablation of the intercostal nerves: 60 oC for 1 minute for each nerve [80].

Abdominal and Groin Pain Syndromes

The coeliac plexus and splanchnic nerve are therapeutic targets for chronic upper abdominal pain, which can be treated as block, neurolysis, or RF. The advantage of RF is that it produces predictable and accurate lesions and has a low risk of iatrogenic damage.

Chronic Pancreatitis

Pain is one of the challenges for patients with chronic pancreatitis, who usually do not respond well to medical treatment. Invasive treatments, such as endoscopic and surgical treatments, also come with different treatment responses. Percutaneous RFA of the splanchnic nerves is one of the new and minimally invasive ways for intractable pain in CP.

Percutaneous RFA splanchnic nerve blockade in CP patients reduced patient pain, opiate analgesia use, and admissions for pain. Long-term debilitating chronic pain, such as anxiety levels, daily activity, overall mood, and general perception of health were also improved [81].

In evaluation of 18 RFSN procedures in CP patients, 15 were successful and reduced the mean of pain score. The pain-free period lasted an average of 45 weeks. RFSN can be an alternative treatment for selected CP patients [82].

In general, since pain in chronic pancreatitis has both visceral and somatic components, extra pancreatic somatic tissues, particularly the retro-peritoneum, should be considered [83].

Acute Pancreatitis Pain

Pain in acute pancreatitis is transmitted through the afferent splanchnic nerves of the celiac plexus [84]. RFA of the bilateral splanchnic nerve can be used in acute pancreatitis pain refractory to medical management.

A young patient with acute pancreatitis and pain intensity of 9/10 and necrosis (>50%) in the body and tail of pancreas on CT did not respond well to medication. After 4 weeks, the patient underwent RFA of the bilateral splanchnic nerve (20G, 10 cm RF needle with 10 mm curved active tip), at the junction of anterior one-third

and posterior two-thirds of the T11 vertebral body. RFA was done at 60 ° C and four cycles of 120 s. His pain stopped immediately, and in the 1-year follow-up, VNRS remained 2/10, and occasional mild analgesics were used [85]. Practically, the prone position requires additional analgesics due to discomfort and pain during RFA procedure.

Resistant Abdominal Pain

In the treatment of 2-year abdominal pain after cholecystectomy, which all images and laboratory work excluded any abdominal condition, suffering from frequent emergency visits and pain medications, bilateral splanchnic nerve blocks with steroid injection were performed. 80% of pain was relieved, which lasted 3 weeks. As pain relief was short lived, RFA was planned for the same nerves. A 20-gauge 145 mm with 10 mm active tip-curved RFA needles was applied in the anterolateral aspect of T11 and T12 under, and thermal RFA was carried out at 80 ° for 90 s × 2 cycles. In a 5-month follow-up, his pain was reduced by 60% [86].

Abdominal Cancer Pain

One of the well-known methods in the treatment of pain caused by upper abdominal cancer is celiac plexus neurolysis, which is used in various methods such as percutaneous approach and ultrasound-guided [87].

In a comparison between RFA and chemical neurolysis of bilateral thoracic splanchnic nerves in the management of *refractory cancer pain*, both groups had significant reductions in VAS and global perceived effect satisfaction scores. But the RF group had more pain relief, operated faster, produced longer duration of analgesia, was effective in a larger percentage of patients, and was safer than chemical neurolysis [88].

Pain in Pancreatic Cancer

US-guided RFA (EUS-RFA) can be used as a palliative treatment in pancreatic neoplasms. In a 2018 study, patients with abdominal pain due to locally advanced or metastatic pancreatic cancer were divided into two groups: celiac plexus neurolysis and RFA; both groups were under the EUS guideline. RFA was performed with a 1F monopolar probe passed through a 19-gauge FNA needle targeting the area of the celiac plexus or visualized ganglia. Quality of life improved in both groups according to the 4-week follow-up. The RFA group had more pain relief, less gastrointestinal symptoms, and better emotional functioning than the EUS-CPN group [89].

Pain Control in Cholangiocarcinoma

A woman with acute and stabbing pain due to cholangiocarcinoma, who did not respond to oral medications, underwent splanchnic nerve block and then bilateral splanchnic nerve rhizotomy at T10 and T11. After rhizotomy and in 6-month follow up, the patient became painless and stopped all his opioids [90].

In *end-stage pancreatic cancer pain* patients, resistant to other therapies, RF thermocoagulation applied on both splanchnic nerves under fluoroscopic guidance. At a 6-month follow-up, pain scores, quality of life improved, and consumption of opioids decreased [91].

Functional Abdominal Pain Syndrome
The thoracic splanchnic nerve block is used in the treatment of abdominal pain, especially abdominal cancers. Interestingly, in a patient with chronic abdominal pain without a specific organic cause, his severe pain responded well to the diagnostic thoracic splanchnic nerve block. Therefore, RF thermocoagulation was performed at the T11 and T12 vertebral level, which reduced his pain from 7 to 2 [92].

Anterior Cutaneous Nerve Entrapment Syndrome
ACNES occurs as a result of intercostal nerve endings. This syndrome is associated with chronic positional abdominal pain that has no severity related to meals, and the "Carnet" test is a simple diagnostic test for that. Nerve blocks can be used for ACNES, and if there is no response, PRF is a new alternative treatment.

In the 2018 study, 26 ACNES patients underwent PRF, which reduced the NRS score from 6.7 to 3.8 after 6 weeks. PRF was effective for at least half of the patients in the short term [93].

Also in another study in 2019, 66 ACNES patients were divided into two groups: that with a 6-minute cycle of PRF treatment and that with immediate neurectomy procedure. Both groups experienced relief at 8 weeks of follow-up, but the neurectomy group had greater relief. PRF was an effective and minimally invasive treatment option for ACNES, which can be used before a neurectomy because it has less potential complications associated with surgery [94].

Abdominal Wall Endometrium (AWE)
Extraperitoneal endometriosis refers to the presence of ectopic, functional endometrium tissue outside the peritoneal cavity that can be painful. The treatment of choice for AWE is surgical excision, but percutaneous RFA under US guidance has also been used and can be a good option for AWE in selected patients, which had no complications [95]. Further, it was shown that cryoablation has similar effectiveness to surgery for local control of AWE while also reducing hospitalization duration and complications [96].

PRF has also been used in analgesia in a patient with *abdominal wall metastasis from colorectal cancer* [97].

Uterine Adenomyosis
Feasibility and efficacy of laparoscopic RF thermal ablation of symptomatic painful uterine adenomyosis were studied [98]. Laparoscopic RFA is an effective way to treat small-sized and non-pedunculated symptomatic uterine fibroids, which can improve the patient's symptoms and quality of life for a long time [99].

Loin Pain Hematuria Syndrome (LPHS)
Is a pain syndrome of unknown origin, resistant to oral, antidepressant, and opioid treatment, which may even lead to nephrectomy and renal auto transplantation. Because visceral pain signals flow through afferent sympathetic fibers, percutaneous catheter-based RF ablation of the renal sympathetic nerve fibers was used as a therapeutic target.

In this way, the RFA applied only to the right renal artery, and at 6 months follow-up, the patient was painless and had no blood pressure problems. Therefore, it was suggested that percutaneous sympathetic denervation could be a mini-invasive method for the treatment of chronic renal pain and LPHS [100]. Also in another LPHS case, with recurrent nephrolithiasis secondary to hypercalcemia, PRF ablation to the splanchnic nerves was performed. Substantial and sustained relief of his flank pain was obtained [101].

Lumbar Spine and Sacroiliac Joint Pain Syndromes

About two-thirds of adults suffer from low back pain at some point in their lives. The components that produce pain in the lumbar spine include the annulus of the disc, the posterior longitudinal ligament, a portion of the dural membrane, the facet joints, the spinal nerve roots and ganglia, and the paravertebral muscles. Each of these components can be studied as a therapeutic target.

PRF can be used in managing *disc herniation and radiculitis*. Several randomized studies have shown that PRF leads to a better outcome and a substantial decrease in pain [102]. PRF leads to greater treatment success in *chronic lumbosacral radicular pain* compared to corticosteroid injection [103], and DRG PRF-intradiscal therapy can also be a promising treatment for it.

The use of RF in *facet joint pain* was discussed in previous chapters. Multiple clinical trials have reviewed the effectiveness of PRF stimulation on *lumbosacral facet joint pain* [104, 105]. CRF had a positive effect on relieving pain in the lumbar medial branch nerves, but PRF did not have these effects; however, this ineffectiveness may be related to short-term follow-up and small sample size. A 2017 study on *lumbosacral facet-joint-origin pain* found the effect of IA PRF stimulation and intra-facet joint CSI similar [106].

Degenerative Spondylolisthesis

A clinical trial on 80 spondylolisthesis patients showed that PRF had a positive analgesic effect on the lumbar medial branch. This effect was even greater than the IA CSI [107].

Sacroiliac Joint Pain

SI pain can be caused by degeneration, infection, malignancy, and trauma. In 2018, on 64 patients, CT-guided IA CRF (80 ° C, 180 seconds) or PRF had similar efficacy for SI joint pain. Both groups had a reduction in VAS at 1 week and 6 and 12 months, but this reduction was greater in the CRF group [108].

RF neurotomy of the nerves supplying the sacroiliac joint has been performed to treat *SIJ pain*. In a 2018 study, 30 patients with sacroiliac joint dysfunctional pain were divided into two groups: intra-articular methylprednisolone and pulsed RF of the L4 medial branch, the L5 dorsal rami, and the lateral sacral branches. Overall,

PRF was able to provide more pain relief and functional improvement [109]. In a clinical study on 64 patients with chronic sacroiliac joint pain, the effectiveness of CT-guided IA PRF and CRF was proven. CRF was superior to PRF in the early and late stage [108].

In patients with buttock pain due to *breast cancer metastases in the SI joint*, PRF neuromodulation of the L4–S3 primary dorsal ram and lateral branches was used. PRF, using a rotating curved needle technique, reduced pain by 70% [110].

RF can also be used for *lumbar disc pain*. We know that chronic, persistent low back, lower extremity, and radicular pain can be due to disc herniation, disc disruption, disc degeneration, spinal stenosis, or post-lumbar surgery syndrome.

Intradiscal PRF for Discogenic Pain

Positive results of intradiscal PRF modulation in managing *disc herniation, spinal stenosis, and post-surgery pain* have been reported [111]. In addition to the intradiscal electrothermal therapy (IDET) technique, there is also an intradiscal PRF (Disc PRF) technique, using Diskit II® needles introduced for chronic discogenic low back pain. A Diskit II® has a needle (15 cm length, 20-gauge needle with a 20 mm active tip), which indicated an improvement in NRS at 6 months of follow-up. Therefore, Disc PRF appears to be an alternative to IDET [112].

Chronic Facet Joint Pain

This is the most common problem in the entire spinal axis. The facet joint is a true synovial joint, innervated by two medial branches of the dorsal ramie, and is a specific target for the treatment of lumbar chronic facet joint pain. It was found that RF treatment of the lumbar medial branches can provide 70% pain relief in these patients, for at least 6 months [113].

Post-Lumbar Surgery Syndrome

In a study of these patients who did not respond to at least two epidural steroid injections, they underwent PRF stimulation. The needles were placed into the epidural space (S2–S3 intervertebral level) through the sacral hiatus. Although only 32% of patients had pain relief, these results are promising given the lack of response to previous injections [114].

Coccygodynia

Is associated with pain and tenderness around the coccygeal region and usually occurs due to trauma. Caudal epidural PRF was applied to patients with coccygodynia, resulting in a VAS score decreasing within 6 months and 81% of patients responding well to treatment [115].

As a new technique for coccygodynia, PRF was applied to the ganglion impar, which significantly reduced the numeric pain rating scale at intervals of 3 and 6 months. Patients were divided into ganglion impar block and ganglion impar pulsed RF. The PRF neuromodulation prolonged pain relief while also reducing the risk of recurrence of pain in chronic coccygodynia [116].

Pelvic and Hip Pain Syndromes

The principles of treatment of pelvic pain with RF were discussed in previous chapters. PRF in the treatment of chronic pelvic pain leads to a reduction in VAS and less use of analgesics [117].

In 2018, a new novel anterior approach to *cooled RF hip denervation* was introduced under the guidance of combined US and fluoroscopy for chronic pelvic pain. The advantage of this method was the prevention of the neurovascular femoral bundle and reach proper landmarks. In these patients undergoing RF, the needle approach to the lateral articular branches of the femoral nerve was easily achieved with more than a 1 cm passage distance from the femoral nerve in all cases, but placing the second trocar to the incisura acetabuli was more difficult. This study suggested that an anterior needle approach to the lateral articular branches of the femoral and obturator nerves is a safe method, followed by RF denervation of these nerves, under a US guide and landmarks from fluoroscopy [118].

Osteoarthritis of the Hip

Relatively common and debilitating, which patients resistant to early treatment will seek joint replacement. RF denervation of the articular branches of the femoral and obturator nerves, which are the nerves of the pelvic joint, is a new technique for treating OA of hip. Some studies have used continuous RF, which has been associated with risks such as neuritis and neuroma formation.

The short- and medium-term effectiveness of PRF on the femoral articular branches and obturator nerves in patients with chronic pelvic pain was evaluated. 57% of patients had a reduction of more than 50% in pain, and disability scores decreased in a 6-month follow-up [119].

Chronic Post-Arthroplasty Hip Pain

This syndrome sometimes occurs after total hip arthroplasty. One study evaluated the effectiveness of cooled (60 ° C) RF lesioning of the articular branches of the femoral nerve for chronic post-arthroplasty hip pain, which showed significant reduction of patients' pain at 6-month and 24-month follow-up [120].

In an 11-year-old patient with *persistent right hip pain after septic arthritis*, a successful ultrasound and fluoroscopic-guided hip denervation was reported. At the 18-month follow-up, improvement and reduction of opioid use were reported [121].

PRF can also be used in cases of chronic pelvic pain, where the patient is not a candidate for surgery. For example, in *bilateral coxarthrosis*, which caused chronic pelvic pain, the intra-articular RF was applied with a 10 cm neurotherm needle at 42 ° C for 480 seconds that improved his pain [122].

For *lumbosacral facet joint pain*, two methods can be used, *medial branch stimulation and IA stimulation*. The stimulation of PRF on the medial branch of the posterior primary ramus can stop the transmission of pain signals from the facet joint to the brain [46].

In IA PRF stimulation, the PRF catheter can be placed in the atlanto-occipital or facet joints, and because the joint is small, PRF stimulation can affect the entire joint [123]. One of the places that have not yet been fully researched with a significant number of samples for PRF effectiveness is the SI joint.

Lower Extremity Pain Syndromes

Post-Herniorrhaphy
Chronic inguinal neuralgia has been reported *after herniorrhaphy, cesarean section, appendectomy, and trauma* to the lower quadrant of the abdomen. In one trial, chronic inguinal pain patients were divided into two groups: PRF and the control group. Both groups also received 0.25% bupivacaine +4 mg dexamethasone in 2 mL for each nerve root. PR has been shown to cause significantly longer duration of pain relief, so it has been suggested that PRF for the dorsal root ganglion can be used for intractable chronic inguinal pain [124].

Chronic Postsurgical orchialgia
The analgesic efficacy of pulsed RF applied to the ilioinguinal nerve and the genital branch of the genitofemoral nerve were assessed in 70 patients. A significant decrease of VAS was observed in 80% of PRF patients and only in 23% of the sham group. The percentage of patients who did not needed analgesics was 50% in the PRF group and only 3.3% in the sham group [125].

Sural Neuralgia
Characterized by pain in the distribution of the sural nerve that provides sensation to the lateral posterior corner of the leg, lateral foot, and fifth toe. The successful effect of RF on the sural nerve has also been reported. Patients who had sural neuralgia after foot or fall surgery, and were resistant to treatment, were effectively treated by pulsed RFA [126].

On a sural neuralgia, which was confirmed by electrodiagnostic studies, PRF application to the right sural nerve was used for 240 seconds at 45 volts and completely relieved the pain, which did not return pain after 5 months [127].

Pudendal Neuralgia (PN), or Alcock's Syndrome
Which is a severe and sharp pain in the pudendal nerve that is aggravated by sitting. RF can be used for chronic pelvic pain due to Pudendal neuralgia, which has led to pain relief for up to 12 weeks [128]. For patients with PN who did not respond to conservative treatment, apply a frequency of 2 Hz and a pulse width of 20 milliseconds for 120 seconds at 42 degrees Celsius, tolerating sitting for 4 to 5 hours increased [129]. Later, percutaneous CT-guided cryoablation was performed for 11 patients with refractory PN. Their mean pain score decreased from 7.6 before treatment to 3.1 6 months after treatment [130]. Also in a 2018 clinical trial, 80 PN patients in two PRF groups (PRF and pudendal nerve block) and NB group were divided. The rate of pain reduction in PRF patients was significantly higher than NB

patients in the 2 weeks and 3 months after surgery. Pudendal nerve PRF, combined with NB therapy, provides more pain relief and even relieves depressive symptoms of these patients [131].

There was also a report of successful PRD treatment under MR neurography. MR neurography has diagnostic value for PN, as well as for ruling out other causes of pelvic pain, such as genitofemoral neuropathy, endometriosis, adenomyosis, or pelvic mass lesion [132].

In a new 2020 report, patients with *recalcitrant neuropathic pelvic pain* underwent CT-guided pulsed RFA of the pudendal nerve, which was associated with more pain relief compared with nerve block injection. This technique provides direct visualization of the nerve to maximize safety and efficacy [133].

Meralgia Paresthetica

A disease of the lateral femoral cutaneous nerve (LFCN), characterized by paresthesia and numbness on the anterolateral aspect of the thigh. Few of these patients require aggressive treatment. In patients with medically intractable MP, and after a positive therapeutic response to the diagnostic nerve block, PRF neuromodulation was applied at 42 degrees for 2 minutes. The mean VAS score decreased from 6.4 to 0.63 after 6 months. 63.6% of patients had complete pain relief in the follow-up. No serious complication was reported. Therefore, PRF of the LCFN can be used as an alternative treatment in patients with MP [134]. A similar report has been reported for the treatment of pulsed RF neuromodulation to relieve the intractable pain associated with MP [135]. When PRF was applied to five LFCN patients for a longer period, they all reported an extended duration (8 minutes), all of which reported remarkable and long-lasting symptom relief and increased daily activity [136].

Chronic Pain After Cesarean Delivery

In a new report, ultrasound-guided pulsed RF to the ilioinguinal/iliohypogastric nerves was used to treat pain caused by cesarean delivery in breastfeeding women [136].

Knee and Distal Lower Extremity Pain Syndromes

An important point in the development of RF in the treatment of knee pain, beyond the main topics covered in previous chapters, is its complex nerve anatomy. For this reason, current CRFA protocols for knee pain may not cover all relevant and accessible sensory afferents of the anterior knee joint capsule. Classically, RFA in the knee targets the superior lateral genicular nerve (SLGN), the superior medial genicular nerve (SMGN), and the inferior medial genicular nerve (IMGN) [137]. But new cadaver studies show more articular nerves in sensory innervation of the anterior knee joint capsule [138]. These studies, in addition to the previous nerves, introduced sensory contributions from the terminal articular branches of the nerves to the vastus intermedius (NVI), vastus lateralis (NVL), vastus medialis (NVM), common fibular nerve, and recurrent fibular nerve.

Tran also showed greater variability in the SLGN, SMGN, and IMGN courses compared to previous studies. Laboratory studies of monopolar cooled RFA (CRFA) showed a spherical lesion size of approximately 0.5–1.0 cm3 in volume, which projects approximately 4 mm beyond the active tip. Therefore, the sensory afferent targets described by Tran, with the current RFA protocol, would not be captured. In particular, SLGN, SMGN, NVL, NVI, and NVM nerves can be missed. A new method was tested in 2020 to address this issue, targeting NVL and NVM, as well as additional placements of CRFA electrodes needed to cover both branches of NVI. This method has better safety because in genicular CRFA, the pes anserine tendon/tendon footprint can be damaged. But with a more inferior and posterior approach, the risk of injury to the pes anserine tendon is reduced [139].

Also in 2020, another method was performed using a *three-tined RFA cannula in patients with chronic knee pain*, which showed a significant difference in their pain relief after 6 months, which has a reduction compared to traditional and genicular nerve methods. The different types of cannulae, such as conventional, cooled, and three-tined cannulae, can cannulae differentiated lesion geometries all creating different neural capture and clinical outcomes depending on the size of the lesion. Conventional and cooled RFA probes differ in the size of the lesion, depending on the gauge of the needle, the length of the active tip, and the temperature of the lesion [21]. Therefore, further longitudinal studies are recommended to compare the clinical consequences of these cannulas.

The three-tined cannula creates the pyramidal lesion that is the largest lesion diameter closest to the cannula's tips, which makes it more likely to capture nerves [140]. This problem has also been addressed in the Finlayson study, which examined multi-tined RFA cannula types. In this study, a three-tined cannula with a distal deployment mechanism can create a stable lesion size up to an angle of 90 to the periosteal surface [141].

Subchondral Insufficiency Fractures of the Knee

Is a painful and refractory fracture. In a patient with debilitating pain due to this fracture, cooled RFA technique of the genicular nerves for knee pain and bisphosphonate injection for poor bone mineralization/density were used. After 4.5 months, an improvement in the patient's pain, function, and range of motion was observed [142].

In a trial, patients with *severe knee osteoarthritis* who had *previous knee arthroplasty* underwent ultrasound-guided pulsed RF of the superior medial, superior lateral, and inferior medial genicular nerves. The pain reduction rate in the 3-week and 3-month follow-up was more than 80% [143]. Also, in *peripheral neuropathic pain due to the metastatic nodule*, which *pressurized the SN nerve* and other nerves adjacent to the adductor canal (from the nerve to the vastus medialis and other sensory branches of femoral and obturator nerves), pulsed RF lesioning of saphenous nerve was successful [144].

We can try to improve efficacy by changing the number of needles. In a 2020 study, safety and efficacy comparison of three- vs four-needle technique in the

treatment of severe knee osteoarthritis using cooled radiofrequency ablation was examined. In 77 treated knees and after 6 months, 79% of patients treated with four needles and 45% of patients treated with three needles showed a reduced need for opioids. Therefore, the four-needle treatment approach showed more efficacy in the treatment of osteoarthritis of the knee [145].

Ankle Pain Syndromes

Acute Achilles Tendon Injury
Laboratory studies have shown that direct RF application can heal acute tendon injury, improve gain, and alleviate pain [146].

Achilles Tendinosis
Caused by a chronic degenerative process in the Achilles tendon. Using a new technology called Topaz micro-debridement, the degenerate micro-architecture in the damaged tendon can be restored. This method has been used in upper limb tendinopathies, but its application is new in tendinopathies of the foot and ankle. After applying the Topaz radiofrequency micro-debridement for Achilles tendinosis, the VISA-A scores improved from 18/100 to 63/100, and all patients had objective improvement in functional outcome. It was suggested that Topaz micro-debridement can be used in the Achilles tendinosis [147].

Insertional Achilles tendinosis
Results in pain at the junction of the Achilles tendon and occurs due to intratendinous degeneration. Because RF Coblation can be effective in treating tendon injuries, percutaneous execution of this procedure is used to treat insertion Achilles tendinopathy. Patient selection, however, must be very careful. As in a review, 14.9% of these treated patients required re-operation, and 6.4% reported Achilles tendon rupture. Interestingly, most patients with complications had a high BMI [148].

RFA is commonly used to treat arthritis, and RF ablation devices are used in *arthroscopic joint surgeries to remove soft tissue.* Numerous other arthroscopic surgeries have used RFA technology in the past, including *chondroplasties, partial meniscectomies, meniscal tears, repairs, and ligament reconstructions* [149]. But little has been done about the use of RF in small joints.

Recently, improvements have been reported in the *combined use of RF with arthroscopic application* to the ankle joint. The effectiveness of RF ablation of dendritic synovitis was evaluated together with ankle arthroscopy for reducing *chronic ankle pain*. In this surgical technique, the hypertrophic synovitis, or synovial accumulation in the joint, was removed using a RF microtenotomy wand.

It was suggested that plasma-mediated, bipolar, RF-based arthroscopic microdebridement could improve chronic ankle joint pain in cases where conservative treatment has failed. Obese patients experienced more pain relief with this treatment.

However, a problem that may occur with the use of RF ablation in arthroscopic surgery is the rise in tissue temperature, which may damage the capsular tissue and especially the chondrocytes. A 2018 study suggested that a high irrigation flow should be established, during the use of RF in arthroscopic surgeries of the ankle joint, to prevent the temperature from rising to 50 ° C/122 ° F. The pressure difference across the ankle joint should be raised as much as possible to prevent tissue damage [150].

Foot Pain Syndromes

Plantar Fasciitis (PF)/ fasciosis

Using RF technology to small peripheral nerves has the same benefit as treating the conventional spine areas. Digital nerve application using small 5 mm exposed tips allows us to precisely place needles in painful phalanges and plantar fascia zones that exhibit pain. Prior to now intergrading RF for plantar fascia pain, most patients would undergo lengthy conservative approach with icing, stretching the fascia and splinting. All of which may improve the condition over time but takes a considerable amount of time and resources. With the application of RFA, the improvement of pain can be much more rapid and improve function sooner, allowing patients to walk better and wear comfortable shoes.

The analgesic effect of RFA for plantar fasciitis/fasciosis may be attributed to inducing a response to heal and reduce pain in inflamed tissue [151]. In patients with refractory chronic bilateral plantar fasciitis, PRF was applied on the medial calcaneal nerve for 6 minutes and TRF on the same nerve and in the opposite heel for 90 seconds. Both modalities were effective, although the PRF heels had significantly better pain scale; therefore, it was suggested that PRF on the medial calcaneal nerve could be a safe and effective treatment for *chronic plantar fasciitis pain* [152].

As another therapeutic indication in RF, the *posterior tibial nerve (PTN)* can also be targeted in the treatment of recalcitrant plantar fasciitis (PF). In a study, ultrasound-guided PRF was applied to the recalcitrant PF, and the control group received a 2% dose of lidocaine. The PRF group clearly had more improvement in first-step pain, overall pain, as well as plantar fascia thickness; therefore, ultrasound-guided PRF can be a novel treatment for recalcitrant PF [153].

Metatarsalgia

Is pain in the forefoot, associated with increased pressure in the metatarsal head region. A novel and successful treatment of recalcitrant metatarsalgia with ultrasound-guided PRF was reported, targeting the posterior tibial nerve (PTN) at the ankle. Three months after the PRF, the metatarsalgia improved partially, without any further conservative treatment needed [154].

Specific Chronic Pain Syndromes

Post-Herpetic Neuralgia (PHN)

Various studies have examined the effectiveness of RF in the treatment of PNH. One of the target therapeutic PRFs in herpes zoster and PNH is DRG, which has been reported to be effective in other pain syndromes. Interestingly, patients receiving PRF as early as the time of zoster onset (e.g., in the first 90 days) will have more pain relief, more PRF success rate, and less need for analgesics [155]. PRF + nerve block therapy for PNH can increase β-EP levels and decrease plasma IL-6 and SP, thereby reducing pain and hyperalgesia. Therefore, the combination of PRF and NBT can be efficient in the treatment of PNH [156].

In the treatment of PNH, the *stellate ganglion* can also be targeted. Although both SG-block and SG-PRF treatments are effective, the reduction in VAS score was greater in the SG-PRF group, and the complications and side effects were greater in the SG block group [157]. Gasserian ganglion can also be a target for PNH. The application of high-voltage and long-duration PRF on Gasserian ganglion may treat acute/subacute zoster-related trigeminal neuralgia [158].

Post-Amputation Pain Syndrome: Including Phantom Limb Pain, Stump Pain, And Phantom Limb Sensation

These syndromes are relatively common and resistant to routine treatments like medication and nerve block. They have complex pathophysiology, and sometimes even surgery and spinal cord stimulation are not so effective.

Although both central and peripheral components are involved in PLP, treatment of a peripheral pain locus with cryoanalgesia or other RF methods can be effective for that.

In one case series, four amputated patients with *residual limb pain (RLP)* and phantom limb pain (PLP) were treated with PRFA after failing conservative management. 80% relief of RLP was obtained in 6 months. The patient's overall function, including prosthetic tolerance, also improved, and the need for oral analgesics decreased [159].

A persistent and refractory upper limb stump pain was also treated *with PRF of brachial plexus*, under ultrasound guidance, with were positive results, suggesting the effectiveness of PRF on refractory stump-neuroma pain [160].

Cryoablation can also be used to treat *refractory phantom limb pain* (PLP). Treatment of phantom limb pain by *cryoneurolysis of the amputated nerve* in five patients with 2.5-year follow-up reported positive outcomes [161]. PLP patients underwent image-guided percutaneous cryoneurolysis in another study, with the technical success rate of 100 percent. The disability scores increased from 11.3 to 3.3 after 45 days, and patients' pain decreased from 6.2 to 2 [162].

The Coblation technology may also be applied to the *femoral and sciatic nerve*, for stump pain and phantom limb pain. After an ultrasound-guided perineural infiltration anesthesia surrounding the neuroma, stump pain was reduced by 60%, but phantom limb pain did not change. Then, the Coblation of femoral and sciatic

nerves was performed, which relieved 80% of stump and phantom limb pain in a 6-month follow-up [163].

PRF was also applied to the *dorsal root ganglia* at the L4 and L5 nerve roots, for post-amputation stump pain. The rate of pain improvement in this method was relatively less than similar studies with different targets, with a 40% decrease in pain on the VAS [164] and 50% in another similar study [165].

Complex Regional Pain Syndrome (CRPS)

Occurs following injury or nerve damage and has a combination of sensory, motor, vasomotor, and pseudomotor dysfunctions and trophic signs. CRPS requires a multidisciplinary approach to treatment, as it has many side effects, such as functional disability, lack of sleep, and poor quality of life. Various treatments, such as sympathetic blocks to spinal cord stimulators, are mentioned for it.

Sympathetic chain neurolysis, or sympathectomy, is one of the treatments for CRPS; however, it has complications, such as worsening pain and the development of new pain syndromes. To prevent these complications, PRF can be an alternative treatment for CRPS.

The effectiveness of PRF on the cervical sympathetic chain for CRPs was evaluated in CRPS patients. PRF was applied under ultrasound guidance for temperature of 42 ° C, on the C6- and C7-level sympathetic chain. 91.7% of patients experienced moderate and more recovery, with no significant side effects [166].

Also, for lower-extremity CRPS type I patients, 14 fluoroscopically guided PRF lesioning were applied on the lumbar sympathetic chain at L2, L3, and L4. Substantial pain relief (>50%) was obtained in 91.7% of PRF cases at 3 months and 83.3% at 6 months. Opioid use decreased significantly [167].

One of the treatment goals in CRPS is the stellate ganglion. Although block of stellate ganglion is a therapeutic target for upper limb neuropathies, the effect duration of a single stellate ganglion block is usually short, and therefore PRF is more effective.

In the review 86 RF stellate ganglion, partial pain relief was observed in 41.3% of patients, complete pain relief in 37.8%, and no pain relief in 20.9%. This review showed that this method could be suitable for *complex regional pain syndrome type II*, *ischemic pain, cervicobrachialgia, or post-thoracotomy pain* [168].

In a position-induced right upper limb neuropathic pain suggestive of CRPS type II, treatment of the stellate ganglion block under fluoroscopic guidance at cervical C7 was performed, which achieved relative improvement. He then underwent a pulsed RF ablation of the stellate ganglion, which resulted in prolonged pain relief even up to 14 months after follow-up [169].

Ablation has advantages over more traditional methods. For example, in 67 patients with *chronic upper limb type I CRPS,* refractory to conventional pain therapies, the RF neurolysis was more successful than stellate ganglion blockade (67% to 21.2%) [170].

Also, in two cases with *post-stroke complex regional pain syndrome*, pulsed RF was applied to the cervical dorsal root ganglia, which was accompanied by improvement in his symptoms in 10 months follow-up [171].

Diabetic Neuropathic Pain

Is a long-term complication of type 1 and type 2 diabetes and causes a decline in quality of life. Recently, efforts have been made to find the effectiveness of PRF in diabetic neuropathic pain. In vitro, rats were induced with diabetes and developed mechanical, thermal, and cold hypersensitivity. Pulsed RF was applied to L5 and L6 dorsal roots of these rats for 2 minutes at 42 ° C. It was observed that the symptoms caused by diabetes improved. Also, the amount of formalin-evoked CSF glutamate concentration increased compared to the sham group. Therefore, PRF can play a role in managing diabetic neuropathic pain by suppressing the nociception-induced release of excitatory neurotransmitters [172].

In the clinical study, patients with painful DPN refractory to conventional treatment were divided into two groups: TENS and PRF lumbar sympathectomy. The 10-point numerical rating scale (NRS) in both groups clearly decreased in early follow-up, but the PRF lumbar sympathectomy had superior efficacy, which was due to pain score in the longer follow-up in the TENS group approaching baseline before treatment [173].

RF can also be used to treat *cancer pain*. For example, CT-guided RFA is effective in patients with *painful bone metastases*. The analgesic effect of RFA was similar to that of microwave ablation, but RFA provided this pain relief at a lower cost [174]. Also, percutaneous RFA therapy has been effective in relieving pain in these patients [175].

RF ablation had positive results in patients with a *malignant solitary bone lesion that caused intractable pain*. Interestingly, the amount of pain reduction after ablation was related to the size of the tumor and presence of pathologic fracture. Further, the presence of an irregular rim after ablation and rim thickness were associated with increased pain [176].

In the treatment of a *painful supraclavicular soft-tissue metastasis of a skin melanoma* invading the brachial plexus, CT-guided RFA was applied, which caused tumor necrosis. The tumor was resistant to chemotherapy and radiotherapy; however, RF relieved pain and released the patient from using analgesics. 19 months later, the tumor recurred, and he underwent the same procedure again [177].

In the case of *prostate cancer and bone metastasis*, suffering from tingling and numbness in the right upper limb, oral analgesics have little effect, while PRF application on *ulnar and median nerve* showed effective treatment. At follow-up, the patient's symptoms were reduced by 80%. Before applying PRF to the peripheral nerves, RF ablation was applied to the dorsal root ganglion, which was not very successful in relieving pain [178]. So, these two environmental and central methods can be compared to the treatment of neuropathies in randomized studies.

RFA is also effective in treating palliation of *painful osteolytic metastases from HCC* [179].

Cancer-Associated Pain

Is usually difficult to treat, especially when the tumor involves peripheral nerves. In a patient with a *metastatic axillary tumor that involved her brachial plexus who was* not responding well to medication, and was not a candidate for surgery due to the

size of the tumor, RFA was applied to her brachial plexus. She responded very well to RFA, with minimal pain remnant [180]. Also, in an *intractable neoplastic plexopathic pain*, due to advanced lung cancer and bone metastasis in the left humerus, pulsed RF treatment is applied within brachial plexus. The pain was controlled moderately [181].

Chemotherapy-Induced Peripheral Neuropathy (CIPN)
Ultrasound-guided pulsed RF on the brachial plexus had positive results in chemotherapy-induced peripheral neuropathy. A patient with shock-like pain in the left upper limb after chemotherapy and mastectomy for left-sided breast cancer was treated with pulsed RF using an insulated-type needle, which reduced his pain by 80% [182].

Chronic Axonal Polyneuropathy (CIAP)
Is a peripheral nerve injury, usually presents with neuropathic pain. PRF can be effective in managing refractory neuropathic pain following CIAP. The effect of caudal epidural PRF stimulation on refractory neuropathic leg pain following CIAP was studied. Also, patients with axonal polyneuropathy were treated with PRF, at 5 Hz using a 5 ms pulse width for 600 seconds at 55 V. Pain score decreased significantly after 3 months post-PRF. Half of the patients experienced pain reduction of more than 50% [183]. This could be due to the disruptive effect of PRF on sensory nociceptive axons.

Of course, hematoma may occur in these patients, as reported after caudal epidural PRF stimulation for chronic idiopathic axonal polyneuropathy. After 7 days, spinal epidural hematoma was found at the L1 to L5 levels, compressing the thecal sac, which inevitably forced decompressive laminectomy with the evacuation of the hematoma. The above patient was taking oral warfarin (2 mg/d), which was not discontinued before treatment [184].

Potential Future Indications of RF in Pain Management

The application of this treatment is not limited to the spine and conventional areas on the body. Thinking outside the previous indication is helpful to develop pain management. Table 16.2 describes the potential targets of RF for pain management in varied pain syndromes, which have been less discussed in the literature and practice.

New Techniques and Applications

New RF techniques and applications in pain management are discussed separately in this chapter, as well as previous chapters. To further illustrate the importance of the novel techniques in the RF, just a few more examples are given in this section.

Table 16.2 Potential future targets of RF in pain medicine. (Most of the titles are extracted from 'Atlas of Common Pain Syndrome' by Steven D. Waldman. Elsevier, 2019) [185]

Region of pain	Specific pain syndrome
Headache pain syndromes	Tension-type headache Swimmer's headache Analgesic rebound headache Pseudotumor cerebri Intracranial subarachnoid hemorrhage
Facial pain syndromes	Hyoid syndrome Reflex sympathetic dystrophy of the face Post-tonsillectomy Auricular-temporal neuralgia Blepharospasm Eagle syndrome
Neck and brachial plexus pain syndromes	Fibromyalgia of the cervical musculature Cervical strain Longus colli tendinitis Retropharyngeal abscess Cervicothoracic interspinous bursitis Pancoast's tumor syndrome Thoracic outlet syndrome
Shoulder pain syndromes	Acromioclavicular joint pain Subdeltoid bursitis Bicipital tendinitis Avascular necrosis of the glenohumeral joint Biceps tendon tear Supraspinatus syndrome Deltoid syndrome Teres major syndrome Glenohumeral osteoarthritis
Elbow pain syndromes	Golfer's elbow Distal biceps tendon tear Thrower's elbow Supinator syndrome Brachioradialis syndrome Lateral antebrachial cutaneous nerve entrapment at the elbow Osteochondritis dissecans of the elbow Olecranon bursitis
Wrist pain syndromes	Flexor carpi ulnaris tendinitis de Quervain's tenosynovitis Ganglion cysts of the wrist
Hand pain syndromes	Trigger finger Sesamoiditis of the hand Dupuytren's contracture
Chest wall pain syndromes	Costosternal syndrome Manubriosternal syndrome Diabetic truncal neuropathy Tietze's syndrome Precordial catch syndrome

(continued)

Table 16.2 (continued)

Region of pain	Specific pain syndrome
Thoracic spine pain syndromes	Costovertebral joint syndrome
Abdominal and groin pain syndromes	Irritable bowel syndrome Diverticulitis Acute appendicitis Ilioinguinal neuralgia Genitofemoral neuralgia
Lumbar spine and sacroiliac joint pain syndromes	Latissimus dorsi syndrome Spinal stenosis Arachnoiditis
Pelvic pain syndromes	Osteitis pubis Gluteus maximus syndrome Piriformis syndrome Ischiogluteal bursitis Pelvic inflammatory disease Interstitial cystitis Testicular torsion Levator ani syndrome
Hip and lower extremity pain syndromes	Snapping hip syndrome Iliopectineal bursitis Ischial bursitis Trochanteric bursitis
Knee and distal lower extremity pain syndromes	Avascular necrosis of the knee joint Jumper's knee Runner's knee Suprapatellar bursitis Prepatellar bursitis Superficial infrapatellar bursitis Deep infrapatellar bursitis Osgood-Schlatter disease Baker's cyst of the knee Common peroneal nerve entrapment Tennis leg
Ankle pain syndromes	Arthritis of the midtarsal joints Deltoid ligament strain Tarsal tunnel syndrome
Foot pain syndromes	Morton's neuroma Intermetatarsal bursitis Sesamoiditis Calcaneal spur syndrome Mallet toe Hammer toe

Anesthetic and Curved Needle: Author's Tip

With the basic principle being the same with the use of an RFA needle and generator, the application of heat/pulse and time should be altered to accommodate more sensitive, superficial areas being treated. The standard use of 80–85 degrees Celsius and

60–120 seconds of treatment time should be reduced to 70 degrees for 90 seconds. Recall that many treatment areas are very close to the surface of the skin, where sensitive nerve endings are located. With the use of minimal anesthetics in an office-based setting, one should take into account the use of topical analgesia with lidocaine gels to reduce cutaneous sensitivity. Because many targeted areas are so superficial, using a 5 mm exposed tip versus a 10 mm tip is essential in preserving the skin and surrounding tissue from being damaged. The author's preference remains the use of a curved needle to best utilize the steerability of the needle to the target.

As an advancement, a newer needle for RF ablation has been introduced, which may improve the safety and effectiveness of RFA. This needle, Accura®, has an occluded tip that allows the solution to flow from the sides in a circular fashion (Fig. 16.1). When the needle is positioned parallel to the desired nerve, it applies the injectate to the target region rather than to the healthy tissue, thereby providing a more precise and larger RF ablation. It allows the nerve to burn more accurately without damaging the surrounding tissue in the immediate vicinity. Injection of 2 percent of lidocaine HCL during lesioning resulted in increased lesion size parameters compared to the control needle without injection. It can be used in the medial branch of lumbar, cervical, and thoracic nerves.

Low-Temperature Plasma Radiofrequency Ablation

This is a relatively new technique that has shown positive applications in the treatment of neuropathic pain. In this method, the radiofrequency energy through the saline medium creates plasma iron particles. These particles can break molecular bonds in the tissue, which leads the tissue to dissolve at relatively low temperatures. This technique has been used in various pains. Including:

- Phantom limb pain: Coblation of the cervical nerve root was performed with computed tomography (CT) guidance for the treatment of phantom limb pain and showed positive results [186]. For this purpose, a Coblation needle attached to a

Fig. 16.1 The curved needle of RF

low-temperature plasma multifunctional operation system is placed adjacent to the C8 nerve root. At intervals of 1–3 and 6 months, the patient's pain was relieved, which showed good effects of this new treatment with fewer complications.

- In trigeminal neuralgia, 217 patients who underwent surgery for primary TN were divided into two groups: the Coblation group and the RF group. After 3 months, 69% of the Coblation group and 42% of RF group were painless. The risk of numbness was reported in the lower Coblation group, which was an advantage over the traditional method in the treatment of primary TN [187].
- Lumbar disc herniation: Coblation annuloplasty is a more effective and safer method than RF for treating lumbar discogenic pain [188].
- Thoracic neuropathic pain: Percutaneous thoracic paravertebral nerve Coblation guided by CT had significant results in pain reduction in this pain [189].

Computational Analysis of RF in Pain Management

In a 2020 study, a computational analysis was done about domain heterogeneity in RF therapy. The differences between the predicted ablation volume in homogeneous and heterogeneous models of typical RF in pain management were examined. Consideration of heterogeneity in the computational domain leads to distorted electric field distribution and resulted in a significant reduction in the attained ablation volume from CRF application. Knowledge of the impact of such heterogeneities on the efficacy of RF can help develop optimal protocols for the different indications of RF [190].

Peripheral Nerve Injury Ablation

As noted in the RF history chapter, both Goldthwait and Ghormley were pioneers in our field of performing nerve ablation to sites that were targeted at the spine. But as we have come to appreciate and value, any target that has sensory nerve tissue can be ablated. The benefit and safety of using RFA to sensory painful nerves are that over time, the nerve regenerates and can be treated again.

There are currently few options for patients suffering from peripheral nerve damage, and the available methods are complicated, risky, and/or expensive. Peripheral nerve ablation is a relatively simple, inexpensive procedure that can produce long-term pain relief without the risks that frequently accompany other methods. These methods can be performed in an office-based setting without sedation or unconscious anesthesia. Local anesthesia is sufficient to anesthetize the nerves in question and allow for pain relief after the procedure, especially with the use of ultrasound technology. The advent of US allows the clinician to avoid radiation exposure and perform this procedure in an office-based setting that is cost-effective and convenient for the staff and patient. One way to significantly alley anxiety is to produce an environment that is non-threatening and provides ease.

As for safety, performing a peripheral RFA with either conventional or pulsed RF to specific areas can take just a few moments, and it can allow the patient to leave the office either on their own or with a companion.

Reduce Complications of RF

Although RF is a relatively safe procedure in general, and its pulsed form in particular does not cause cell damage, limited side effects have been reported. These include hypoesthesia, a neuritis-like reaction, hematoma, numbness, transitory diplopia, meningitis, Horner's syndrome, and urinary retention.

More complications for specific cases were described before. For example, the occurrence of hematoma complication in genicular nerve radiofrequency ablation (RFA) was shown. In a severe case of osteoarthritis and severe chondromalacia, the patient underwent bilateral genicular nerve RFA and presented 4 days later with right medial thigh pain. A MRI showed a hematoma along the anteromedial aspect of the right distal femoral diaphysis. This was one of the first cases of iatrogenic vascular injury in the genicular RFA procedure. Careful attention to the vascular anatomy of the knee and the RF target organs, especially variations after previous surgeries, was recommended to minimize vascular complications [191].

Conclusion and Future Research

There are several hundred pain syndromes for which mainly conservative therapies with limited response therapy are performed, and the development of RF for these pains is needed, as an effective treatment modality with low side effects. RFA can be applied to any area where sensory and autonomic nerves are found.

Further research should focus on the RF efficacy for pain syndromes and reducing the complications. This can be done by improving and changing the type or number of needles, combination therapies (such as combining RF with corticosteroids, nerve block, saline, and physiotherapy), and usage of newer technologies in generators and generated frequencies, to cite a few examples.

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T. R. Deer, N. Azeem (eds.), *Essentials of Radiofrequency Ablation of the Spine and Joints*, https://doi.org/10.1007/978-3-030-78032-6