Radiofrequency Treatments on the Spine

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Preface

Radiofrequency (RF) is a medical procedure mainly used to reduce pain. An electrical current produced by a radio wave is used to heat up a small area of nerve tissue, thereby decreasing pain signals from that specific area. In the last 5 years, an important field of application of this procedure is the spine and its pathologies.

The purpose of this book is to describe the principle and field of application of RF. This technique is accompanied by fewer complications and side effects, reduced risks of anesthesia, and lower costs.

World-renowned researcher will describe the RF application for the treatment of disc herniation, discogenic and radicular pain, and facet joint arthropathy and for the treatment of benign and malignant lesions of the vertebral column.

This book will cover a gap in the literature and meet the need expressed by a large number of specialists (interventional neuroradiologists and radiologists, neurosurgeons, and orthopedists) for a topical and handy guide that specifically illustrates the application of RF.

Cagliari, Italy
06-Aug-2016

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1 Anatomy and Biomechanics of the Spine

Mario Muto, Gianluca Muto, Francesco Giurazza, Mario Tecame, Zeccolini Fabio, and Roberto Izzo

1.1 Introduction

Spine is a multiarticular system controlled by muscles supporting the head and trunk during posture and movements; it protects the spinal cord, nerve roots and, at cervical level, the vertebral arteries. The normal function of the spine presupposes its stability [1]. Furthermore spine stability is the essential principle to transfer power forces between the upper and lower limbs and the active generation of forces in the trunk [2, 3].

Clinical stability is the spine's ability under physiologic loads to limit patterns of displacement in order not to damage or irritate the spinal cord and nerve roots and to prevent incapacitating deformity or pain caused by structural changes [4]. Vertebral stability during movements is obtained with bony and soft movement restraints. The loss of stability is an important cause of back pain; because spinal movements are not isolated but coupled among them, tissue derangement frequently causes dysfunctional motions in multiple directions.

Spinal stability is based on three connected systems (Fig. 1.1):

- Column
- Muscles and tendons
- Central nervous system and spinal nerves

The column includes bones, discs, ligaments and joint capsules; these structures fulfil an intrinsic structural role [5] and contain mechanoreceptors which act as transducers, sending a continuous flow of proprioceptive information on loads, motions and posture through the spinal nerves to the central nervous system that, in turn, replies via an appropriate and coordinated feedback muscular action [6, 7].

Degeneration or any traumatic lesion to the bony and soft components of the spine tends to increase the demand on muscles and nervous systems in order to preserve or restrict the segmental instability [5].

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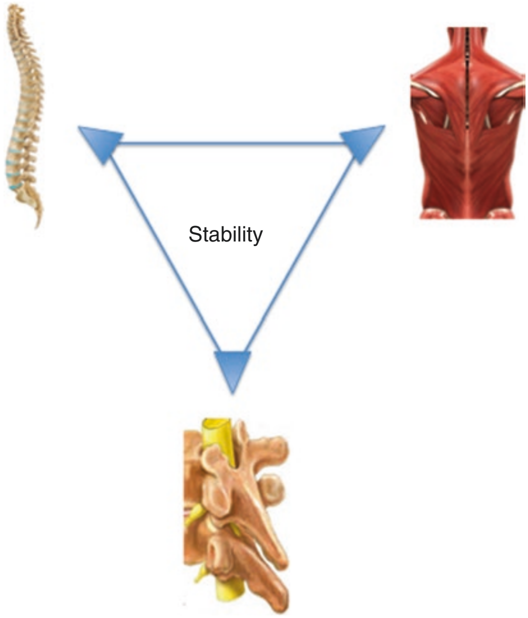

Fig. 1.1 Spine stability is guaranteed by the strict connection between three systems: column, muscles and central nervous system. Their activities are regulated on the basis of the reciprocal feedbacks

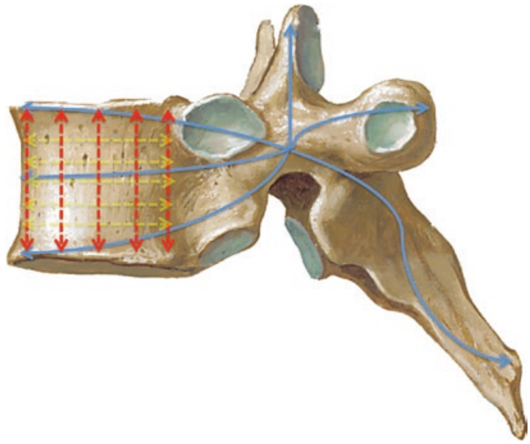

Fig. 1.2 The four trabecular systems: vertical, horizontal and curved force lines are constant in all the vertebral components of the spine. The vertical system (*red lines*) supports the central portion of the soma lending resistance to cranio-caudal compression. The horizontal (*yellow lines*) and the two curved systems (*blue lines*) strongly attach the posterior arch to the soma

1.2 Column

The intrinsic structural and stabilization role of the spine depends on:

- Vertebral architecture
- Disc-intervertebral joints
- Facet joints
- Ligaments
- Curves

1.2.1 Vertebral Architecture

The passive load-bearing ability of the vertebral body depends on the size, shape, integrity of the trabecular system and bone density. The vertebral body mainly consists of spongy bone with a three-dimensional honeycomb structure that yields the best strength/weight ratio [8]. The progressive increase in body size downward in the spine is the only physiological answer to increasing weight loads [9].

The cancellous bone of any vertebral body has four main trabecular systems (Fig. 1.2):

- A vertical system extending between the endplates which accepts and transmits vertical loads
- A horizontal system travelling in the posterior arch and joining the transverse processes
- Two curved oblique systems, superior and inferior, starting from the endplates and crossing in the peduncles to end in the spinous and joint processes

Their function is to withstand the horizontal shear stresses ensuring the neural arch to the body.

Compared to spongy bone, the cortical bone presents much lower elasticity but is more resistant. The resistance of spongy bone also strongly depends on mineral density; indeed bone loss in osteoporosis results in a disproportionate exponential reduction of resistance: a bone loss of 25 % leads to a reduction of resistance of about 50 % [10].

1.2.2 Disc-Intervertebral Joints

Thanks to its peculiar structure, the disc has both the tension-resisting properties of a ligament and

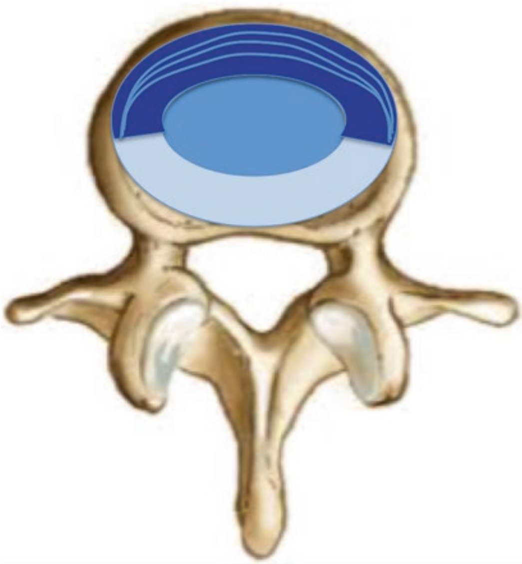

Fig. 1.3 Framework of a normal disc: the central nucleus (azure) presents a homogeneous hydration acting as shock absorber; the circumferential annulus has fibres resistant to stretching, stiffer in the anterior portion (*dark blue*) than in the posterior (*clear blue*)

the compression-resisting properties typical of joint cartilage. The disc behaves as a ligament allowing for and controlling the complex three-dimensional movements of the spine: vertical compression and distraction, flexion–extension, lateral bending and axial rotation. The outermost fibres of the annulus are the first controller of abnormal micro-movements [11].

With the nucleus behaving like a pressured cylinder, the disc is also the main shock absorber of mechanical stresses transmitted during motions to the skull and brain. The biomechanical behaviour of the normal young nucleus is homogeneous and isotropic, equal in all its parts and all directions: independently from the spatial position of the spine, the load is transmitted on the endplates avoiding any focal concentration [12]. By contrast, in the degenerated disc the nucleus loses its normal fluidlike properties and loads asymmetrically assuming a solid-like behaviour.

The tensile circumferential properties of the annulus are also inhomogeneous, the anterior annulus being stiffer than the posterior annulus (Fig. 1.3) and the outer annulus stiffer than the inner ring [13]. When the normal disc is loaded, tensile circumferential loads are generated in the annulus because of the pressurization of the nucleus and the resistance of its fibres to stretching and bulging under axial compression [14].

The water content and thickness of the disc continuously change during normal daily activities under the opposite influences of hydrostatic and osmotic pressures [15]; under load, the high hydrostatic pressure leads to a gradual release of water out of the disc whose thickness diminishes until it is counterbalanced by the osmotic pressure exerted by proteoglycans whose concentration increases progressively [15]; in the recumbent position the re-prevailing osmotic pressure again recalls water back into the disc.

1.2.3 Facet Joints

Facet joints fulfil two basic functions:

- Control of direction and amplitude of movements
- Sharing of loads

According to the three-column model of Louis, the weight of the head and trunk is transmitted first on two columns placed on the same frontale plane, the atlanto-occipital lateral joints, then, from C2 to L5, on three columns arranged like a triangle with an anterior vertex [8]. The anterior column is composed of the superimposing bodies and discs, the two posterior columns of the vertical succession of the facet joints (Fig. 1.4).

In physiological conditions a balanced action exists between the three columns so that the posterior facets accept from 0 % up to 33 % of the load depending on the posture [16]. Like the vertebral bodies the increasing size of the facet joints downward compensates the increasing functional demand. The spatial symmetry of the facets is an essential requirement for correct functioning: every significant asymmetry predisposes to instability and premature degeneration of the facets and discs.

Long-standing remodelling and destabilization of the facet joints along with degenerative changes in posterior ligaments lead to degenerative spondylolisthesis with sagittal orientation of the facet

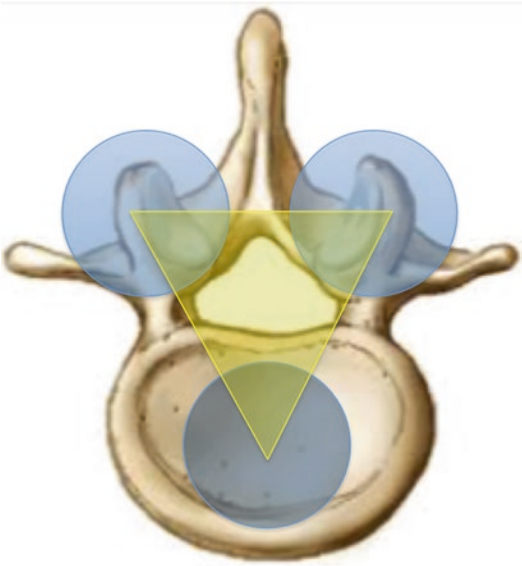

Fig. 1.4 Representation of the three-column model of Louis (from C2 to L5): the anterior column (*dark blue circle*) is composed of the superimposing bodies and discs, the two posterior columns (*clear blue circle*) of the vertical succession of the facet joints; these structures form a triangle with an anterior vertex (*yellow triangle*)

joints acting as a predisposing factor [17]. An estimated 15–40 % of chronic low back pain cases are thought to be caused by lumbar facet joints due to joint capsule mechanical stresses and deformation with activation of nociceptors [18].

1.2.4 Ligaments

Ligaments are the passive stabilizers of the spine. The interspinous and supraspinous ligaments being located far away from the rotational axis and working with a long lever arm oppose spinal flexion more than the flava ligaments having a shorter lever arm [19]; on the other hand being very close to the spinal rotational axis and intrinsically less resistant, the posterior longitudinal ligament presents a double mechanical disadvantage.

1.2.5 Physiological Curves

Sagittal curves are acquired and represent the evolutionary response to the needs of the upright standing position [20]. Dorsal kyphosis is the only sagittal spinal curve present at birth. Cervical and lumbar lordoses develop with head rising and standing and walking.

Both in normal individuals and in pathologic conditions, sagittal spine curves are regulated by pelvic geometry expressed by different parameters, namely, pelvic incidence, sacral slope and pelvic tilt [20, 21]. Pelvic incidence is a fixed morphologic parameter which after birth remains unchanged in each subject: any sagittal balance change is obtained because of the adaption of other positional parameters [21].

Sagittal spinal curves also increase the resistance to vertical loads up to 17 times by directing deformations into pre-ordered directions which can be quickly controlled by the fast intervention of muscle contraction.

1.3 Muscles and Tendons

Muscles and tendons provide active stabilization of the spine under the control of the nervous system; their action stabilizes the spine during standing, lifting and bending activities. Without the muscles, the spine would be highly unstable, even under very light loads [5, 18].

The muscles may be divided into superficial (rectus abdominis, sternocleidomastoideus) and deep (psoas) flexors and superficial (long) and deep (short) extensors.

The function of the superficial, multisegmental muscles differs from that of deep unisegmental muscles. Being small and located very close to vertebral rotation axes, the short muscles (inter-transverse, interspinous, multifidus) globally act primarily as force transducers sending feedback responses to the central nervous system on the movement, load and position of the spine [22]. The long superficial muscles are the main muscles responsible for generating movements: the lumbar erector spinae and the oblique abdominal muscles produce most of the power forces required in lifting tasks and rotation movement, respectively, having only limited insertions on the lumbar motion segments, while the multifidus muscle acts as a dynamic stabilizer of these movements [22]; the oblique and transverse abdominis muscles are mainly flexors and rotators of the lumbar spine but stabilize the spine at the same time, creating a rigid cylinder around the spine by increasing intra-abdominal pressure and tensing the lumbodorsal fascia [23]. The complexity of the posterior musculature excludes any possibility of voluntary control upon single units.

The large number of muscles, the complex antagonistic activities and the variability of spine insertion control the determination of muscle force and its contribution to spinal loading.

All these components, together with joints and tendons of each segment, send inputs through the spinal nerves to the central nervous system that regulate and coordinate the muscle activity [5].

1.4 Spinal Nerves and Vertebral Pain

Spinal nerves are mixed nerves, which carry motor, sensory and autonomic signals between the spinal cord and the body. Each spinal nerve is formed from the combination of nerve fibres from its posterior and anterior roots. The posterior root is the afferent sensory root and carries sensory information to the spinal cord and then to the brain. The anterior root is the efferent motor root and carries motor information from the brain passing through the spinal cord. The spinal nerve emerges from the spinal column through the intervertebral foramen between adjacent vertebrae [24].

Outside the vertebral column, the nerve divides into branches: anterior and posterior.

The anterior ramus contains nerves that serve the anterior portions of the trunk and the upper and lower limbs, carrying visceral motor, somatic motor and sensory information to and from the ventrolateral body surface, structures in the body wall and the limbs.

The posterior ramus contains nerves that serve the posterior portions of the trunk carrying visceral motor, somatic motor and somatic sensory information to and from the skin and muscles of the back.

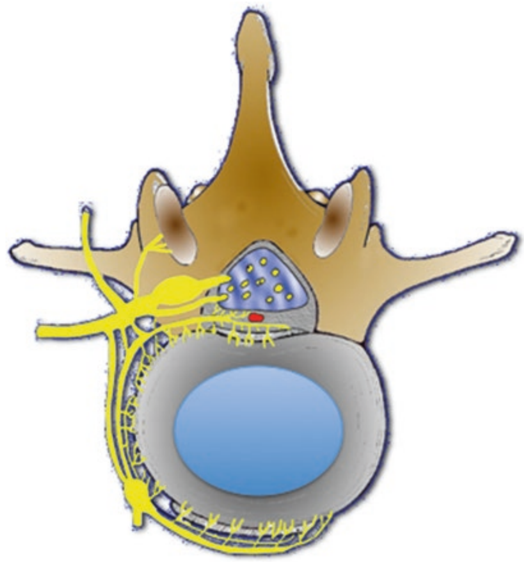

Fig. 1.5 Schematic overview of the nerves of Luschka: small meningeal branches of the spinal nerves that originate near the bifurcation of the anterior and posterior rami and receive fibres by the facet joints, the annulus fibrosus of the intervertebral disc, the ligaments and the periosteum of the spinal canal

The vertebrogenic pain presents three origins:

- Nociceptive, induced by direct stimulation of nervous branches (receptors) present in the structure involved in the pathology (cortical bones, periosteum, subchondral region)
- Neuropathic, if there is a direct compression of the spinal nerve or nerve root
- By breakthrough (oncology patient)

In the spine, nociceptors are localized in subchondral area, on the periosteum, near ligaments and the facet joints and around the disc; these are activated by direct physical damage or by chemical substances that are released by damaged tissues [25].

The nerves of Luschka (called also recurrent nerves because part of their fibres re-enter the intervertebral foramen) are small meningeal branches (Fig. 1.5) of the spinal nerves that branch near the bifurcation of the anterior and posterior rami; they are divided into two branches, superior and inferior, receiving fibres by the facet joints, the annulus fibrosus of the intervertebral disc, the ligaments and the periosteum of the spinal canal; furthermore Luschka nerves joined a nervous branch coming from the sympathetic chain. They present an anastomotic distribution so that a single nerve provides a sensitive innervation of multiple levels. They are crucial elements in the origin of the spinal pain: any type of mechanical or chemical stimuli that determines a modification of the structures innervated by Luschka nerve is responsible for the local spinal somatic pain [26].

1.5 Neuroradiological Evaluation

Different radiological approaches are available in the clinical practice to evaluate the soft and bony spine structures; X-ray, computed tomography and magnetic resonance present each one a peculiarly recognized role in the neuroradiological diagnosis of spine diseases. Furthermore dynamic studies allow to obtain a complete assessment adding the functional biomechanical parameters to the morphological data.

1.5.1 Dynamic Radiography

Radiographs are acquired in dynamic modality with upright anterior–posterior and true neutral–flexion–extension lateral projections (Fig. 1.6) [27].

The main goal of this approach is to investigate the presence of instability, namely, listhesis; two methods are mainly reported to measure the degree of listhesis [28, 29]:

(a) A baseline is drawn along the upper endplate of the vertebral body; two perpendicular lines are drawn passing through the superior posterior edge of the vertebral body and the posterior inferior edge of the adjacent vertebral body; the distance between the two perpendicular lines represents the degree of listhesis, being significant if > 3 mm
(b) The ratio, in terms of slip percentage, between the sagittal translational displacement and the vertebral body depth, being significant if exceeding 8 % (L1-L5) or 9 % (L5-S1) [27, 29]

It should always be considered that flexion–extension radiographs in the standing position are dependent on patient cooperation, which has challenged the relevance of such images in the evaluation of vertebral instability in the view of some authors [30–32].

1.5.2 Computed Tomography

Computed tomography (CT) is the optimal technique to study the bony structures (Fig. 1.7); it can yield high-resolution reformatting in every

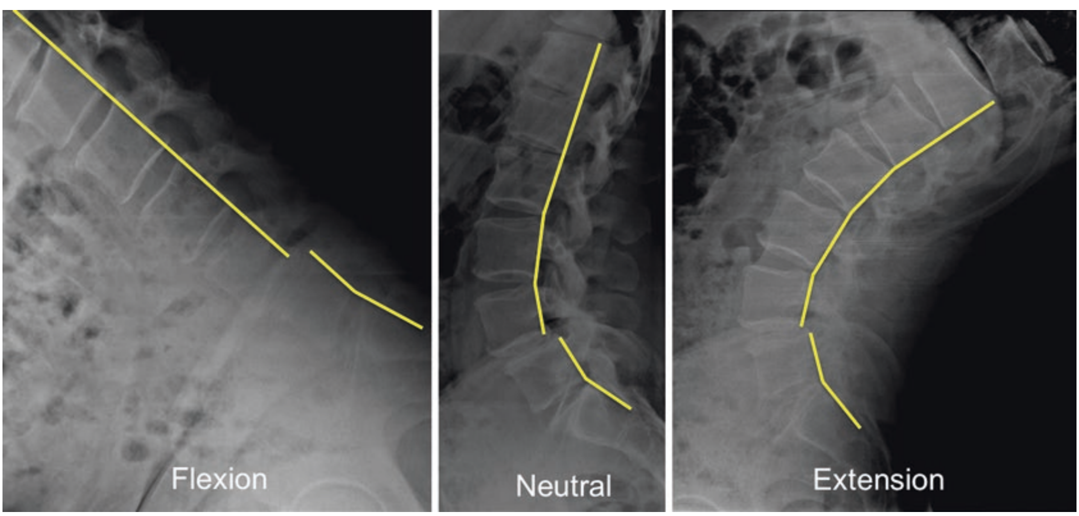

Fig. 1.6 Dynamic radiography of the lumbar spine: upright flexion–neutral–extension lateral projections. Grade I anterolisthesis at L4-L5 level is appreciable (*yellow lines*)

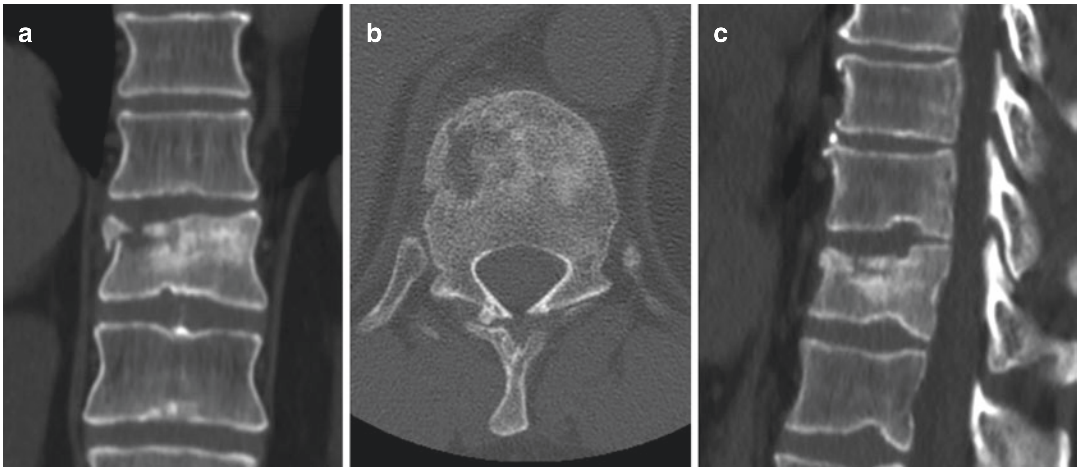

Fig. 1.7 CT of the thoracic spine showing a complete fracture of the upper plate of the soma of D11 with deployment of a fragment of the right antero-lateral portion; coronal (**a**), axial (**b**) and sagittal (**c**) planes

spatial plane starting from isotropic image voxels. Thin fractures are detectable revealing potentially unstable lesions and the spatial position of dislocated bone fragments [33].

CT allows an excellent evaluation of vertebral alignment and the spatial position of dislocated bone fragments, both in the cervical and thoracolumbar districts when conventional radiography failed [34]. This method presents a negative predictive value of 98.9 % for ligamentous lesions and 100 % predictive value for unstable cervical spine injuries, so a normal CT study alone may exclude unstable cervical injuries [35]; in the thoracolumbar district, the sensitivity of CT in detecting fractures reaches 97.2 % [36]. On the other hand, up to two thirds of all unstable fractures are missed by conventional radiographs.

Thanks to the greater accuracy, high speed and reduced patient manipulation, CT is actually the preferred imaging modality in acute multi-trauma patients.

Some authors [37, 38] proposed CT also for studying spine sagittal alignment during axial load in order to simulate the standing loading posture with dedicated compression devices; however compared to other modern techniques, this approach presented relevant limitations and so has been almost abandoned.

1.5.3 Dynamic Magnetic Resonance

Magnetic resonance (MR) imaging is widely used to evaluate various diseases of spine. Conventional MR examinations of the spine are performed in supine position; in this condition the column is in functional rest and so the loading conditions differ from those known to elicit the symptoms in patients affected by spine instability, being exacerbated by upright standing [39, 40].

Various pathologic features, as deformation of the dural sac, nerve root compression, disc bulging, thickening of the ligamentum flavum and/or narrowing of the intervertebral foramen, remain undetected in supine position compared with that observed in the upright standing [41]: pathological findings could be hidden with conventional supine MR. For these reasons, a certain rate of false negative in MR should be taken into account [42].

Dynamic MR (Fig. 1.8) allows to assess spinal biomechanics with detailed soft tissue evaluation using T1- and T2-weighted morphological sequences; images are obtained with patient both supine and upright in the flexed, extended, rotated, standing and bending positions [43]. New appearance of spondylolisthesis is appreciable in up to 9.5 % of the cases.

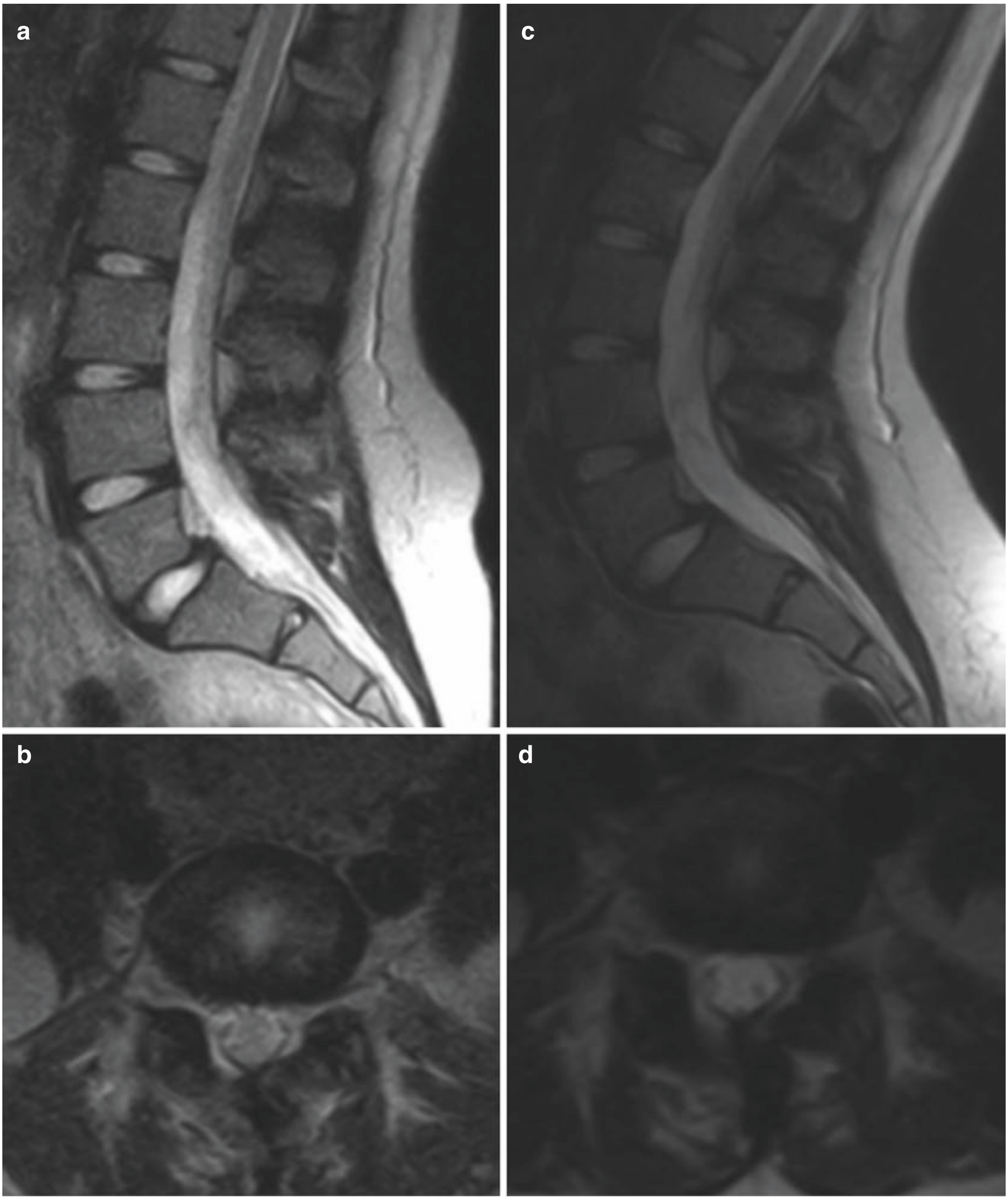

Fig. 1.8 Dynamic MR of the lumbar spine: (**a**, **b**) standard MR scan patient standing supine, sagittal (**a**) and axial (**b**) planes; (**c**, **d**) MR scan patient standing upright, sagittal (**c**) and axial (**d**) planes. c and d show respectively an increase of the lumbar lordotic angle and reduction of the left foraminal space with nerve root compression

Apart from instability assessment, in many cases dynamic MR has proven [39, 42–46] to reveal disc-radicular conflicts not depictable on conventional MR studies; with the passage from supine to upright position, appearance of disc protrusions and spinal canal stenosis is detectable in 11 % and 9.2 % of the cases, respectively. Furthermore in up to 70 % of patients, an increment of disc protrusions and/or spondylolisthesis in the upright position is reported [42].

Overall dynamic MR improves the clinical meaning of image findings offering an optimal linkage of the patient's syndrome with the imaging abnormalities responsible for the clinical presentation [43–46].

However it must be considered that this approach requires long scanning time and is performed with low field magnet (0.25–0.6 T) resulting in a low signal to noise ratio and finally an overall reduced image quality compared to the common high field magnet.

Conclusions

The spine is a complex structure whom integrity depends on multiple anatomical elements that are functionally strictly related to each other. Different pathological processes can modify this biomechanical balance, creating spinal instability and consequent back pain and functional impairment.

Multiple imaging modalities are available in the daily practice to evaluate these anatomical structures; it is essential that an accurate neuroradiological evaluation is performed choosing the best radiological technique case by case.

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2 Principle of RF in Medicine

Dimitrios K. Filippiadis, Argyro Mazioti, Sean Tutton, and Alexis Kelekis

2.1 Introduction

d' Arsonval in 1891 was the first one reporting increase in local temperature when radiofrequency waves pass through [1]. Years later, radiofrequency energy was introduced for the first time to everyday clinical practice in the form of bovie knife which was using variable radiofrequency current for cauterizing and cutting tissues [1]. In 1992 Rossi and McGahan et al. (for liver tumor ablation) and Rosenthal et al. (for osteoid osteoma ablation) used radiofrequency energy for neoplasm destruction [1, 2]. Ever since, radiofrequency has become the most widely used, studied, and evaluated energy form in the field of tumor ablation. In addition to tumor destruction nowadays, radiofrequency energy is also used in neurolysis for pain management.

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2.2 Physics and Principles

The electromagnetic spectrum is a continuous wave spectrum including energy forces with common characteristics differing however in terms of frequency. The electromagnetic spectrum includes radio waves, microwaves, infrared radiation, visible spectrum, ultraviolet radiation, x-rays, and γ-rays in increasing frequency (Fig. 2.1). Energy in the electromagnetic field makes ions and polar molecules, which are charged particles, move. This movement is transmitted to the surrounding molecules through friction transforming thus the electromagnetic into kinetic energy at the molecular level resulting in heat production. Heating causes protein coagulation and subsequent necrosis.

Radiofrequency energy is characterized by a frequency between 3 Hz and 300 GHz. Wave frequency is the main characteristic defining energy – tissue interaction since it characterizes both penetration length (which affects the power distribution) and absorption rate (which affects the heating velocity). At frequencies below the visible light simply by increasing the frequency, the absorption rate of water increases. Due to this absorption, the intensity of the electromagnetic field steeply decreases during crossing electromagnetic tissues. Penetration length is defined as the distance traveled before the intensity of the field decreases to one third of the initial

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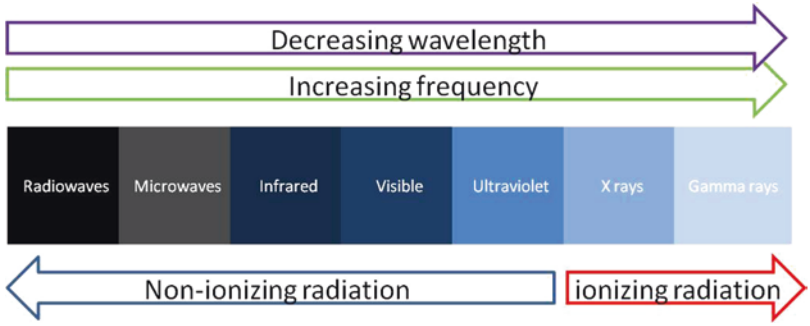

Fig. 2.1 The electromagnetic spectrum is a continuous wave spectrum including energy forces with common characteristics differing however in terms of frequency

value. Absorption rate and penetration length are inversely proportional: a high absorption rate causes a short penetration and vice versa.

In clinical applications radiofrequency energy is applied as a continuous sinusoidal waveform at a frequency between 400 and 500 kHz. The radiofrequency current flows into tissues through the electrode's active tip (which is uninsulated) and causes ions such as sodium, chloride, and potassium to oscillate at a frequency between 400 and 500 kHz. This rapid ionic movement results in friction and subsequent heating with coagulation necrosis as end result. The produced heat is primarily generated in the tissue around the electrode's active tip and is conducted both inward (to the cannula lumen) and outward (creating concentric tissue lesions of lower temperature as the distance increases).

Clinical indications for application of radiofrequency energy include cutting and cauterization in surgical operations, treatment of chronic venous insufficiency, renal denervation, cardiac arrhythmias and Barrett's esophagus, neoplasm destruction (for both benign and malignant cases), and neurolysis for pain management. Radiofrequency energy in clinical applications work through a closed circuit: the radiofrequency electrode acts as the circuit's cathode, and applied ground pads act as the anode with energy being conducted from the generator to the electrode through the tissues to the grounding pads (Fig. 2.2). The electrode's small sectional area results in very high energy flux, while the large cross-sectional area of ground pads disperses and minimizes the energy flux. The electromagnetic field induces ohmic dissipation of the ionic currents resulting in heating. The dissipated power density governs the generated heat amount. This relation is proportional to the square power of the current and to tissue properties (impedance).

Radiofrequency ablation depends upon current intensity, lesion duration, distance from the active tip, as well as electrical and thermal tissue conductivity for increasing the temperature locally. Around the radiofrequency electrode, the heating pattern can be subdivided in three distinct areas (Fig. 2.3):

Active (Direct) Heating Area Here the primary heat source is the energy emitted by the applicator. This is the area with the highest temperatures reached, not affected by heat sinking with very fast and intense heating.

Mixed Area Transition area between the active and passive heating locations with intermediate characteristics.

Passive (Indirect) Heating Area Here the main heat source is the heat conduction from the hot active region. This is the area with the lowest temperatures reached, highly affected by heat sinking with the slowest heating.

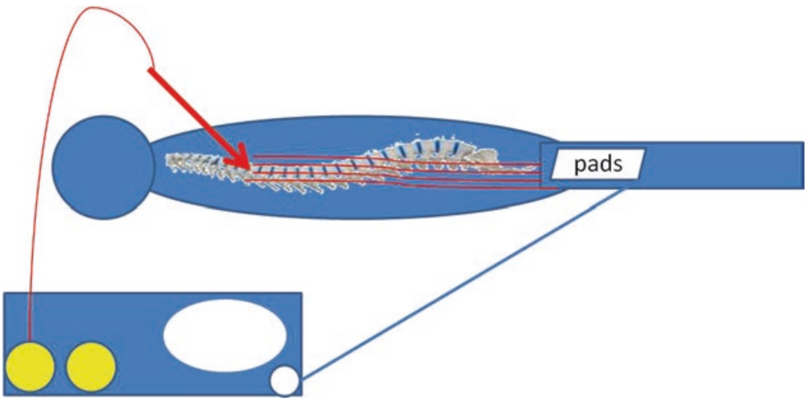

Fig. 2.2 Radiofrequency energy in clinical applications works through a closed circuit: the radiofrequency electrode acts as the circuit's cathode, and applied ground pads act as the anode with energy being conducted from the generator to the electrode through the tissues to the grounding pads

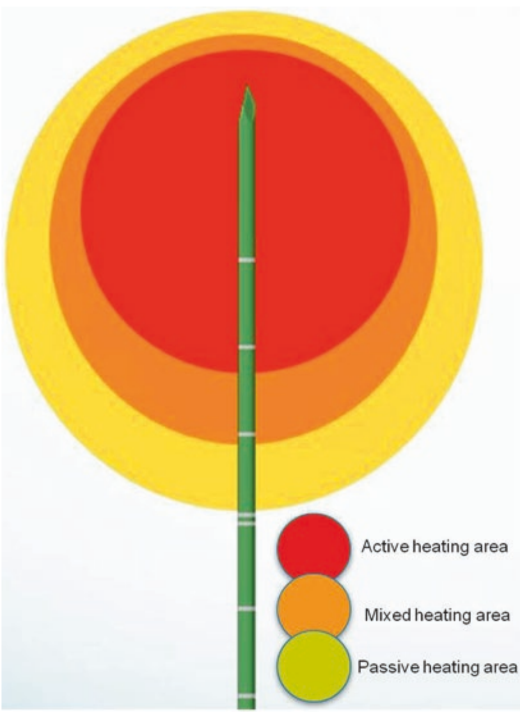

Fig. 2.3 Around the radiofrequency electrode, the heating pattern can be subdivided in three distinct areas: active, mixed, and passive

The properties of the active heating actually set the ablation footprint: the geometry of the necrosis is determined by the power's distribution, while the duration of the ablation is determined by the active heating velocity. Tissue impedance measures the tissue resistance "opposed" to the radiofrequency current circulation and is governed by the tissue hydratation.

Temperature increase is lethal for mammalian tissue. Exposure to 50 °C for 1 h results in cell death; exposure to 60 °C results in immediate cell death [3]. At 100 °C death is instantaneous; evaporation (with micro-bubbles formation) and charring occur immediately. The desiccated tissue acts as insulation preventing further energy conduction and thus limiting tissue destruction. In order for achieving large ablation volumes and extensive tissue destruction, time is equally important to tissue conductivity. The objective is to heat the tissue in temperatures between 50 °C and <100 °C for 4–6 min without causing charring and tissue vaporization [3].

Apart from charring and tissue vaporization, "heat sink" effect limits the effectiveness of radiofrequency ablation. When the target lies close to a vessel with diameter>3 mm, blood flow "cools down" the tissue during ablation preventing production of lethal temperatures. The potential result is viable residual tumor tissue near the vessel wall. Successful ablation is governed by coagulation necrosis extent which depends upon deposited energy; the latter is governed by local tissue interactivity minus heat lost.

This has been expressed by Goldberg and Depuy in the form of the following equation:

$$\text{Induced coagulation necrosis} = \left(\text{deposited energy} \times \text{local tissue interactivity}\right) - \text{heat loss}\ [4].$$

2.3 Tools and Instruments

A radiofrequency ablation system consists of a generator and the applicator which is the electrode.

2.3.1 Generators

Almost all generators have internally two terminals; one for high voltage output in order to apply radiofrequency current to a tissue target through the electrode's active tip and another one serving as the applied current's return pathway. Generators act as a single energy source, but radiofrequency energy can be directed in quick succession to multiple active tips of different electrodes. Nowadays generators produce output of 150–200 W delivering high frequency alternating current through the radiofrequency electrode. Most of these generators have maximum power delivery between 50 and 100Ω; outside this range the power delivery decreases steeply. Different vendors have different algorithms for energy deposition with different ablation end points (Fig. 2.4). According to these algorithms, the energy is deposited in the tissues in such way in order to delay carbonization as much as possible.

Especially in the field of pain management, generators can generate multiple RF lesions which are independent and monopolar with the current flowing between the bare tip of each cannula through a common return pathway on the skin. Additionally there is the ability to set different temperature levels at these different channels with the lesions either starting at the same time or having staggered starts. Furthermore these lesions can be either individually stopped or all together at the same time. An advance in the pain reduction field is the quadrupolar radiofrequency lesion output produced by providing output to the equally spaced and parallel electrodes in a simultaneous and equal mode [5]. This process differs from the use of multiple RF cannulae in a monopolar mode in that no reference electrode is used and all current is limited to flow between the probes. Quadrupolar radiofrequency output results in a long and continuous strip lesion.

Fig. 2.4 The AMICA radiofrequency ablation system (Courtesy of HS Hospital Service S.p.A.)

2.3.2 Electrodes

Radiofrequency ablation electrodes consist of a metallic needle ending with a cutting tip, an electric insulator deployed over most of the electrode shaft and an active tip (i.e., the exposed tip which is the portion not covered by the insulator). The length and maximum diameter of the ablation zone are approximately equal to the length of the exposed tip with the ablation zone extending only a few mm in front of the electrode's tip. With present technology, radiofrequency electrodes vary from 10 to 20 cm in length and 16–20 G in diameter. By increasing the length of the electrode, there is increase in both the ablation zone's length and width; by increasing the electrode's diameter, there is an increase mainly in the ablation zone's width [1]. In the market there are different electrode types that can be used during radiofrequency ablation. In general there are two major large categories: monopolar and bipolar electrodes. In bipolar radiofrequency electrodes, the applied current runs from one pole to the other without the need for padding. The resultant shape from bipolar

Fig. 2.5 The STAR Tumor Ablation System consists of the MetaSTAR generator and the SpineSTAR ablation instrument (Courtesy of DFINE, Inc.)

electrodes is a more or less rounded-corner rectangle ablation zone. As far as monopolar electrodes are concerned, subtypes include single active tip electrodes which can be standard or internally cooled as well as perfusion electrodes; additionally multi-tined expandable electrode arrays (umbrella-like) can be found in the market.

Internally Cooled Electrodes In this device chilled saline is pumped through the chamber shaft of the electrode reducing thus charring and impedance and draining excess heat.

Perfusion Electrodes Based on the concept that high local sodium chloride ion concentration augments radiofrequency ablation and increases the ablation volume, perfusion electrodes can inject during ablation saline into the tumor in order to replace the water lost due to evaporation.

Multi-tined Expandable Electrode Arrays By deploying expandable multiple tines in the target tissue, the current is distributed, minimizing its concentration at the probe tip.

The resultant shape from monopolar electrodes is a more or less elliptically shaped ablation zone abutting the electrode's distal end.

Radiofrequency ablation in the spine, due to the unique anatomy, requires a reproducible, successful, and safe procedure [6, 7]. Specifically for the spine and the treatments of vertebral metastasis, there are in the market sets containing needle trocar (for vertebral access), bipolar radiofrequency electrode (for ablation) with thermocouples (for temperature measurement close to neural structures and inside spinal canal), and injectors for cement augmentation (vertebroplasty). These sets provide one step single treatment including ablation of the lesion combined to augmentation, achieving significant pain reduction, mobility improvement, and local tumor control (Figs. 2.5 and 2.6). Specific systems use a bipolar, articulating electrode that has an extensible, beveled tip that enables access and navigation to the posterior lesions in the vertebral body. Retracted during insertion to assist in navigation, the articulating electrode is extended once in desired location to assist in energy dispersment. Additionally multiple thermocouples are embedded in the articulating segment in order to enable real-time assessment of the tissue temperatures at the posterior edge of the ablation zone continuously monitoring the temperature in order to minimize patient risk. The maximum ablation zone crated in the spine with these systems is around 2X3 cm. Another advantage of such therapies is that patients can continue their current systemic treatment without interruption.

Fig. 2.6 The OsteoCool RF spinal tumor ablation system (Courtesy of Medtronic)

Additionally in the spine there are a number of techniques for radiofrequency ablation of sensory input and joint denervation aiming in pain reduction (Fig. 2.7). Positioning of the cannula is performed under imaging guidance (fluoroscopy, ultrasound, CT, or MR). Correct cannula positioning is verified with electrical stimulation prior to ablation. Electrical stimulation is always monopolar performed at one location at a time with the electrical stimulus being applied at the target site through the electrode's active tip and return path through the ground pads on skin surface. During this stimulation the density of the current is very high at the electrode's active tip and very low at the return pathway; in other words the response occurs only at the active tip level [5]. Prior to neurolysis there are two stimulation types performed:

1. Sensory stimulus: high frequency repetition rate (50 Hz cycles/s) in a duration of 1 ms with a threshold voltage of 0.2–0.5 V [5]
2. Motor stimulus: low frequency repetition rate (2 Hz cycles/s) in a duration of 1 ms with a threshold myotomal voltage of at least 2 V [5]

Fig. 2.7 The Diros RF system for pain management (Courtesy of Diros Technology Inc.)

In sensory stimulus the expected threshold voltage depends upon the length and diameter of the electrode's active tip. In a successful electrical sensory stimulation, the response's location should be concordant with the distribution of the patient's usual pain. As far as motor stimulus is concerned, there should be no motor response in a threshold below 2.0 V. Sensory testing prior to ablation seems to increase efficacy of the technique; on the other hand, motor testing prior to ablation is advised for safety increase.

Conclusion

During radiofrequency ablation, a closed circuit is created including the generator, the electrode (acting as the cathode), and the dispersing ground pads. The energy deposition and the temperature are exponentially decreased in relation to the distance from the electrode. Radiofrequency ablation is the most frequently used and most extensively studied ablation technique with the longest track record. The technique can be used for both tumor destruction and for neurolysis in pain management.

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Causes of Chronic Low Back Pain

3

Luigi Manfrè

There is probably no other disease as *chronic low back pain (LBP)* that has generated a so large amount of literature about, and it is impossible to concentrate all the causes of a so common and diffuse disease. For this reason, we will analyze the most frequent causes as useful as for the main topic of this book, as different causes of LBP generate different treatments. A correct investigation of the correlation between local degenerative changes at the level of the disc and for facet joints and nerves is hard as it's difficult to obtain complete characterization of the pain (too much variables generating LBP) as well as the possibility to have disc or articular normal samples from a control healthy population. Mice models have been suggested, in a specific population with the secreted protein, acidic, rich in cysteine (SPARC) deficit, this protein being involved in regulating the composition of extracellular matrix. As a consequence, the population of SPARC-null mice usually suffer from an increased disc degeneration, and recent studies suggest the internal disc disruption to be one of the main causes of axial LBP, while no effect has been found about sciatica generation [1].

LBP is one of the most widespread and common diseases, definitely among the first causes of disability affecting working people (in the USA, approximately 149 million days of work/year lost, the total cost being estimated in 100–200 billion USD), and one of the most common causes of hospitalization (second only to upper respiratory system diseases) [2]. The 2010 Global Burden of Disease Study considers LBP one of the ten diseases occurring worldwide [3], the forecast being even worst considering global increase in age of population. It is the fifth common reason for all medical visits in the USA [4, 5].

The incidence of LBP has been documented in 50 % of people having light physical activity and in more than 70 % of those performing heavy activities and is the most frequent cause of cessation of activity in patients younger than 45 years old, even if only 7–8 % of patients with LBP have symptoms persisting over 2 weeks and just 1 % need a real treatment: among them symptoms usually improve rapidly in 1 month [6], 1/3 of them having – on the contrary – a persistent moderate to severe LBP after 1 year [7].

Prevalence of LBP is considered among 60–70 % in European and US countries, with a recent increase even in younger population and a peak at 35–55 years of age [8–11]. The dramatic social cost of LBP, together with the increasing number of population suffering from, explains the industry effort in discovering and inventing new therapeutic strategies as minimal invasive chem-

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ical and physical treatment, new biomaterials, stem cell therapies, and disc regenerative growth factors.

While the etiology of chronic low back pain remains generally unknown or nonspecific (up to 85 %), there are several known causes of LBP syndrome (i.e., different from LBP) as age, psychosocial aspects (depression, stress, stop working), education (increasing LBP in low-educational status) [4], stress overload (heavy working or sport activities), smoking (the nicotine being a vascular degeneration agent reducing physiological disc nutrition), even genetic cause (74 % heritability in twins), and obesity (body mass index of more than 30 kg/m2) [12]. Obesity in early adult age definitely increases the risk of nonspecific LBP as well as degenerative changes in lumbar spine [13].

Pure LBP conversely is generally related to pathologic degeneration of several structures involved in the spinal unit, as lumbar intervertebral discs, facet joints, fascia, sacroiliac joints, ligaments, nerve root, and muscles [14].

Discogenic low back pain (DLBP) is the leading cause of LBP. Discogenic pain is generally speaking an inflammatory pain, as inflammatory components as prostaglandins have been documented inside degenerated disc, explaining the efficacy of intradiscal steroid injection [15, 16]. Moreover, stimulation of peridiscal nerve plexus widely contributes to disc pain generation. Though discography has been used in the past as gold standard in proving the existence of a discogenic pain, actually simple intradiscal injection of sterile solution is used too [17].

One of the main causes of low back pain is definitely axial *spinal instability*. Spinal instability is one of the hardest questions to define from a clinical and neuroradiological point of view, as abnormal axial movement can be incidentally discovered in fully asymptomatic patients and spinal instability symptoms can be conversely detected in patients with no neuroradiological signs of instability. Spinal instability can be considered the loss of functional spine unit (FSU) stability, resulting in increased mobility, less elasticity, and abnormal motion. Punjabi and coworkers defined spinal instability as “the loss of spine’s ability to maintain its pattern of displacement under physiologic loads” [18]. The spinal physiologic load is well known from numerous experimental data, demonstrating the reduced ability of instable spine counterbalancing the load (normal spine resists up to 12,000 N load, instable spine 100 N only) [19]. Degenerative segmental axial instability can be related to local degenerative disease (primary instability) as for progressive degenerative scoliosis, disc degeneration, axial rotation, listhesis, or acquired or secondary instability, as for post-disc excision, decompressive laminectomy, fusion techniques, pseudoarthrosis, and disc disruption with chemical or physical agents.

Neuroradiological demonstration of instability of the spine using conventional radiological findings did not undergo significant progress in the past decades, as Nachemson was used to say in the 1960s that spinal instability was “an unproved label for back pain patients” [20]. This apparent impotence of radiology still continued in modern times as the most of the examinations occurs the patients laying supine on the cradle, while the pain is generated by stand-up position only.

Nevertheless, there are several indirect signs on CT and MRU examination, suggesting a focal FSU instability as asymmetrical orientation and/or bone sclerosis of facet joints related to chronic bone remodeling for asymmetrical load, intersomatic space reduction, asymmetric paravertebral muscles trophism, and mild vertebral anterolisthesis (Fig. 3.1a–e).

More recent dynamic CT [21] and MRI studies [22] proved occult instability to be one of the most popular causes of LBP in apparently normal conventional neuroradiological studies (Fig. 3.2).

Directly connected to disc degeneration is the *chronic facet joint syndrome* (CFJS): the asymmetrical spinal load at the level of facet joints is the main cause of pathological degeneration of the joint cartilage, as well as bone remodeling [23].

Facet joint disease, generally related to chronic arthritis and/or segmental degeneration, remains one of the most common causes of chronic lumbar pain both in young and elderly patients. The mechanism of facet joint syndrome pain is both related to mechanical and inflammatory damage

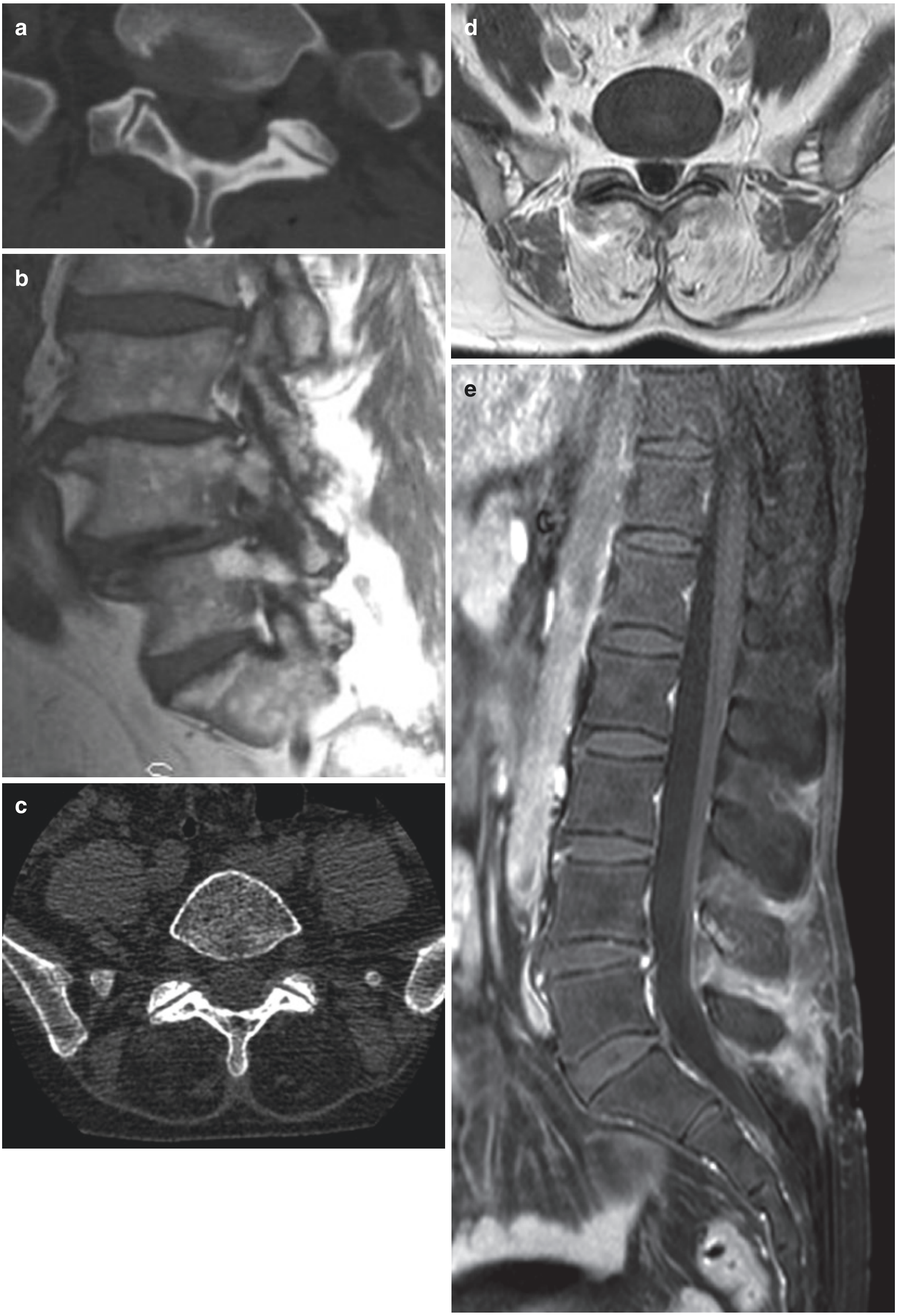

Fig. 3.1 Some indirect sign of chronic spinal unit instability. Asymmetrical orientation of facet joint related to bone remodeling (**a**), fatty degeneration of the vertebral pedicles (**b**), abnormal paravertebral muscles atrophic degeneration (**c**, **d**), signal enhancement of interspinous ligaments (**e**)

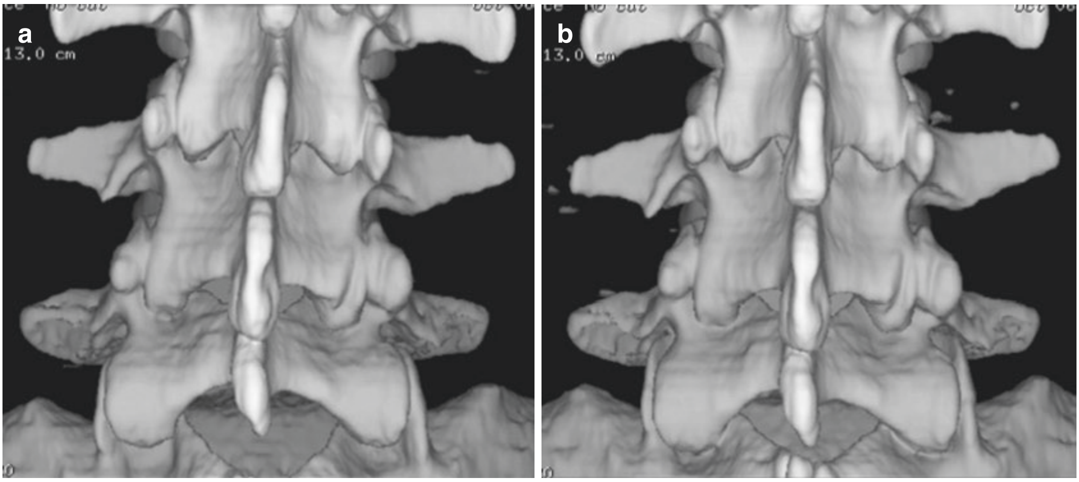

Fig. 3.2 Occult facet joint instability demonstrated on axial-loaded CT scan (courtesy of R. Cartolari). On 3D preload image, normal aspect of L5/S1 facet joint (**a**). After axial load, because of sagittalization, abnormal cranial dislocation of superior S1 facets can be appreciated, disconnected from normal articular contact with L5 (**b**)

of the facets, both concurring in generating local painful arthritis [24].

Medial branches of the dorsal rami are responsible for facet joint innervation [25]. Anatomical studies demonstrated the presence of "free and encapsulated nerve endings in lumbar facet joints." Moreover, P-substance and calcitonin-related peptide have been discovered in facets, as additional cause of local pain [26, 27].

A frequent (5–25 % of all LBP causes) [28–31] and frequently misunderstood cause of LBP in adult males, and particularly females, is *chronic sacroiliac joint arthritis* secondary to acquired focal instability. The sacroiliac joint (SIJ) is the strongest and richest joint in human body as for ligaments (anterior sacroiliac, interosseous, sacrospinous, and sacrotuberous) and muscles (gluteus maximus, piriformis, and biceps femoris) concur to stabilize the joint [32]. Despite the great stability of this joint, there are several conditions that can reduce the stability of SIJ, generating chronic pain in a patient. SIJ ligaments are weaker in female patients as they are estrogen dependent, preparing the sacrum to the delivery nutation: as a consequence, postpartum chronic pain at the level of the sacrum can occur even after months after the delivery [33]. Another frequent cause of SI chronic pain is biomechanical changes in lumbar spinal unit mobility, as a consequence of surgical procedures like posterior interbody fixation (PIF) – generally performed in case of lumbar instability but conversely generating sacral instability: it has been calculated that 75 % of patients underwent PIF treatment suffer from painful SIJ instability in 5 years [34, 35]. Clinical symptoms related to SIJ disease are numerous, and no specific clinical sign supports the diagnosis. This uncommon uselessness of clinical symptoms analysis is related to the complexity of SIJ innervation, as the posterior surface of the joint receives collaterals from L3 to S4 dorsal rami [36] while anterior articulation is supplied by L2 to S2 nerves [37, 38]. Consequently, SIJ syndrome is responsible for pain referred in several different areas of the body, as the lower limbs, pelvis, coxofemoral area, buttock, and abdomen, overlaying other common causes of radicular pain. Even if several physical maneuvers are suggested to evocate the pain and propose a SIJ disease, diagnosis and neuroradiological examinations (MRI, bone scanning) – inserire immagini – can show focal SIJ abnormalities proposing a SIJ syndrome, only diagnostic block of the SIJ injecting intra-articular anesthetics (lidocaine) is considered the gold standard method to confirm the disease [39].

Finally, *after-surgery LBP*, usually known as *failed back surgery syndrome (FBSS)*, is one of the most frequent causes of back pain in patient underwent surgical treatment, the etiology being controversial and complex. Epidural fibrosis is generally considered one of the most common causes of LBP after surgery, with patients having extensive epidural scars having 3.2 more frequent LBP and radicular pain that those with mild epidural fibrosis [40]. Moreover, epidural scars are responsible for neurological impairment demonstrated by electrophysiology and nerve root tethering as well as nerve inflammation induced by high local cytokines, and other inflammatory agent level has been described [41, 42]. In FBSS, the pain moves from a mechanic/inflammatory origin through a *neuropathic pain*: patients affected by it suffer from an increased sensitivity and responsiveness of receptors that generate an amplified reaction to mild algogenous stimuli ("hyperalgesia") and/or misinterpretation of stimuli coming from non-nociceptive receptors ("allodynia"), generally related to abnormal activation of nonneuronal cells as microglia, together with changes in local pain neurotransmitter molecules, increasing pain feeling [43].

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RF for Treatment of Cervical Disk Herniation

4

Giuseppe Bonaldi

4.1 Introduction

Open surgical diskectomy has long been the treatment of choice for lumbar and cervical herniated nucleus pulposus. Although considered a well-established, highly successful procedure, it possesses the usual drawbacks of almost any surgical intervention, including damage to the bone and muscle; risk of nervous, parenchymal, and vascular lesions; and a potentially long postoperative recovery. Consequently, psychological acceptance of cervical disk open surgery by most prospective patients is low. Surgical techniques entailing an interbody fusion are also burdened by the longer-term risk of stress overload, chronic damage to the adjacent disks, and other complications [1–5]. For these reasons, a number of minimally invasive intradiskal methods for treating cervical disk herniation, most commonly involving mechanical or energy-based removal of some portion of the nucleus pulposus, have been developed over the last decades, since the early nineties [6–15].

4.2 Historical Perspective

In 1963, Lyman Smith, an orthopedic surgeon in Chicago, first described a minimally invasive attempt to treat sciatica through a percutaneous injection of chymopapain in the disk, with intent of achieving enzymatic chemolysis of the nucleus pulposus and of its protruding fragments compressing the nerve root [16–18].

Hijikata et al. [19, 20] described percutaneous nucleotomy for disk herniation, a technique later advocated by other workers [21–25]. The technique involves manual removal of the nucleus pulposus by means of forceps of different sizes.

In 1985, Onik et al. [26–28] introduced "automated" percutaneous diskectomy, using a mechanical probe with a vacuum generator (Nucleotome, Surgical Dynamics, Alameda, California, now Clarus Medical, LLC, Minneapolis, MN), which removes the nucleus pulposus by means of a "suction and cutting" action. The main advantages are clinical results similar to manual percutaneous procedures, with a lower degree of invasiveness [29–34]. Later on many other percutaneous techniques have been proposed, entailing removal of the nucleus pulposus with different types of instruments or different types of energy (radiofrequency, laser, coblation, etc.) for the reduction of pressures exerted by the protruding components of the disk on the neural structures. Among them are worth mentioning: the Dekompressor, proposed by the

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Stryker Company in 2003, is a single-use probe, introduced through a 15-mm cannula, intended for percutaneous diskectomy in the lumbar, thoracic, and cervical spine. The probe utilizes an Archimedes pump principle to remove nucleus material from the disk.

The SpineJet probe, produced by HydroCision (North Billerica, MA), utilizes a hydraulic aspiration principle similar to that of Onik's probe.

The Disc-FX diskectomy system is proposed by Elliquence, LLC, New York (formerly Ellman Innovations, LLC). It works in bipolar mode at 1.7 MHz. In particular, the bipolar Trigger-Flex probe is used to obtain a radiowave energy application both for removal of nucleus material and a modulation of weak collagen fibrils and sealing of annular tears (shrinking or eliminating defects in the annulus) as well as contributing to depopulating nerve fibers sensitizing the outer annulus due to its smooth thermal effect. This RF-based system was never proposed for use in the cervical spine (a cervical probe is announced for the end of the year 2016).

Percutaneous laser disk decompression (PLDD) was introduced by Choy et al. [35–38] in 1986. By 2002, more than 35,000 PLDDs had been performed [39]. Advantages of the laser diskectomy are the tiny access port, the tiniest among the different percutaneous diskectomy modalities. For the diode laser, the size of the optic fiber is as small as 220 μm. Many observational studies report on the laser disk decompression results, but no RCTs are available [40].

4.3 Coblation Technology

Coblation, or plasma RF-based diskectomy, with commercial name nucleoplasty (ArthroCare, Sunnyvale, CA, now Smith & Nephew), was approved for general use in 1999 and initially used to treat symptomatic contained protrusion in the lumbar spine. It is a controlled, non-heat-driven process, which uses radiofrequency energy to excite the electrolytes in a conductive medium. It is conducted by using a bipolar radiofrequency-based device, which functions via a plasma-mediated process [41–43], to perform precise removal of disk tissue. In this process, bipolar voltage pulses at 100 kHz are applied to the active electrode at the distal end of the device, which produces a strong electric field region around the electrode. The electrolytes in the surrounding conductive medium (e.g., sodium ions resident within the nucleus pulposus) respond to the electric fields, and if the voltage is sufficiently large, a localized finely focused plasma field (ionized vapor) is produced between the electrode and adjacent tissue [44, 45]. The plasma field (a layer of only 100–200 μm thick) around the active electrode comprises a complex mixture of gas-phase radical chemically reactive and nonreactive molecules and a very small fraction of ionized particles (predominately positive ions and electrons), some of which can break molecular bonds in the adjacent tissue by energetic particle bombardment and chemical reactions. The organic molecules in the disk material (particularly long-chain molecules such as collagen) are thought to be susceptible to fragmentation by the plasma particles, resulting in their conversion into liquid and gaseous products that are subsequently desorbed from the targeted site. Water molecules (which compose a significant fraction of most types of tissue) can be fragmented into excited and ground-state hydroxyl radicals and hydrogen atoms. Both of these species are chemically active and can cleave long-chain molecules (e.g., collagen) into smaller fragments that are either more easily liquefied or gasified. Moreover, electrons emitted from the electrodes at the distal end of the device when the voltage is applied can develop sufficiently high energies not only to cause the water molecules to fragment but also to directly dissociate the chemical bonds in the nearby targeted tissue structures (in this case disk tissue) into smaller fragments [43]. The net result is a reduction of soft tissue volume and effective excision of the soft tissues within the nucleus.

The plasma radiofrequency-based process has been reported to have minimal histopathological effect on tissues immediately adjacent to the treated site [44, 45], particularly annulus, end plates, neural elements, and nerve roots [45]. Because radiofrequency current does not pass directly through tissue during the coblation process, tissue heating

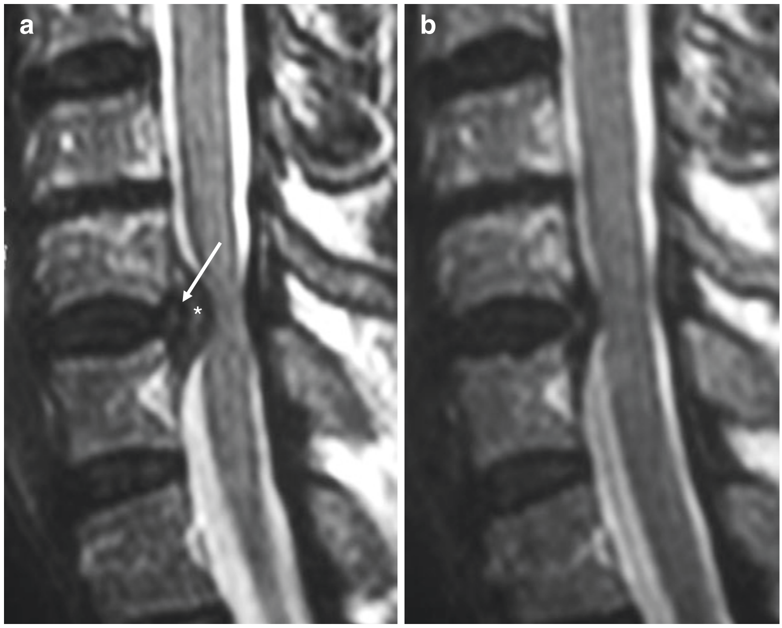

Fig. 4.1 (**a**) A 58-year-old female patient. Magnetic resonance imaging shows a contained central disk (C5–C6) herniation. Compression of the spinal cord is also due to a heavy inflammatory reaction swelling the epidural space (*asterisk*). In (**b**) imaging follow-up at 6-month post-coblation shows almost complete regression of both herniation and inflammatory epidural reaction; spinal cord is no longer compressed; patient is totally asymptomatic

is minimal. Most of the heat is consumed in the plasma layer or, in other words, by the ionization process. The temperature is kept below 70 °C (typically between 40 °C and 70 °C) to minimize tissue damage and avoid tissue charring.

Because of the mechanism of action on hydrated nuclear components, tissue ablation and consequently intradiskal decompression are supposedly higher in younger patients and in hydrated, nonadvancedly degenerated disks [44]. Actually, an exclusion criterion for lumbar nucleoplasty must be considered a disk height less than 50 % [46].

Action of coblation on disk tissues and nuclear herniations seems not only mechanical (in terms of tissue removal and intradiskal pressure reduction) but also chemical. Symptoms of herniations are not only a consequence of pressure against the nerve roots, since inflammation may well be a major mechanism in the pathophysiology of radicular pain, mainly as a result of injury or exposure of nervous tissue to nucleus pulposus material [47]. Alterations in cytokine expression potentially associated with the mechanism of pain relief have been observed after plasma radiofrequency-based diskectomy [48]. Moreover, coblation appears to effectively degrade the PLA2 activity in the degenerative intervertebral disks in an animal model, and also this might contribute to reduction of inflammation and thus represent a potential mechanism of action of coblation in relieving symptoms of disk herniations [49]. Thus we could speculate that the final clinical effect of coblation is partially due to reduction of inflammatory response, never observed after mechanical nucleotomy in our experience. This anti-inflammatory mode of action, stimulated by the plasma radiofrequency-based treatment, would be similar to that proposed with treatment of other chronic pathology [50] (Fig. 4.1).

4.4 Indications

Percutaneous decompression of disks has been shown effective in relieving radicular pain and to a lesser extent axial pain from contained disk protrusions. Patient selection criteria include the presence of a contained disk herniation documented by spinal imaging, causing radicular pain greater than axial pain. We do not treat patients for neck pain alone. Usually patients complain of cervical and upper limb pain, in most cases radiating down to the hand and often to the scapular, occipital, or auricular regions. Pain is most of the times accompanied by paresthesias radiating to

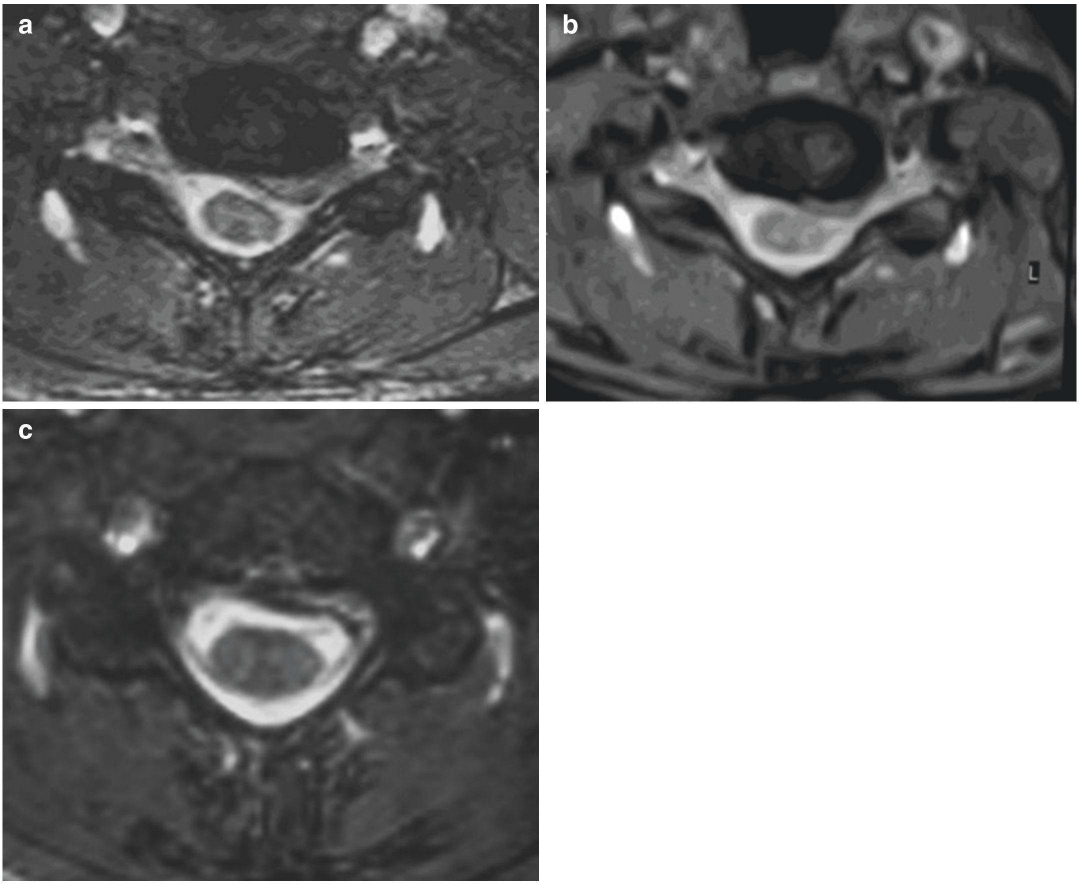

Fig. 4.2 (**a**) Magnetic resonance imaging at baseline for a 34-year-old female patient who underwent percutaneous plasma radiofrequency-based diskectomy for a disk (C6–C7) herniation compressing the spinal cord and causing clinical signs of myelopathy. (**b**) A 7-week MR follow-up shows regression of both herniation and cord compression; the patient is almost asymptomatic. (**c**) An MR 9-month follow-up shows almost complete regression of the disc herniation; the patient is completely asymptomatic

the upper limb and hand. Preoperative clinical evaluation includes a neurologic examination, at which radicular deficits may be present, such as hyposthenia, hypoesthesia, dysesthesias, or hyporeflexia consistent with the radicular level compressed by the herniation. Also mild to moderate hypotropia of the muscular territory involved may be observed. Signs of moderate myelopathy, such as lower limb hyposthenia with pyramidal signs and sensory disturbances, do not contraindicate the treatment Fig. 4.2.

Disk herniations are known to have a tendency to self-heal. Spontaneous regression of herniated lumbar disks in the lumbar region is well established [51, 52], but the same phenomenon is increasingly observed in cervical disks as well [53–56]. For this reason the patient must have failed conservative measures, including anti-inflammatory and analgesic medications and physical therapy, for at least 2 months or longer.

Imaging and clinical correlation is of utmost importance. The success of the procedure depends greatly on selecting the lesions to treat: the protruding nucleus pulposus must be at least partially contained by the external fibers of the disk, without a large extrusion or migrated fragments [57, 58]. Thus patients receiving plasma radiofrequency-based disk decompression may carry a bulging, protruding, or extruded disk, which is not sequestered or migrated, compressing the exiting nerve root, thecal sac, or spinal cord. To this purpose, all patients must undergo preoperative both CT and MR studies of the cervical spine, the latter for its much higher diagnostic value, in terms of both herniation visualization and clear definition, and also of evaluation of its effects on neural tissue. CT must essentially rule out large osteophytes and/or large calcifications of the herniation itself, conditions that contraindicate coblation.

The disk should have maintained at least 50 % of its height on imaging studies. Disks with more advanced degrees of degeneration are more difficult to access and are less likely to achieve much further pressure reduction [44].

Given the low morbidity and invasiveness of the procedure, it can be offered to a wider range of patients, such as the ones with partially uncontained prolapses, as an attempt to avoid surgery, or when the risks of open surgery are higher because of age, general medical conditions, or other contraindications. This typically applies to patients who have already undergone open surgery at the same or, more frequently, at a different disk level and to elderly people. In these cases the patient must be disclosed the lesser likelihood of clinical success of the procedure.

4.5 Anatomical Considerations

The day before the procedure, we perform a preoperative sonographic study of the neck to determine whether any normal or pathologic structures residing near the surgical pathway are in a position to increase risk for complications [8, 59]. We also previously described [8] intraoperative use of sonography for percutaneous cervical decompression, and such technique helped us in understanding the behavior of local anatomical structures during the surgical maneuvers.

In the anterolateral area of the cervical region, several major anatomical structures deserve attention during percutaneous diskectomy. The trachea and esophagus are well depicted with sonography: we verified that they are easily displaced from the midline by even mild pressure and consequently most of the initial worries regarding esophageal puncture, with possible diskitis or mediastinitis, decreased. Similar remarks apply to the neurovascular bundle (carotid artery, vagus nerve, and jugular vein); this can be detected easily with sonography and is easily palpable and thus readily displaced laterally, while being protected by the operators' left fingers.

The sympathetic chain lies posterolateral to the anterior convexity of cervical disks, so it cannot be involved by the trajectory of the devices. Several upper cervical nerves describe anteriorly concave loops related to mobility of the head, the lingual, IXth, and XIIth nerves, among them. The lowest of these loops goes down to the C3–C4 level: the superior laryngeal nerve, pointing toward the larynx between the hyoid bone and the thyroid gland. When we perform a procedure on the C3–C4 disk (although in rare cases), the superior laryngeal nerve is easily shifted beyond the midline together with all the neighboring anatomical structures (particularly the hyoid bone) and so removed from the surgical trajectory. The hypoglossal nerve loop is close to the neurovascular bundle, so that the remarks about carotid arteries also apply here.

A consideration of which structures most hinder cervical disk puncture should begin with the thyroid gland. Its isthmus lies roughly at the C6–C7 level, while the lobes extend upward for the height of two vertebral bodies, diverging from the midline. The gland is surrounded by a rich venous network and has superior and inferior vascular pedicles. While a venous injury can be treated by compression, puncture of the thyroid arteries should be avoided. The superior one arises from the external carotid artery and joins the superior vein to form the superior vascular pedicle, while the inferior, coming from the thyrocervical trunk of the subclavian artery, runs medially and reaches the inferior pole of the gland separately from the vertically running veins. The superior vascular bundle can be displaced from the midline by the hand displacing the carotid artery, as can be confirmed by color Doppler. This maneuver creates a space between thyroid gland and trachea through which the probe can easily be inserted; while operating at the upper disks (C3–C4, C4–C5), the superior lobe of the gland, which lies far from the midline,

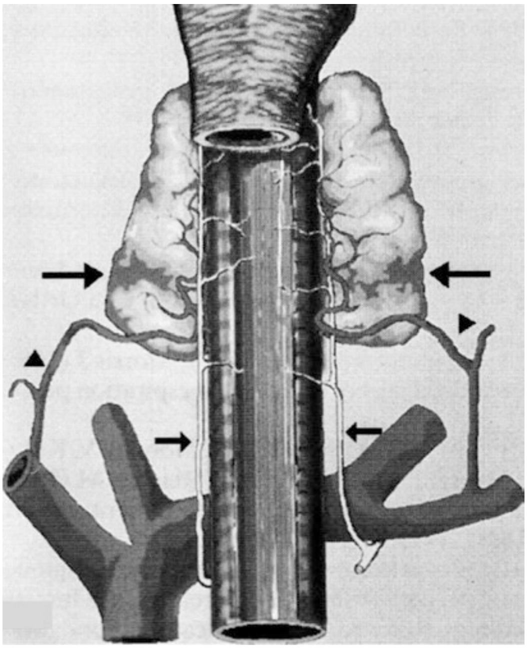

Fig. 4.3 Posterior view of the anatomical relationships in the neck: recurrent laryngeal nerves (*small arrows*) and inferior thyroid arteries (*arrowheads*) cross at the inferior pole of the thyroid gland (*large arrows*)

is displaced laterally and the instrument passes medial to it. The middle part of the thyroid gland is less mobile and closer to the midline but probably can safely be needled and probed because of the absence of important arteries. The inferior third of the gland cannot be pulled far laterally because of the isthmus; insertion of instruments lateral to it is risky, since the inferior thyroid artery crosses the inferior pole of the gland, running medially from the subclavian artery, and therefore lies at its lateral margin.

Near the inferior third of the thyroid lies another high-risk structure, the inferior (recurrent) laryngeal nerve, which originates from the vagus nerve in the upper thorax and runs along the trachea up to the inferior third of the thyroid, where it crosses the inferior thyroid artery Fig. 4.3. The inferior laryngeal nerve, injury to which causes a vocal cord paralysis, is detectable by sonography in a high percentage of cases [60], even in unfavorable intraoperative conditions; moreover, individual variations in the position of the nerve are exceedingly rare [59]. The considerable mobility of the inferior laryngeal nerve makes displacement from the trajectory of the instruments during manual displacement of the carotid artery and trachea probable. For these reasons, in our opinion, there is a "blind zone" at the inferior third of the thyroid gland, in which percutaneous approach to the intervertebral disk must be carefully considered. This zone is easily defined preoperatively by sonography; 3D-CT surface reconstruction of the neck may help preoperative planning by delineating the relationships between disks, vascular structures, and thyroid gland. The disk space most often related to the "shadow" of the inferior third of the thyroid gland is C6–C7. Yet we think that the protection of the nerve can be significantly increased by dilatation of soft tissues performed with coaxial mandrel with a trocar tip (see ahead), instead of a sharp needle. This mandrel does not have a sharp cutting effect, and structures are more likely to be deflected rather than resected. This feature limits the risk of vessel or nerve injuries. The use of intraoperative sonography can also help reduce the risks and rule out dangerous structures on the trajectory of the devices.

No significant risks for the spinal cord or nerve roots are posed by the procedure: the anterolateral approach does not involve crossing nerve roots, as in the lumbar spine, and this fact would permit performance of the procedure under general anesthesia. Fluoroscopic and/or CT guidance should preclude any risk of posterior displacement of the probe with involvement of the spinal canal and the spinal cord itself.

4.6 Surgical Technique

Patients receive a prophylactic intramuscular injection of 2 g cephalosporin 1 h prior to conducting the procedure. The procedure is performed under fluoroscopy using a C-arm unit, with the patient placed in supine position. The procedure is usually conducted under general anesthesia, although it is also doable under local anesthesia with sedation as necessary, particularly in fragile patients. The plasma diskectomy procedure is performed using an anterior approach. The head and neck are slightly hyperextended to

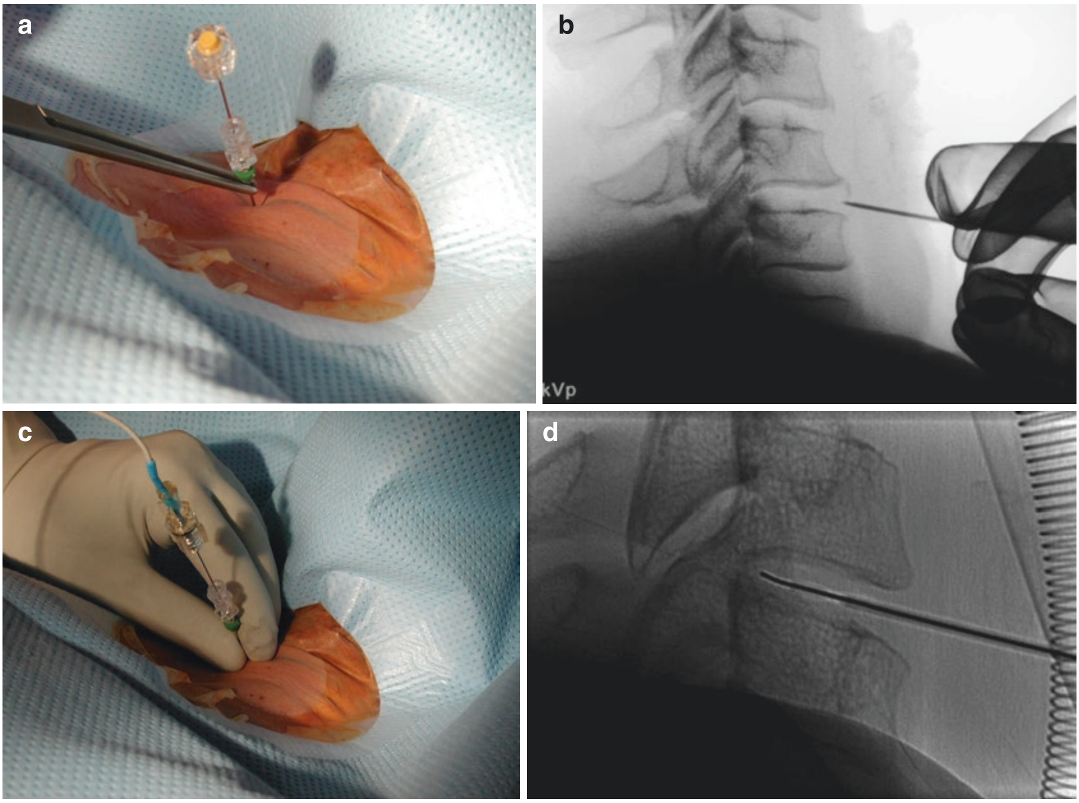

Fig. 4.4 (**a**) The 19-gauge cannula with an internal mandrel is positioned against the anterior surface of the annulus fibrosus. The cannula is held by a surgical forceps to minimize X-ray exposure of the surgeon's hand. (**b**) Cannula placement as observed under fluoroscopy. (**c**, **d**) The cannula is advanced into the disk, and the SpineWand device is introduced into the nucleus pulposus via the cannula

facilitate access to the cervical disks. For better visualization of the lower cervical disks, it is beneficial to stabilize the shoulders. In these cases, traction is achieved by tying a belt to the patient's wrists, and the belt is fixed to the foot of the table and pulled if necessary during the procedure, to uncover the lower disks from the shoulders.

The entry point for the port cannula is placed off-midline toward the patient's right side in order to make an anterolateral approach. Local anesthetic is administered using a 22-gauge needle, inserted as deep as the annulus fibrosus; the anesthesia needle is positioned using an extended holder to reduce X-ray exposure to the surgeon's hands (Fig. 4.4). While palpating vital structures away from the surgical pathway (the trachea is pushed across the midline, while the neurovascular bundle, the carotid artery in particular, and sternocleidomastoid muscle are maneuvered laterally and protected manually) (Fig. 4.5), a 19-gauge cannula with an internal mandrel is positioned against the anterior surface of the annulus fibrosus. Because the esophagus resides to the left of the midline, a relatively more right-sided approach is deemed safer at the more caudal cervical levels. The C-arm is positioned to gain a lateral view of the surgical field, and the cannula and mandrel are advanced under fluoroscopic guidance into the disk. The mandrel is replaced with the Perc DC SpineWand (Smith & Nephew, London, UK). The active electrode at the tip of the probe is less than 2-mm long and gently angled (Fig. 4.6). With the radiofrequency controller set at "3," the SpineWand device is activated and then rotated 360° to create a cone-shaped void. The plasma radiofrequency-based process

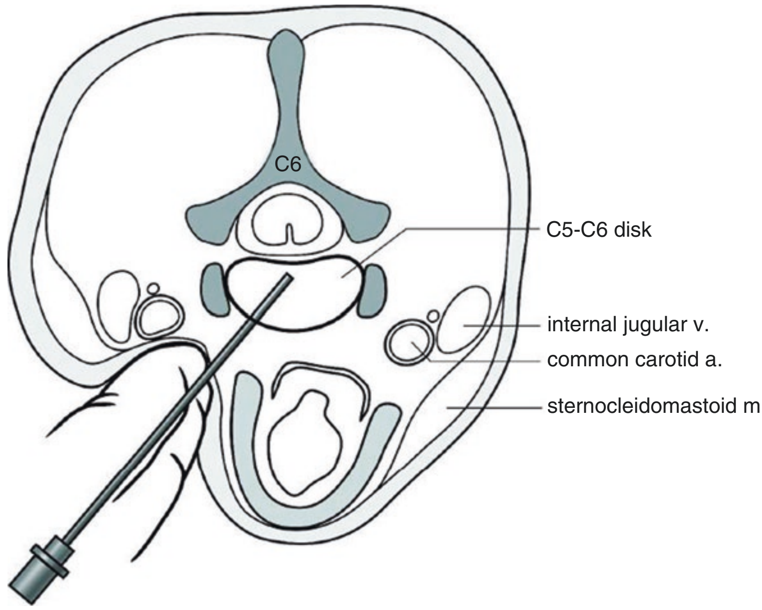

Fig. 4.5 A schematic drawing shows the entry route, with the clinician's fingers pushing the trachea across the midline while protecting the neurovascular bundle

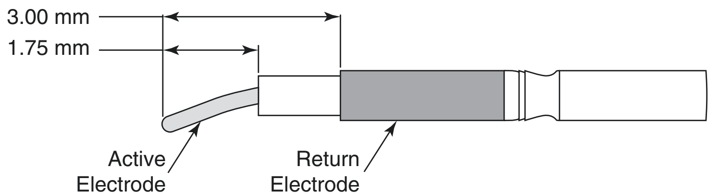

Fig. 4.6 A sketch of the distal active end of the coblation bipolar probe. The active electrode is less than 2-mm long and gently angled. The device is activated and then rotated 360° to create a cone-shaped ablation void. Between 2 and 4 voids are ablated in a linear direction to create a channel

removes a small amount of tissue within the nucleus pulposus to achieve disk decompression. After 8 s of ablation, the device is repositioned to a different part of the nucleus, with the placement depending on the topography of the herniation. For both left- and right-sided lesions, voids are created along two channels. On the left side, the first channel is made in an oblique direction, from the right anterolateral entry point toward the left posterolateral herniation; the other channel is made on the midline and directed toward the posterior profile of the disk. For a right-sided lesion, the first channel is directed obliquely toward the left, crossing the center of the disk; the second channel is directed toward the right paramedian, along the medial surface of the uncal process to reach the herniation in the posterior aspect of the disk (Fig. 4.7). With these maneuvers, a total of 4–8 voids are made in the nucleus pulposus and inside the herniation itself. The ablation portion of the procedure takes less than 5–8 min for a single diskal level. After completing the ablation procedure, the SpineWand is withdrawn from the disk. A three-way stopcock is connected to the cannula, still resting with its distal end in the center of the disk. To the stopcock are connected a 20 cc syringe to one way and a 3 cc syringe with 40 mg Depo-Medrol to the other one. Aspiration is applied for few seconds with the 20 cc syringe, then the stopcock is turned, so that Depo-Medrol is aspirated inside the disk space. No pressure is applied to the 3 cc syringe to inject Depo-Medrol more than that simply aspirated. The cannula is then removed and manual compression is applied for a few minutes on the surgical site to favor hemostasis.

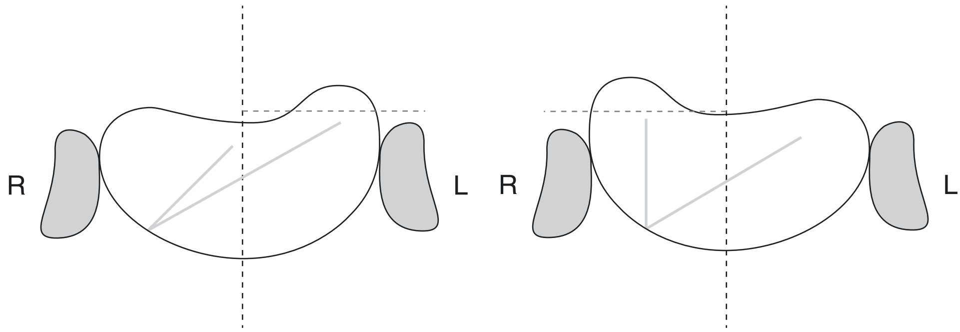

Fig. 4.7 After the first channel into the disk is completed, the device is repositioned to a different part of the nucleus, with the placement depending on the topography of the herniation. For left-sided herniations, the first channel is made in an oblique direction, from the right anterolateral entry point toward the left posterolateral herniation; the other channel is made on the midline and directed toward the posterior profile of the disk. For a right-sided lesion, the first channel is directed obliquely toward the center of the disk; the second channel is directed toward the right paramedian, along the medial surface of the uncal process to reach the herniation in the posterior aspect of the disk

The procedure can be performed on an outpatient basis, although we prefer to keep patients in the hospital overnight, mostly because of general anesthesia. When discharged, patients received a prescription for a nonsteroidal analgesic anti-inflammatory drug (to be taken for 7–10 days) and for a rigid neck collar, recommended to be used during the daytime for 2–3 weeks.

The introducer cannula for the SpineWand device has a 19-gauge caliber, probably the narrower among nonchemical procedures, laser excepted, and it is smaller than the needles currently used for direct puncture of the carotid artery or for diagnostic and interventional angiography. This cannula is easily inserted by means of a coaxial mandrel with a trocar tip. This is an important safety feature, since such mandrel does not have a sharp cutting effect, and structures are more likely to be deflected rather than resected. This feature limits the risk of vessel or nerve injuries. A 19-gauge puncture of the thyroid is of no clinical relevance, as confirmed by the wide experience in thyroid biopsies and carotid angiography.

In addition, unlike bevels, the symmetric trocar point follows a straight trajectory, allowing more precise positioning easily, particularly when driving the instrument into a relatively rigid tissue structure like the annulus fibrosus. Nevertheless, a thorough knowledge of the anatomy of the underlying structures of the neck intersecting the treatment pathway and a good quality fluoroscopy system are mandatory. Alternatively, the surgeon could choose to position the cannula under CT guidance and switch to direct fluoroscopy for the remainder of the procedure. The use of CT allows a better control of the position of the coblation probe, particularly when it must be positioned inside the spinal canal or foramen for treatment of larger herniations (Figs. 4.8 and 4.9).

4.7 Clinical Results and Evidence

In February 2003, we began a prospective study of percutaneous plasma radiofrequency-based diskectomy for treating patients with symptomatic cervical disk herniation [61]. At 2 months, outcomes were good or excellent in 44/55 (80 %) patients; the success rate was similar at 6 months, when 44 (85 %) patients ($n = 52/55$) had good or excellent results. Seven patients (14 %) never showed improvement. One clinically relevant complication (infectious diskitis) occurred, which was successfully resolved. Three patients with clinical myelopathy experienced regression of cord compression symptoms; in two of these patients, magnetic resonance imaging showed morphological evidence of reduction of cord compression.

Three randomized controlled trials are available in the literature.

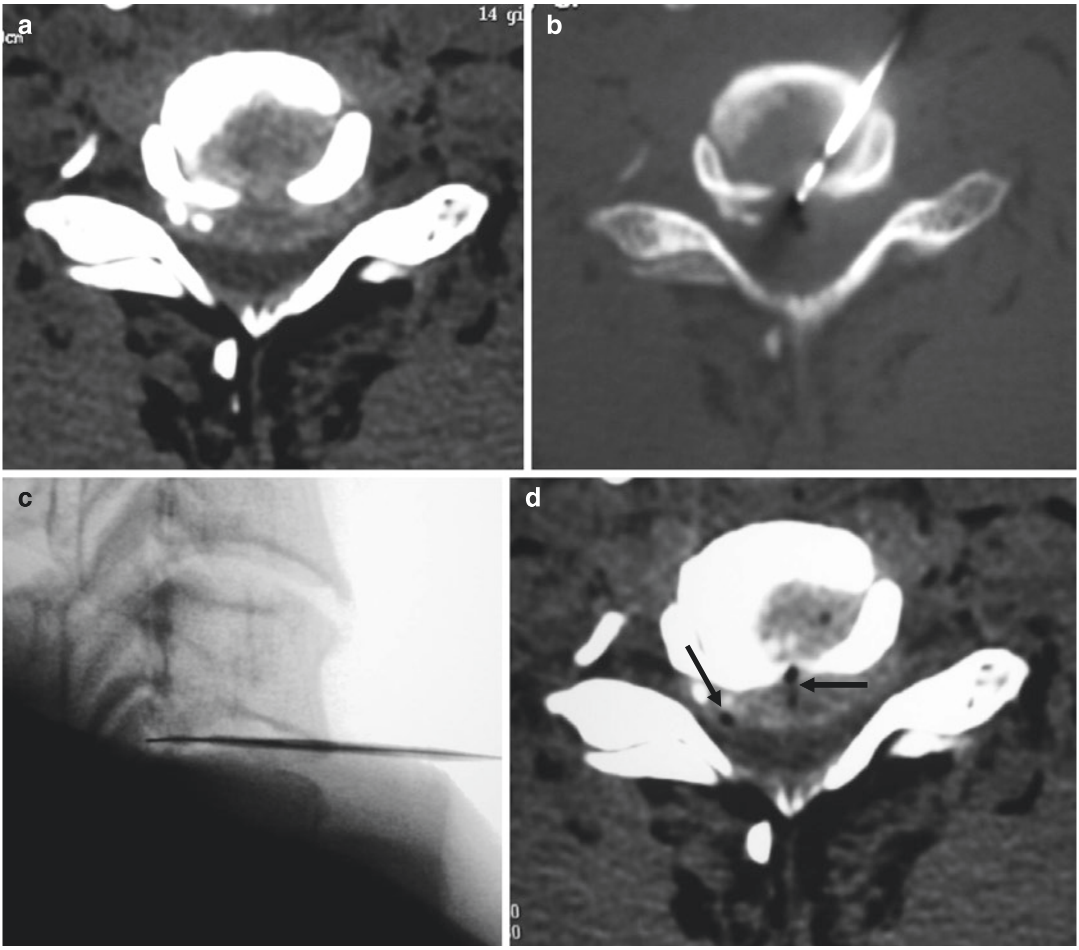

Fig. 4.8 (**a**) Bilateral disk herniation at C6–C7 encroaching the spinal canal. The intervention was conducted under CT guidance for positioning the SpineWand device, switching to direct fluoroscopy during the ablation procedure. This allowed activation of the plasma-field energy directly inside the herniation. (**b**, **c**) The active electrode is beyond the posterior limit of the vertebral body, inside the spinal canal. (**d**) The trajectory of the device and gas from tissue excision (*arrows*)

A study by Nardi et al. [62] showed complete resolution of symptoms in 80 % of all cases ($n = 50$) at 60 days after nucleoplasty compared with only 20 % in the control group ($n = 20$). Ten percent had no complete amelioration and remained under clinical FU with a wait-and-see prospective. The remaining 10 % without any clinical improvement were treated with alternative traditional methods. No complications were observed during the study. Overall, at short term, the nucleoplasty group significantly improved from baseline ($P \leq 0.001$), unlike the control group ($P = 0.172$).

Birnbaum [63] compared 26 patients with a conservative care control group ($n = 30$). Nucleoplasty showed lower VAS pain scores compared with conservative treatment at short-, mid-, and long-term FU. The pain scores (VAS) in the nucleoplasty group were 8.8 (preoperatively), 2.0 (3 months), 2.7 (6 months), and 2.3 (24 months), respectively. No complications were observed during the study.

Cesaroni et al. [64] compared 62 patients treated with nucleoplasty to a conservative care control group ($n = 58$). The nucleoplasty group had significant lower VAS pain scores at all FU time points ($P < 0.0001$). The Neck Disability Index (NDI) also improved significantly at 6 weeks ($P < 0.0001$) and 1 year FU ($P = 0.005$), and

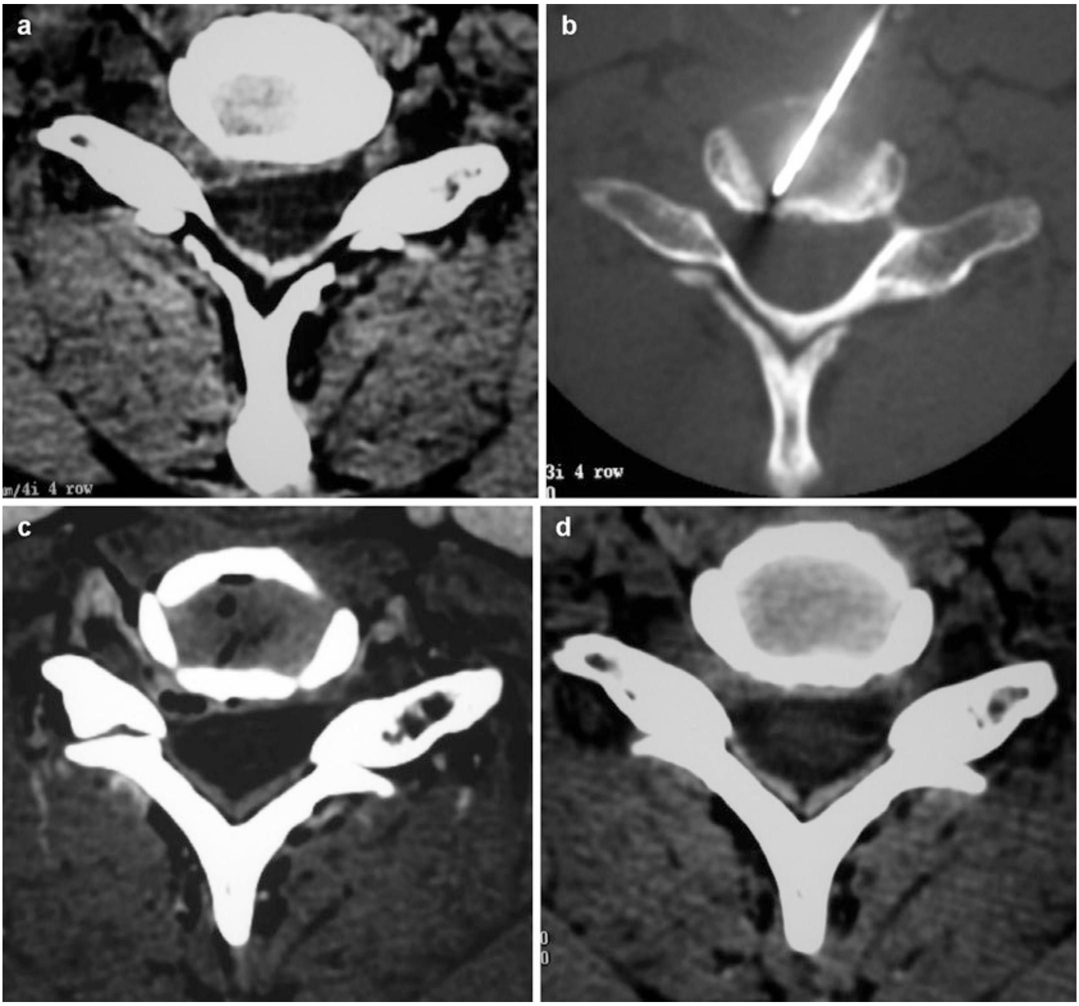

Fig. 4.9 (**a**) Lateral disk herniation compressing the nerve root. (**b**) The cannula and SpineWand device are positioned under CT guidance and then safely and precisely directed toward the herniation. (**c**) Note gas from tissue ablation diffusing inside the herniation itself. (**d**) A 4-month CT follow-up shows partial regression of the lesion; the patient reports a definite clinical improvement

correspondingly, the SF-36 physical component summary (PCS) improved significantly at 6 weeks ($P=0.004$), 3 months ($P=0.0237$), and 1 year FU ($P=0.0003$). No complications were observed during the study. Overall, the statistical analyses favor Nucleoplasty, mainly at short- and long-term FU. This study was appraised to be of high methodological quality [65].

Other nonrandomized studies were published [66–71], all claiming nucleoplasty to be a safe and effective procedure in the treatment of (contained) herniated disks at short-, mid-, and long-term follow-up. One nonrandomized study [71] shows excellent or good patient satisfaction in 87.9 % of patients after 1 week, 72.4 % after 1 year, 67.7 % after 3 years, and 63.4 % at the last follow-up and concludes that although short- and medium-term outcomes appear satisfactory, long-term follow-up results show a significant decline in patient satisfaction over time.

In a review article, ten studies were included, representing a total of 823 patients (≥892 disks) treated by nucleoplasty. Satisfactory or good to excellent results were found in ≥77.3 % of the treated patients at final FU ranging from 6 to 60 months. However, the level of evidence is considered moderate and showing only low to moderate applicability and clinical relevance [65].

Clinical improvement may frequently be observed despite an unobservable lack of volumetric modification of the disk at imaging studies performed in the postoperative follow-up. This finding may be a result of one or more pathogenic mechanisms, such as decompression of the nerve root itself, local circulatory improvement due to a reduction of pressure on the periradicular vessels, and elimination of leakage from the inner disk nuclear components that may be eliciting a periradicular inflammation.

In our experience, and comparing data from the literature, percutaneous intradiskal treatments seem to be more effective at the cervical level than at the lumbar level. The reasons for this are not clear. One explanation could be anatomical. First, the cervical root is less myelinized than its lumbar counterpart, and it is confined to a smaller space. For both of these reasons, the cervical root is more sensitive (i.e., more prone to induce symptoms) to even a small amount of compression. Consequently, even a small reduction in the volume of the disk, such as that usually obtained with an intradiskal treatment, may result in root decompression and consequent clinical amelioration. In contrast, a relatively larger herniation is necessary to induce symptoms at lumbar levels; a large herniation is more difficult to treat using percutaneous intradiskal decompression. At the cervical level, a small, focal protrusion can produce marked symptoms, but such a condition can be more easily treated percutaneously. Another explanation could be related to the topography of the lesion and direction from which it is approached for treatment. For treatment of cervical herniations, a percutaneous procedure is carried out from an anteroposterior direction, while in the lumbar spine, the approach is carried out from the posterolateral direction. Since a symptomatic herniation is directed posteriorly (both at cervical and lumbar levels), it is much more easily reached from an anterior approach. This difference in approach between the cervical and lumbar spine may affect success rates of the two procedures.

4.8 Contraindications and Complications

Contraindications include sequestered herniation, herniation greater than one third of the sagittal diameter of the spinal canal, progressive neurologic deficit, bony deformity not allowing a safe percutaneous image-guided disk access, or other bone lesions which could compress a root and cause radicular symptoms. Other conditions contraindicating the procedure are cervical fracture or instability, cervical cancer, or a patient unwilling to provide informed consent.

Absolute contraindication to a disk procedure is local or significant systemic infection.

A systemic condition causing uncorrected coagulopathy is also a contraindication. With regard to bleeding risk, although there are different policies at different institutions [72], we set our threshold for a safe performance of an intradiskal procedure, to a minimum of 80,000/mm3 platelet count, and 1.3 INR. We perform the procedure in patients treated with nonsteroidal anti-inflammatory drugs, including ASA, without special considerations. We recommend withholding the assumption of other antiaggregants before the procedure, such as clopidogrel (7 days) and ticlopidine (14 days). In case of patients treated with low-molecular-weight heparin (LMWH), we perform the procedure at least 12 h (LMWH prophylaxis regimen) or 24 h (LMWH therapeutic regimen) after the last dose, and we recommend to withhold the LMWH for 24 h after the procedure. Patients treated with unfractionated SQ heparin less than 10,000 units daily can undergo spinal procedures, whereas patients treated with more than 10,000 units daily, and those who receive unfractionated intravenous heparin, can undergo a spinal procedure 4 h after the last dose, provided that the activated partial thromboplastin time is normal, and their heparin can be restarted as early as 1 h after the procedure.

Besides observed local anesthetic-related side effects, soreness at the needle insertion site, new numbness and tingling, increased intensity of pre-procedure pain, and new areas of pain, the only true complication observed in the literature and in our experience is diskitis.

All surgical interventions, including percutaneous ones, harbor a significant risk of disk infection.

We recommend absolute sterility of the procedure, with particular care in the prep and drape process and strict use of full drape, full gown, gloves, mask, and hat. In addition, we administer to the patient an intravenous antibiotic 1 h prior to the procedure for prophylaxis, cephalosporin 2 g intravenous or, in case of allergy to penicillin, ciprofloxacin 400 mg intravenous.

Conclusion

Percutaneous cervical diskectomy performed by means of coblation nucleoplasty is a rapid procedure, of very low invasiveness for the cervical bone-joint-ligament complex; it is simple and low risk when performed under strict technical conditions. These consist of a thorough study of the anatomy of the neck in each patient, easily accomplished by sonography and CT.

Natural history of symptomatic cervical disk herniation suggests that spontaneous healing may occur: even patients who have a soft disk herniation causing a cervical myelopathy have been treated conservatively with good results [73]. Thus, when providing options for patients with symptomatic cervical disk herniation, the presented treatments must have a low morbidity rate. In this respect, the use of coblation nucleoplasty for treatment of this pathologic condition is a viable solution, thanks to the very low morbidity and the good clinical results that are achieved early-on following the procedure. Because of its minimally invasive nature, this technique, in our opinion, could be justified as a means to shorten the painful, incapacitating period of a disease that has a favorable longer-term natural history for spontaneous resolution.

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5 RF for Treatment of Lumbar Disc Herniation

Stefano Marcia, Alessio Mereu, Alessio Spinelli, and Luca Saba

5.1 Background

Approximately 80 % of the people suffer from some type of low back pain, during the course of their lives [1–21], and this pathology is one of the most common causes of workday loss and it has a huge impact on social life [2, 11, 18, 19, 21, 41]. Several causes can trigger low back pain, such as congenital disorders, tumors, traumas, intoxication, degeneration related to aging, infections, vascular disorders, mechanical causes, and psychogenic causes [13, 18, 35]; by far degenerative disorders, and in particular disc herniation, are the most common causes [1]. Treatment of disc herniation evolved in the last years: a switch from surgical to conservative approach took place, because many researches point out that more commonly than not, disc herniation heals from itself [11, 19, 23, 34, 37, 40]. Percutaneous disc decompression is in a middle ground between surgery and waiting approach, which should combine them and therefore should carry the best of both worlds [1, 4, 15, 17, 23, 25, 26, 32, 39, 42].

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5.2 Anatomy

The spine is composed of 32–34 vertebrae: 7 cervical, 12 dorsal, 5 lumbar, 5 sacral, and 3–5 coccygeal. Sacrum and coccyx have their vertebrae fused together, so in the end, the spine is composed of 26, more or less, free vertebrae. Since low back pain is caused by lumbar and sacral vertebrae, they will be taken in consideration particularly. Lumbar vertebrae have a voluminous body, which gets bigger from the first till the last, to better sustain the weight of the body. The arc is big, the laminae are thick, the spinous process is horizontal, and the rectangular and thick facet joints are vertical.

The vertebral body does not contact directly the one above or below itself but is connected and separated from them by the intervertebral disc. Those discs connect the vertebrae together and act like a ligament, and they form a symphysis which allows slight movements, but they act like an airbag too, reducing traumatism. They have a slightly biconvex surface, to better shape to the body of the vertebrae; furthermore, they are ticker in their anterior part, like a triangle, to better shape the lumbar curve. They constitute around 30–35 % of the total length of lumbar spine. Every disc consists of two parts: annulus fibrosus and nucleus pulposus. The annulus fibrosus consist mostly of fibrous tissue, with filaments organized in different directions, which intersect each other with angles of 45-70-120°.

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Those filaments are incompressible and thickness and strength are greater on the anterior part of the disc. Beginning from 30 to 40 years old, the filaments start to tear and degenerate. Nucleus pulposus is composed of the largest part of water and mucopolysaccharides, which make it deformable but not compressible. They are substituted slowly by collagen with aging; this inevitable process makes the nucleus pulposus less elastic, so it can possibly tear just like the annulus fibrosus: both of those phenomena together could determine disc herniation, that is, the migration of the nucleus pulposus through the annulus fibrosus.

Innervation is limited to the superficial part of the annulus fibrosus and is provided by the amyelinic recurrent nerves of Luschka, so only this part of the disc could trigger, at least directly, a pain response.

5.3 Low Back Pain

Every day, about one in six Americans suffers from low back pain; about four in five Americans suffers from low back pain for a considerable period of time during the course of their life. Epidemiologically, peak incidence is at around 35 years old; low back pain does not correlate with sex, except that women tend to suffer it on an average of 10 years after men. Hard work, both physical and mental, is a clear risk factor. No racial or environmental risk factors are acknowledged.

It will be taken in consideration in particular the low back pain caused by disc herniation, which is on the other hand the commonest cause of low back pain.

Disc herniation can trigger a pain response both directly and indirectly: directly, it can determine a gangliar compression, it can stimulate the nociceptors linked to the ligaments and the annulus fibrosus when it determines a deformation or stretching of the latter, and it can determine direct deformation or stretching of the nervous fiber of the thecal sac and nerve root; indirectly, it can lead to ischemic changes compressing the vasculature of the nervous fibers, and it can lead to venous stasis with alteration of the venous reflux, therefore causing edema and trophic nervous changes.

Clinically, low back pain has a natural history of several years: it usually begins with a pain felt in the lumbar or sacral zone, which is not continuous in this phase but it could happen often. After an interval of around 3–5 years, the pain increases and becomes continuous, and after that the irradiation to legs begins, which is often followed by a reduction of the pain felt in the low back. The irradiation of the pain to the legs is characterized, besides the pain, by a sensation of numbness, which develops from the center to the periphery; only in later stages, motion deficits could make their apparition. Therefore, clinical history is particularly useful in orientating.

Clinical exam plays a key role in the definition of low back pain: when accurate, it permits a diagnosis which is almost invariably correct, because different localizations of the disc herniation mean different symptoms; of course imaging plays another key role, to seal the diagnosis undoubtedly and even for legal issues which, it is mandatory to remember, are very contingent because of the frequency of low back pain and the huge amount of money which it can move [27, 37]. It is mandatory to request medical imaging with a precise indication of the supposed localization of the disc herniation and attaching the clinical exam. In case of a mismatch between clinical exam and diagnostic imaging, an electromyography can be helpful. MRI scans are the leading modality to assess spine and disc health status and the potential herniations of the latter irrefutably, because they can define amount and localization of the disc herniations precisely without using ionizing radiation [3, 9, 16, 24, 28, 36, 38]. Protocol is quite simple: sagittal T1W and T2W images are correlated to the findings with the transverse T2W images of the levels of suspected pathology. It is important to note that annular tears differ substantially from disc herniation, because in the first case the herniation is internal to the disc and does not propagate beyond the intervertebral space, because if that happens, then there is a frank disc herniation. It is important to observe if the herniation is contained inside the annulus fibrosus or not, since it could change the therapeutic approach and constitute a contraindication to nucleoplasty; furthermore, the presence of sequestration, that is, displaced disc material not united to the disc itself, could mean a less successful decompressive procedure, since that material does not react to intradiscal pressure anymore. The areas to study while reporting are basically the disc, the lateral recess, the foramen, and the extra-foraminal area, that is, many pathologies could be present at the same time. A systematic approach to evaluate the intervertebral disc and its degeneration is possible using Pfirrmann grades applied to T2 spin-echo weighted MRI scans, which distinguish between five grades, with an increase in seriousness from 1 to 5. Besides that, even a not expert radiologist can make the diagnosis without too much effort.

The primary level affected is L4–L5, followed by L5–S1 and L3–L4. The symptomatology depends on the involvement of the descending root or the exiting root. A foraminal herniation usually involves the exiting root of the same level (i.e., L4 for L4–L5), while a medial disc herniation involves the descending root of the level below (i.e., L5 for L4–L5). For each compressed nerve root, there are different symptoms, which differ for localization of pain and paresthesia, muscular dystrophy, and alterations of reflexes: compressed L4 tends to show pain irradiated to the lumbar zone, hip, thigh in its posterolateral area, and leg in its anterior area, paresthesia localized to the thigh and knee, and decreased strength of the quadriceps; patellar reflex is abolished. Compressed L5 tends to show pain irradiated to the sacrum-ilium, hip, thigh, and leg in their lateral area, paresthesia localized to the leg and first interdigital space, and decreased strength of the dorsiflexion of the hallux and foot, with possible falling of the forefoot; reflexes are often normal (eventually, there could be reduction of posterior tibial reflex). Compressed S1 tends to show pain irradiated to the sacrum-ilium, hip, thigh, and leg in their posterolateral area, to the talus; paresthesia localized to gastrocnemius, external side of the foot and fifth toe; decreased strength of plantar flexion of the hallux and foot (eventually there could be difficulty tiptoeing); and decreased strength of gastrocnemius and soleus (Achilles reflex is reduced).

It's important to remember that modern times mandate medical imaging, even if clinical exams could theoretically bring a correct diagnosis most of the time.

5.4 Radiofrequency

The radiofrequency widely used in the treatment of contained disc herniation is the coablation technique (Disc Nucleoplasty®, ArthroCare, USA). Coablation consists of radiofrequency ablation and coagulation of the nucleus pulposus through an electrode needle introduced by percutaneous approach using CT or fluoroscopy; the ablation consists of the formation of an ionic plasma, derived from the activation of sodium, in the nucleus pulposus. In that way radiofrequency energy is applied to remove a small part of the nucleus pulposus and to create small channels within the disc.

The ability of radiofrequencies to ionize is paramount, because such capacity leads to the ionization of the sodium atoms of the nucleus, so the ablation is determined by the molecular dissociation of tissue close to the device, which in turn is converted to various molecules and gas; so in the first part of the procedure, the probe sends bipolar radiofrequencies with low energy, and after that, the full power of the device is released, and this generates a temperature around 160 °F, which combined with precise movements of the probe, determining the coagulation of the remaining tissue. Thus, nucleoplasty combines coagulation and tissue ablation to create channels in the nucleus pulposus and reduces the volume of the herniated disc.

5.5 Indications and Contraindications

The goal of percutaneous disc decompression by means of coablation technique is to decompress the annulus fibrosus through the reduction of the volume of the discus pulposus, but as previously said, many researches point out that more commonly than not, this happens without any intervention. So, the first approach is conservative.

Interventional approach is indicated only if a conservative approach fails for at least 1 month, but of course it is worth considering the amount of distress of the patient, so this time could be between 2 and 12 weeks. Generally small disc herniations have better results than bigger ones [4, 8, 17]. When the annulus fibrosus is fissured, a worst result is expected since there is already a way to decompress itself, because the discus pulposus can leak through those fissures; moreover, this means a worst transmission of the warm coming from the probe. Similarly, the presence of sequestration is another contraindication for the aforementioned reasons. Best results are expected when the disc herniation is contained, with Pfirrmann grade between 1 and 3. Contraindications are coagulation disorders, local or systemic infections, canal stenosis, cauda syndrome, fractures, spondylolisthesis, instability, and allergy to local anesthetics. Main indications for emergency surgical intervention are progressive motor paralysis and cauda syndrome. The overlap of more contraindications, like voluminous disc herniation and fissured annulus fibrosus, sums up to determine an even more contraindicated treatment, even if the risk associated to nucleoplasty is so low that the balance of risk-benefit ratio is favorable most of the time. Calcification of the disc herniation and degeneration of the spine mean a worst result, the last one because the procedure could treat only a part of the diseases which determine the symptoms of the patient. Another contraindication is previous surgery in the site of the procedure, because in these cases recurrence is a usual event. Needless to say, pregnancy is the biggest contraindication of them all: X-rays and local anesthetics are known teratogenic agents.

5.6 Procedure

No particular preparation is necessary for the patient: the procedure is so minimally invasive that the only need is to suspend anticoagulant therapy 2 days before the surgery and to provide protection from infection with wide-range antibiotics. The procedure is performed in day surgery under fluoroscopic or CT guidance; this helps to reduce the costs of the procedure and to make lighter the distress of the patient [4].

First of all, informed consent is acquired. The patient is positioned prone; the skin of the low back affected area is sterilized with iodine or similar; after that a small quantity of local anesthetic (lidocaine, 4 ml) is administered percutaneously under the skin and along the presumed course of the needle (Fig. 5.1). A 17-gauge Crawford needle is then introduced. Oblique view under fluoroscopic guide allows a good visualization of the target point for needle positioning, with parallel end plates just anteriorly to the articular process (Fig. 5.2). At that site it is possible to introduce the needle to avoid injury on the nerve root and to get the correct angle to reach the middle of the nucleus pulposus in optimal position. Because of anatomical reasons, for L5–S1 space, the entry point consists of a triangle whose sides are the ileum, the articular process, and the inferior end plate of L5.

When the needle is in the proper position, as assessed by AP and LL view (Fig. 5.3) under fluoroscopic guide, discography could be performed in order to check the integrity of the annulus fibrosus.

The coaxial electrode needle is then introduced into the working cannula (Figs. 5.4 and 5.5) and after connecting to the radiofrequency generator to proceed with coablation by means of the formation of an ionic plasma; for each procedure six channels in the nucleus pulposus are performed with clockwise rotation of the needle tip.

When it is done, the probe is retracted, the needle is extracted, and 2 cc of steroids and ropivacaine 7.5 % (1:1) is injected close to the nerve root.

A gentle pressure is applied to the skin hole to help hemostasis and a small bandage is applied there. The entire procedure takes approximately no more than 20 min.

5.7 Follow-Up

The recovery is relatively quick: there is a hiatus of around 1–2 weeks in which the pain could increase, but this is not always the case. The best way to recover from the procedure is maintaining a balance between excesses: the patient should

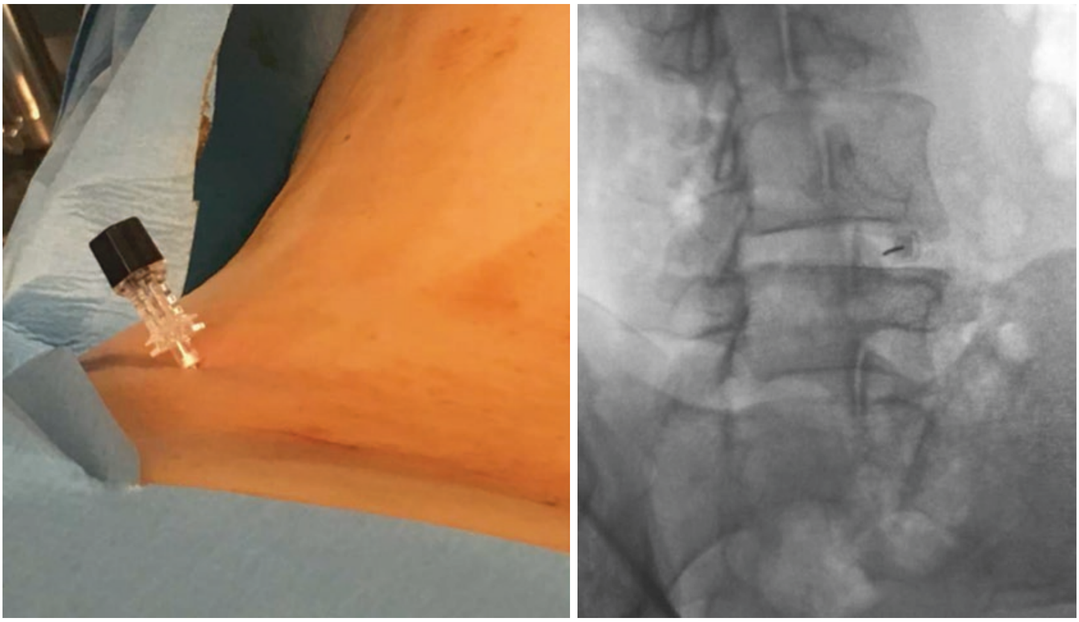

Fig. 5.1 The correct position of the spinal needle for the local anesthesia: lidocaine is administered percutaneously under the skin and along the presumed course of the needle

Fig. 5.2 Oblique view (approximately 45°) with parallel end plates allows a correct discal approach: the target point where to introduce the needle is just anteriorly to the articular process

avoid immobility; in fact, walking is encouraged, as well as heavy work or heavy sport. Swimming represents an excellent physical activity; prescription medications such as NSAIDs and other painkillers can help as well [8]. To consolidate the effects of the procedure, a full course of physical therapy 3 weeks after the procedure is advisable which will help to fully recover too.

Complications are uncommon; they consist principally of hematoma (the size of the needles makes post-procedure bleeding rare), allergic reaction to drugs (administered before, during, or after the procedure), trauma to the spinal nerve by the needle (even if puncturing it is common, considering the size of the needle, a real harm is exceedingly rare), and abscessualization and spondylodiscitis (which are rare especially if a complete course of wide antibiotics is administered) [1, 4].

5.8 Discussion and Conclusions

Success of this procedure is estimated in around 80% of the patients [2, 8, 22, 30, 31]; complications are observed in around 1.8% of the patients [15]. Many studies in literature assessed the efficacy of coablation in the treatment of contained disc herniation, but the lack of randomized controlled trials in the literature led to a fair level of evidence in several reviews. A systematic review of Manchikanti et al. (2009) [43] assigned a level II-3 of evidence for disc nucleoplasty for mechanical

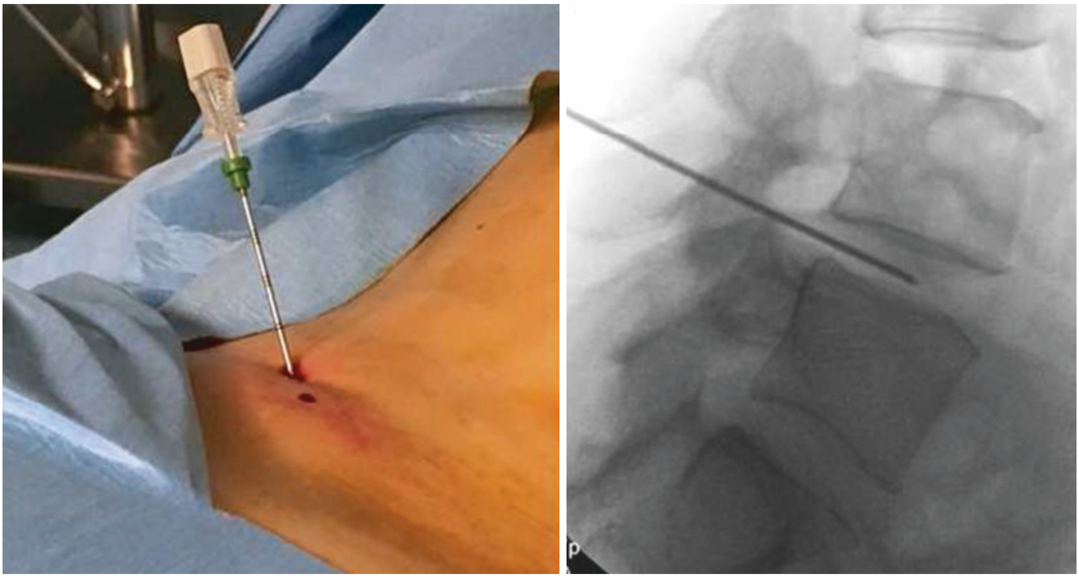

Fig. 5.3 The properly position of the Crawford needle in LL view: just in the middle of the nucleus pulposus

Fig. 5.4 The introduction of the bipolar electrode (probe) into the working cannula

lumbar disc decompression with leg pain: nucleoplasty may provide appropriate relief in properly selected patients with contained disc herniation without significant complications and minimal morbidity. No evidence is available for lumbar axial pain. Gerges et al. (2010) [17] concluded that "Observational studies suggest that nucleoplasty is a potentially effective minimally invasive treatment for patients with symptomatic disc herniations who are refractory to conservative therapy. The recommendation is a level 1C, strongly supporting the therapeutic efficacy of this procedure. However, prospective randomized controlled trials with higher quality of evidence are necessary to confirm efficacy and risks, and to determine ideal patient selection for this procedure." The new review made by Manchikanti et al. in 2013 [29] illustrated "limited to fair [44]" evidence for nucleoplasty in managing radicular pain due to contained disc herniation. Nucleoplasty may provide appropriate relief in properly selected patients with contained disc herniation without significant complications and minimal morbidity.

The same year, according to USPSTF criteria, a systematic review [44] based on one randomized trial of moderate quality and 15 moderate quality observational studies indicated the evidence for nucleoplasty as limited to fair.

In 2014, Eichen et al. [15] brought 27 studies in a systematic review and meta-analysis, of those 4 RCT are controlled; they concluded that

> Nucleoplasty reduces pain in the long term and increases patients' functional mobility. Compared to other treatments, it is an effective, low-complication, minimally invasive procedure used

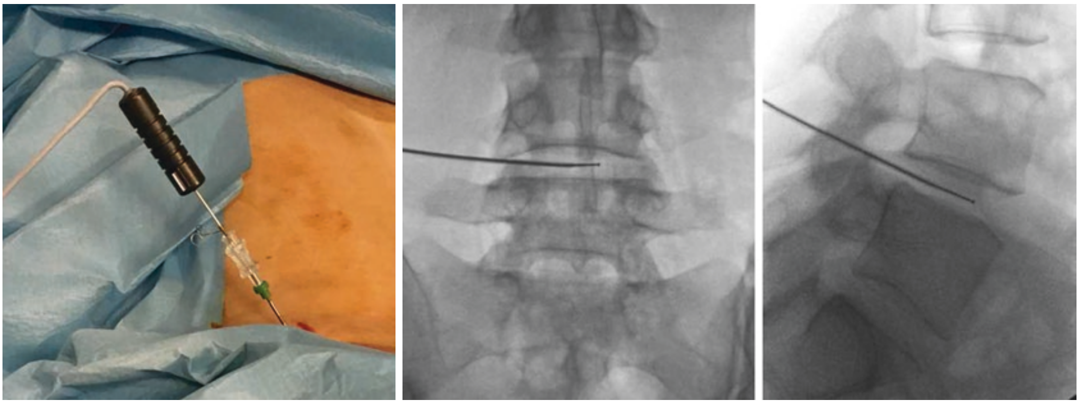

Fig. 5.5 The probe properly positioned into the working cannula as assessed by AP and LL view

to treat cervical and lumbar disc herniations. Under the given catalog of indications, it appears to be superior to conservative therapy. Patients experience greater pain relief after cervical nucleoplasty than after lumbar nucleoplasty. Studies published to date show a heterogeneous picture of inclusion and exclusion criteria. Therefore, a bias of the data presented here cannot be ruled out with certainty. Initial results suggest the possibility of extending the indication to include disc extrusions.

In conclusion, we can assume that the paucity of randomized controlled trials determines that the evidence for disc nucleoplasty is still to be considered limited to fair, but the last evidences suggest a further value for this technique, safe and effective [1, 8, 15, 17, 23, 25, 29, 33]: however, better and more numerous randomized studies with higher level of evidence are still needed.

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6 Cervical and Lumbar Facet RFA: Evidence and Indications

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6.1 Introduction

The prevalence of facet joint pain increases in the population with age, type of work and activities. Symptoms are more often of mechanical origin and pain increases with mobility (rotation and bending) and disappears with resting. Movements increasing pain include rotation, lateral bending and hyperextension. It is sometimes associated with post-traumatic disorders. Clinical examination provides information about the level of pain; at cervical spine, painful facet joint is elicited by lateral palpation behind the sternocleidal muscle. Patient's history and medical record, clinical examination, imaging and diagnostic infiltrations contribute to the identification of a facet joint as a potential plain source. Imaging findings include joint space narrowing with/or intra-articular vacuum phenomenon or fluid, osteophytes (usually involving the upper articular surface of the lower vertebra) and hypertrophy of flaval ligaments, stenosis usually of the lateral recess or of the neural foramen and rarely of the central canal and potential synovial cyst formation [1]. Additionally single photon emission bone scans or positron emission tomography-computed tomography (PET/CT) can detect facet joint's inflammation (Fig. 6.1) [2]. Alternatively, a radio-opaque landmark can be placed on the skin to help define the level of pain under X-ray.

Standard and dynamic X-rays define normal and pathological curves of the spine. Spine and facet joint have a higher chance of suffering in locations where curves change physiologically; as far as upper spine is involved, these locations include low cervical level and cervicothoracic junction. In case of pathologic spinal curves (scoliosis, listhesis, inversion of lordosis or hyperkyphosis), X-rays may reveal the area of potential maximum pressure and pain along with findings suggestive of arthritis such as osteosclerosis and osteophytes. On the other hand, MRI and CT scan may additionally reveal ligament hypertrophy, subchondral hyper-pressure and intra-articular effusion [1]. Any imaging examination has to be correlated with data from clinical examination in order to select the area of potential painful source and additionally exclude other causes of suffering (vertebral fracture, disc herniation-degeneration, etc).

Once diagnosis of a painful facet joint is confirmed, the first therapeutic approach includes a 4–6-week course of standard conservative treatment (including medication and physiotherapy); once and if this course fails, interventional treatments have to be considered. A faster approach

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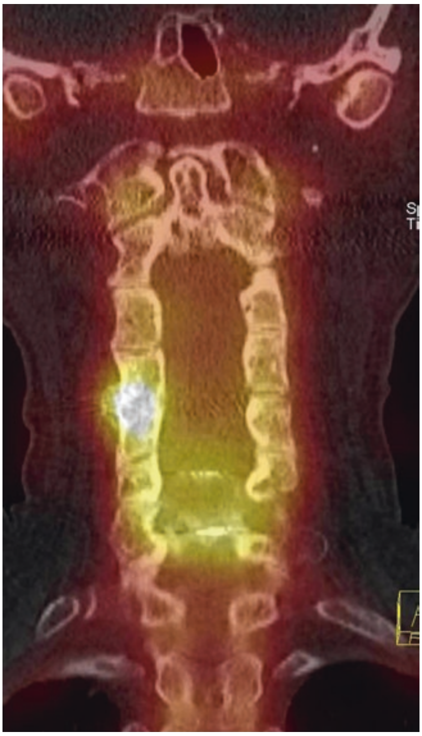

Fig. 6.1 PET/CT scan, coronal reconstruction illustrating a right C4–C5 facet joint which is FDG avid

circumventing medication treatment might be used in cases of intolerance to NSAIDs.

6.2 Steroid Injections

Under imaging guidance and local sterility measures, a 22 G spinal needle is advanced intra-articularly inside the facet joint of interest. Contrast medium injection with subsequent joint opacification will verify correct needle placement inside the joint. Depending on an operator's preference, a mixture containing steroid with local anaesthetic or normal saline is injected. This injection is not considered a selective pain bloc, but provides information and identifies the facet joint as a potential pain source due to three different responses:

- During the injection (pain is usually reproduced in the symptomatic area)
- During the anaesthetic period (pain reduction or diminishment due to the local anaesthetic)
- During the follow-up period (pain reduction or diminishment due to the anti-inflammatory effect of steroid)

As stated previously, intra-articular facet joint steroid injections should not be considered facet specific, for two main reasons:

1. The volume of injected products is higher than the joint's capacity and a diffusion of anaesthesia has to be considered probable (epidural or periradicular); pain reduction post injection could be related to this extra-articular diffusion as well [3].
2. A general effect of steroid is usually observed in the days following the injection and patients often report to be better in other arthritis-related locations after a facet injection.

Prior to radiofrequency denervation, according to most guidelines, two specific nerve blocs are mandatory [4–6]. These are performed by accessing the median branch, which transfers the sensory stimulus of the posterior articulation at each level of spine. It can be accessed by needle under fluoroscopic or CT guidance for diagnostic or therapeutic purposes (Fig. 6.2). Median branch block, in contrast to facet injection, should be considered a selective pain bloc; with this technique a small quantity (0.2–0.3 cc) of local anaesthetic—in order to avoid potential liquid diffusion—is performed under imaging guidance at the level of the median nerve.

As far as the cervical spine is concerned, the access for a median branch block is posterolateral and ascending to the antero-lateral part of the joint (Fig. 6.3) [7]. Under strict sterile condition, a 22 G spinal needle is advanced to the define target with our without skin anaesthesia (paraspinal muscle anaesthesia on the way of the needle is usually not performed to diminish false positive response due to muscular relapse). The anaesthetic is injected gently after imaging control proving good positioning of needle and needle tip assuming a bone contact in the defined area. Patient is clinically evaluated before and after the selective pain bloc to define diminishing of pain and comfort. Generally, pain bloc is considered positive if the pain is diminishing during the

Fig. 6.2 Lateral fluoroscopy view: *yellow lines* indicate the location of median nerve branches at C3–C4 level

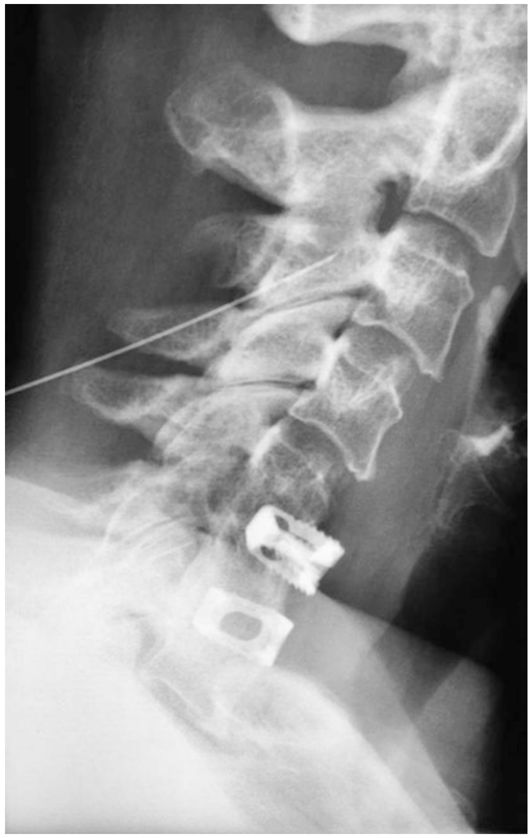

Fig. 6.3 Lateral fluoroscopy view: the access for a median branch block is posterolateral and ascending to the antero-lateral part of the joint

anaesthetic period at least four VAS graduations. According to the life expectancy of the anaesthetic, the patient should inform when the pain is returning at a specific level. If two selective blocs performed at least 48 h apart are positive, radiofrequency treatment is indicated.

6.3 Radiofrequency Facet Joint Treatment

This treatment is performed upon ambulatory basis with or without sedation depending on the operator's preference. Local anaesthesia for patient's comfort is injected at the beginning of the session. During RF denervation, a probe (i.e., a needle with active tip) has to access the medial branch nerve in the most possible parallel route, with a similar approach as in the median nerve block. An electrical system using a generator is used to induce an alternating high frequency current with an important electric field near the RF needle active tip.

There are two types of radiofrequency energy currently applied:

- The thermic (continuous) radiofrequency ablation, during which a 5–10 mm length active tip needle produces an elliptic thermic lesion. This thermic lesion ranges from 3 to 5 mm in diameter depending upon the needle diameter and the active tip's length.
- The pulsed radiofrequency ablation, using the same probe and generator, but in this application the temperature is controlled in-between 40 and 42 °C, using the effect of the electric magnetic field.

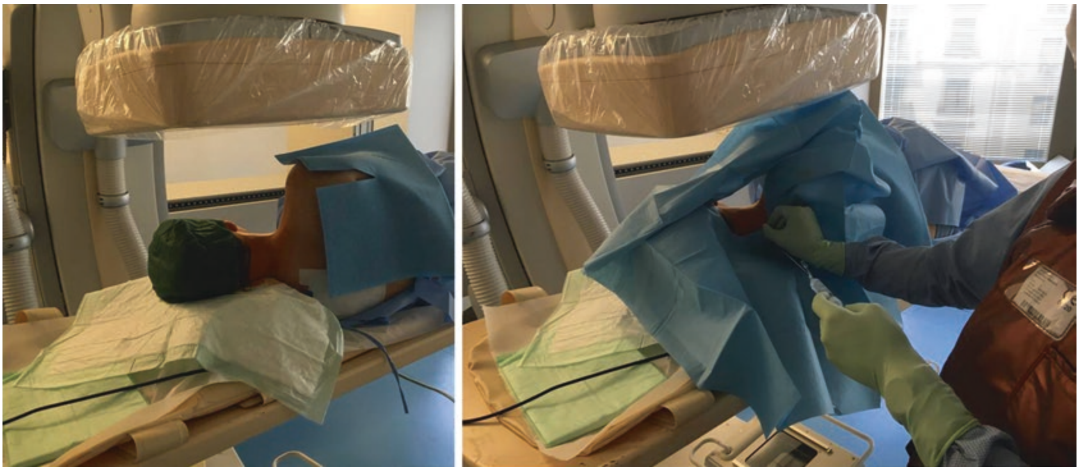

Fig. 6.4 During RF denervation in the cervical spine, patient is placed in a lateral decubitus position with the affected side upwards

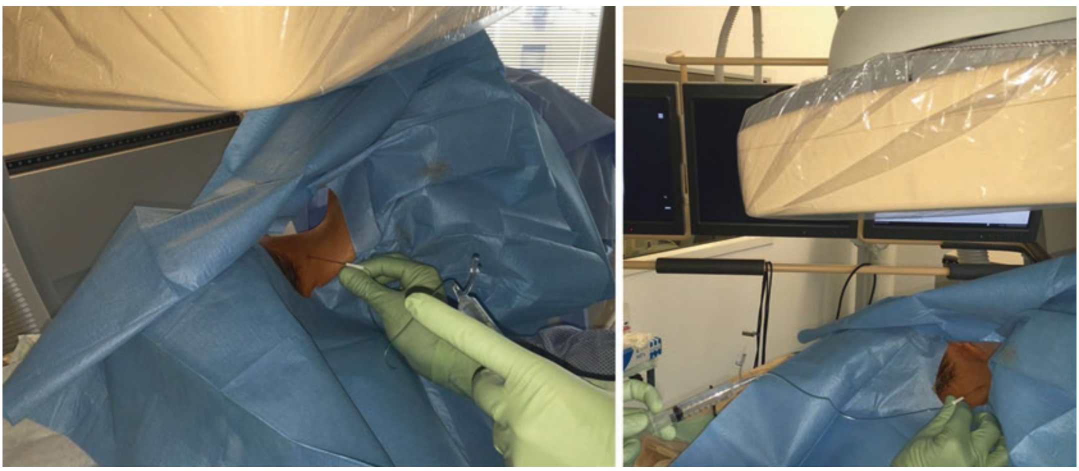

Fig. 6.5 The needle approach is posterolateral and ascending with the patient placed in a lateral decubitus position

Results of pulsed radiofrequency for facet joint denervation are considered transient ranging from 2 to 4 months. As far as continuous thermic RF of facet joints is concerned, the technique should be performed on two or three circles of 90 °C and 90 s duration, aiming to cover the whole area where the medial branch is supposed to be located. Curved RF needle can be used in order to cover by heating a larger volume; this type of needle is easier to be placed and just by rotating can alter the geometry of the ablation zone. In order to obtain a larger ablation zone, a 20 G needle should be preferred over the 22 G diameter. Between two cycles a rotation of 90° can cover a bigger surface area.

Once the needle is positioned next to the nerve (the same approach as a median nerve block is applied), sensory and motor tests should be performed in order to evaluate proximity to the median branches and distance from the motor nerve (Figs. 6.4, 6.5, 6.6 and 6.7). Combining fluoroscopic guidance for needle positioning and cone beam CT (3D acquisition) to check needle tip position augments safety and efficacy of the

Fig. 6.6 Sequential lateral fluoroscopy views (same patient) illustrating the needle's posterolateral and ascending approach towards the joint's antero-lateral part

Fig. 6.7 The generator's screen as it appears during motor and sensory stimulation tests as well as during continuous thermal ablation mode

technique (Fig. 6.8). During the sensory test, the stimulation energy is increased (up until 1 V) using an impedance of 50 Hz. If the medial branch nerve is close, patient informs of a clinical change during this procedure (most of the time pain appears before the highest voltage). During the motor test, stimulation is performed by increasing voltage at 2 Hz of impedance. The position of needle is considered safe if no motor contraction during this phase is observed for a voltage stimulation which is at least double compared to the sensibility test or for two volts if no contraction is observed.

Pain reduction or diminishment is reported up to 90% of cases lasting for 3–4 years after the procedure [4–6]. In certain cases the nerve could be restored after this period, or sometimes even before, thus making the pain re-appear. Since denervation is a simple and low-risk procedure, the technique could easily be repeated.

6.4 Post-Procedural Care

Post facet joint denervation patient remains bed-ridden and hospitalized for 30–60 min. Patient exits the hospital with an accompanying person in order to avoid driving. Clinical follow-up is advised 1 and 6 weeks later (because neurogenic pain can occure up to 5 weeks after procedure).

Conclusion

Percutaneous facet joint neurolysis in the cervical spine using radiofrequency ablation is a safe and cost-effective technique which is performed under imaging guidance and local

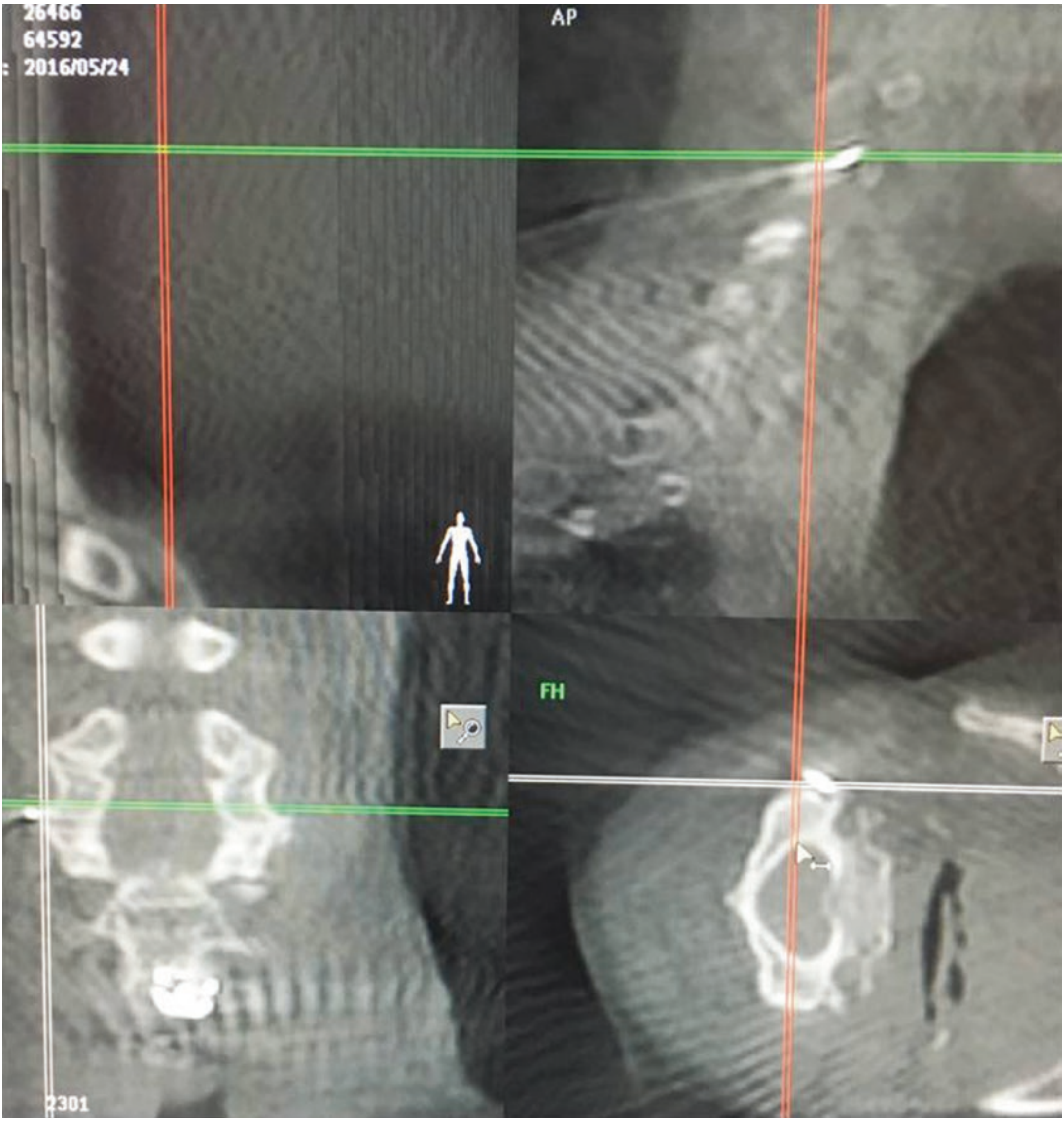

Fig. 6.8 Combining fluoroscopic guidance and cone beam CT (3D acquisition) augments safety and efficacy of the technique by providing anatomical details of needle tip position

anaesthesia as outpatient procedure. Extensive and strict sterility is a prerequisite. Radiofrequency neurolysis is a feasible and reproducible, efficient and safe therapy for the treatment of symptomatic facet joint syndrome. Imaging guidance increases technical and clinical success and decreases potential complications rate; recent advancements allow combining fluoroscopic guidance for needle positioning and cone beam CT (3D acquisition) to check needle tip position, augmenting thus safety and efficacy of the technique.

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7 RFN on Lumbar Facet Joint

Alexis Kelekis and D.K. Filippiadis

7.1 Introduction

Pain in the lower back radiating to buttocks and upper thighs is multifactorial with potential pain sources including intervertebral disc, facet or sacroiliac joints and rarer muscles or ligaments. Goldthwait in 1911 reported for the first time facet joints as a potential pain source, whilst 60 years later in 1971 the first surgical denervation of a facet joint was performed by Rees; a few years later in 1974 Shealy using radiofrequency energy performed the first percutaneous facet joint denervation [1–3].

Patient's history and medical record, clinical examination, imaging and diagnostic infiltrations contribute to the identification of a facet joint as a potential pain source. Imaging findings include joint space narrowing with/or intra-articular vacuum phenomenon or fluid, osteophytes (usually involving the upper articular surface of the lower vertebra) and hypertrophy of flaval ligaments, stenosis usually of the lateral recess or of the neural foramen and rarely of the central canal and potential synovial cyst formation [4]. Additionally single photon emission bone scans or positron emission tomography-computed tomography (PET/CT) can detect facet joint's inflammation [5]. During clinical examination, suspicion of painful facet joint syndrome is raised with pain at the facet joint level exacerbated with pressure, hyperextension, torsion and lateral bending; this pain is usually worse when waking up from bed or trying to stand after prolonged sitting and might radiate to thigh, iliac crest and rarely to the groin [6].

The therapeutic armamentarium for painful facet joints includes conservative therapy (analgesics, muscle relaxants, non-steroidal anti-inflammatory drugs, immobilization, bed rest and physical therapy), percutaneous intra-articular infiltrations with a mixture of long-acting corticosteroid and local anaesthetic and facet joint denervation by means of radiofrequency ablation or cryoablation [7]. The term neuromodulation describes the application of pulsed radiofrequency for 140 s raising temperature at 42 C, whilst the term neurolysis describes the application of continuous radiofrequency for 60 s raising temperature at 60–90 C [8].

Prior to any denervation procedure in the facet joints, a diagnostic infiltration should be performed to verify that the specific facet joint is the actual pain source of the patient. Based on the operator's personal preference, either an intra-articular or a median branch nerve infiltration can be performed under imaging guidance. The infiltrate may contain only local anaesthetic or a mixture of long-acting corticosteroid and local

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anaesthetic. If the patient reports pain reduction (even transient) of 70–80 %, it is considered a positive predictive factor for successful denervation.

7.2 Anatomy

Zygapophysial joints (else called facet joints) articulate two vertebrae; the joint consists of the inferior articular process of the upper vertebra (forming the joint's medial part) and the superior articular process of the lower vertebra (forming the joint's lateral part) (Fig. 7.1). Facet joints are bilaterally located in each level of the lumbar spine and are true synovial joints lined with hyaline cartilage. The function of facet joints includes structural support, weight bearing and movement including flexion, extension and rotation.

In the posterior part of the joint's superior articular process, the mamillary process is located where multifidus muscle is inserted. In the dorsal surface of the transverse process, the accessory process is located varying in length and shape; the longissimus muscle is attached to the accessory process. Both mamillary and accessory processes are the attachment locations of the mamillo-accessory ligament which along with the superior articulate and the transverse process form a tunnel within which runs the medial branch of the posterior primary ramus [9] (Fig. 7.2).

The junction of ventral and dorsal spinal cord roots forms the lumbar spine nerves which run in the intervertebral foramen; in their course outside

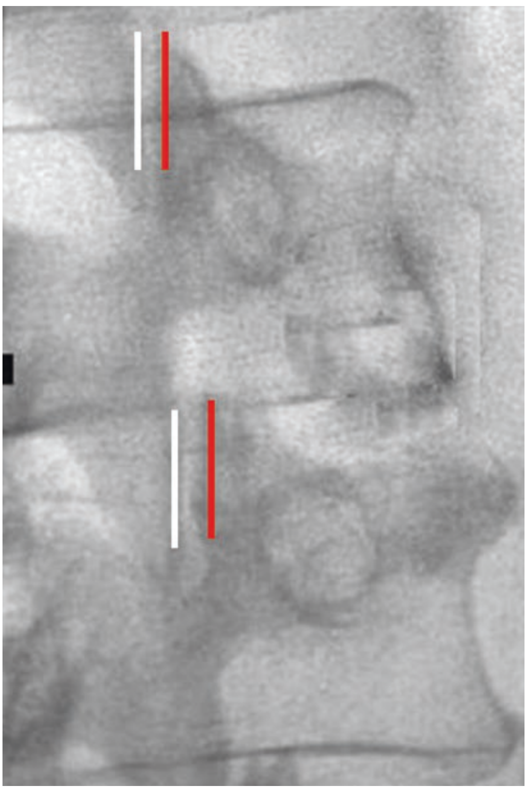

Fig. 7.1 Oblique fluoroscopy view ("Scottie dog" projection): Facet joint consists of the inferior articular process of the upper vertebra (forming the joint's medial part – *white line*) and the superior articular process of the lower vertebra (forming the joint's lateral part – *red line*)

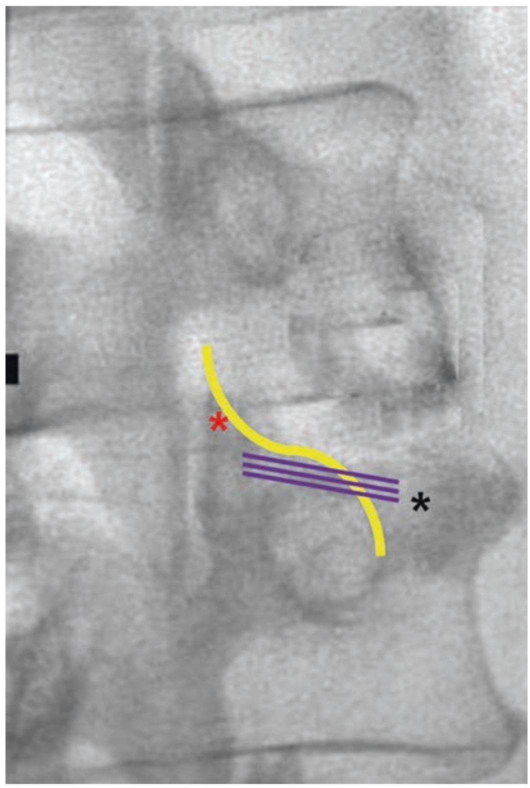

Fig. 7.2 Oblique fluoroscopy view ("Scottie dog" projection): The mamillo-accessory ligament (*purple lines*) along with the superior articulate (*red asterisk*) and the transverse (*black asterisk*) process form a tunnel within which runs the medial branch of the posterior primary ramus (*yellow curved line*)

the foramen (shortly after exiting), the spinal nerves are separated into anterior and posterior primary rami, with the posterior ramus being divided into medial and lateral branches. The medial branch runs in a groove located at the junction of superior articulate and the transverse process under the mamillo-accessory ligament [9]. Exception is the L5 posterior primary ramus which is much longer and runs caudally towards the dorsal side of the sacral ala inside a groove formed by the ala and the sacral superior articular process. Each medial branch in the lumbar spine is divided into an ascending and a descending articular branch; each facet joint in the lumbar spine is innervated by two medial branch nerves, one from the joint's level and one from the above level. For example, the L3–L4 facet joint is innervated by the L2 and L3 median branch and therefore in case of denervation the ablation process must be performed in both L2–L3 and L3–L4 levels.

7.3 Procedure

7.3.1 Pre-procedural Care

Radiofrequency denervation of lumbar facet joints is an outpatient procedure performed under local anaesthesia and imaging guidance. The latter ensures the correct needle placement which is a key factor for safety and efficacy. Facet joint denervation should be performed at least 48 h post the diagnostic infiltration in order to ensure that all the local anaesthetic effect has been cleared and motor or sensory stimulation will not be affected. For the same reasons, no opioid medication is administered the day of the procedure. Patient fastens 6 h prior to the technique. In case of anticoagulants, administration these is discontinued; the discontinuation period depends on the type of the anticoagulant. Although the technique is performed under local anaesthesia, an IV access should be established in all cases.

Each patient undergoes physical examination and coagulation laboratory tests at least 24 h prior to the radiofrequency denervation session. Consulting with the patient and explaining potential benefits, outcomes and complications is pre-requisite; patient is additionally advised to be accompanied by an adult capable of driving for the return home. An informed consent is obtained just prior to the session.

7.3.2 Technique

Imaging is a key factor for safety and efficacy of RF facet joint denervation in the lumbar spine; fluoroscopy is the most commonly used imaging guidance method. Patient is placed in prone position with a pillow under the head for comfort. Depending on an operator's preference, a second pillow can be placed under the lower abdomen in order to flatten lumbar lordosis. Under fluoroscopic guidance, the technique is similar for all facet joints from L1–L2 till L4–L5 levels.

Starting the session, the operator defines the level of interest; on A-P projection, the spinous process should be on the midline and the endplates of the vertebral bodies aligned; occasionally this will require medial-to-lateral and cranio-caudal beam angulation. Once a true A-P projection is obtained, the beam is angulated 25–45° to obtain the "Scottie dog" projection (oblique projection). In this projection the snout of the dog is the transverse process, the ear is the superior articulating process, the front leg is the anterior articulating process, and the dog's body is the lamina of the vertebra. The target point is the junction of the transverse process and the superior articulating process where the median branch nerve runs to innervate the facet joint (i.e. the junction of the dog's nose and ear) (Fig. 7.3). Needle is advanced parallel to the beam angulation ("gun barrel view") until bone contact is made at the dorsal and superior part of the transverse process in the junction with the superior articulating process. Specifically for the L5-S1 facet joint, one needle is placed in the L4–L5 level with the aforementioned technique and a second needle is located at the junction of the dorsal side of the sacral ala and the sacral superior articular process (Fig. 7.4).

Once bone contact is performed on the "Scottie dog" projection, the needle's correct location is verified in A-P and lateral projections. The A-P projection verifies that the cannula is placed against

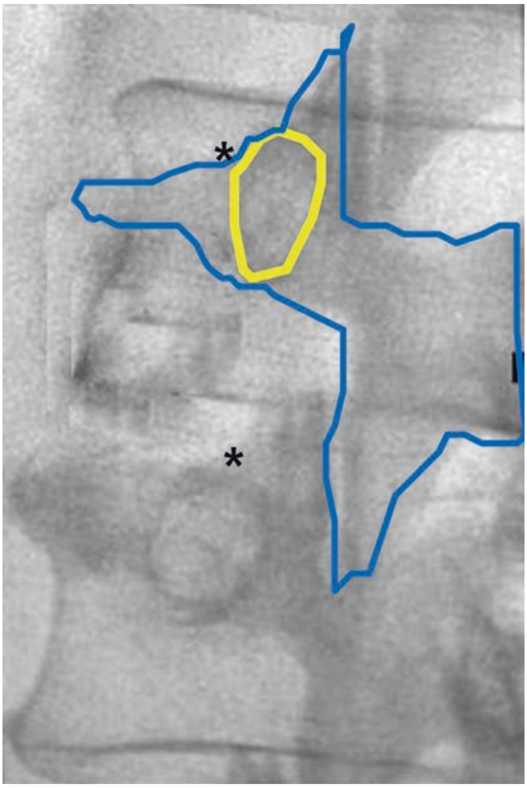

Fig. 7.3 In the "Scottie dog" projection (oblique projection), the snout of the dog is the transverse process, the ear is the superior articulating process, the front leg is the anterior articulating process, and the dog's body is the lamina of the vertebra. The target point (*black asterisks*) is the junction of the transverse process and the superior articulating process where the median branch nerve runs to innervate the facet joint (i.e. the junction of the dog's nose and ear)

the superior articulating process in the upper and lateral margin of the pedicle (Fig. 7.5). The lateral projection verifies that the cannula has not advanced past the joint level inside the intervertebral foramen where the segmental spinal nerve lies.

Once the correct cannula location is fluoroscopically verified in all three projections, electrical stimulation follows to verify that the tip is at the appropriate target point (close enough to the sensory nerve ensuring technique's efficacy and away enough from motor branch to ensure technique's safety) (Fig. 7.6). Electrical stimulation is always monopolar performed at one location at a time with the electrical stimulus being applied at the target site through the electrode's active tip and return path through the ground pads on skin surface. During this stimulation the density of the current is very high at the electrode's active tip and very low at the return pathway; in other words the response occurs only at the active tip level (Fig. 7.7). Prior to neurolysis, there are two stimulation types used:

1. Sensory stimulus: high frequency repetition rate (50 Hz cycles/sec) in a duration of 1 millisecond with a threshold voltage of 0.2–0.5 V
2. Motor stimulus: low frequency repetition rate (2 Hz cycles/sec) in a duration of 1 millisecond with a threshold myotomal voltage of at least 2 V

The above tests should be performed without the use of local anaesthetic. In sensory stimulus the expected threshold voltage depends upon the length and diameter of the electrode's active tip. In a successful electrical sensory stimulation, the response's location should be concordant with the distribution of the patient's usual pain. As far as motor stimulus is concerned, there should be no motor response for at least the double of the sensory test with a maximal threshold of 2.0 V. Sensory testing prior to ablation seems to increase efficacy of the technique; on the other hand, motor testing prior to ablation is advised for safety increase.

Following the fluoroscopic and electric verification of the cannula's correct location, a small amount of local anaesthetic (~1 cc) is injected at the ablation site. Then, once again the electrode is coaxially inserted in the cannula and the ablation session is performed (two circles of 80–90 °C for 90 s, rotating the cannula tip in between). Notice that ablation session in different levels should be performed consecutively rather than simultaneously in order for the operator to be able to recognize the level of a potential adverse event and act accordingly.

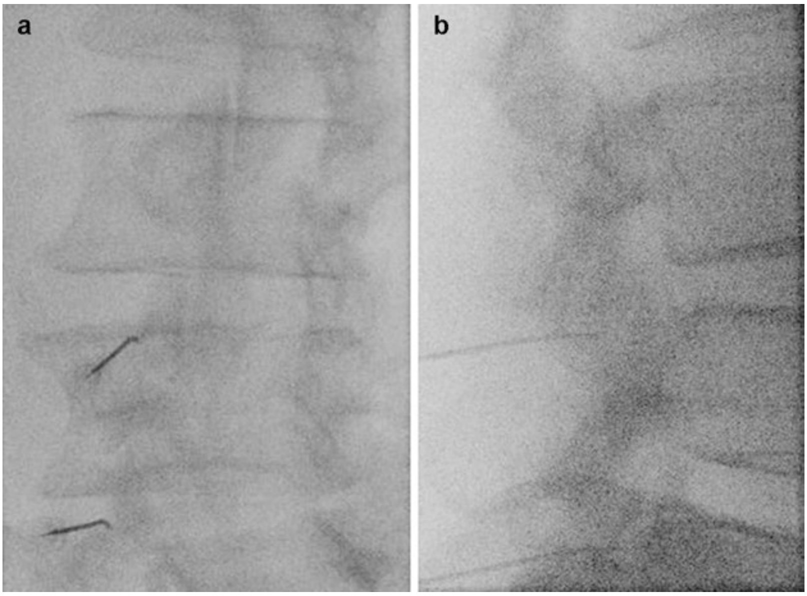

Fig. 7.4 (**a**). Oblique fluoroscopy view ("Scottie dog" projection): For the L5–S1 facet joint, one needle is placed in the L4–L5 level (target point is the junction of the transverse process and the superior articulating process), and a second needle is located at the junction of the dorsal side of the sacral ala and the sacral superior articular process. (**b**) Lateral fluoroscopy view: The lateral projection verifies that the cannulae have not been advanced past the joint level inside the intervertebral foramen where the segmental spinal nerve lies

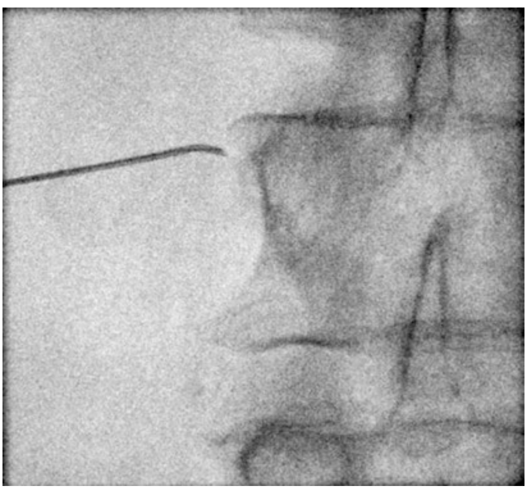

Fig. 7.5 The A-P projection verifies that the cannula is placed against the superior articulating process in the upper and lateral margin of the pedicle

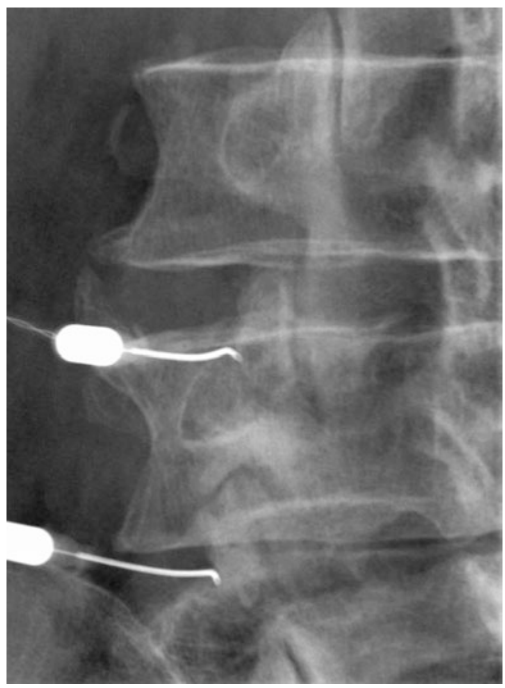

Fig. 7.6 Once the correct cannula location is fluoroscopically verified in all three projections, the RF electrodes are coaxially inserted. Electrical stimulation follows to verify that the cannula tip is at the appropriate target point (close enough to the sensory nerve ensuring technique's efficacy and away enough from motor branch to ensure technique's safety)

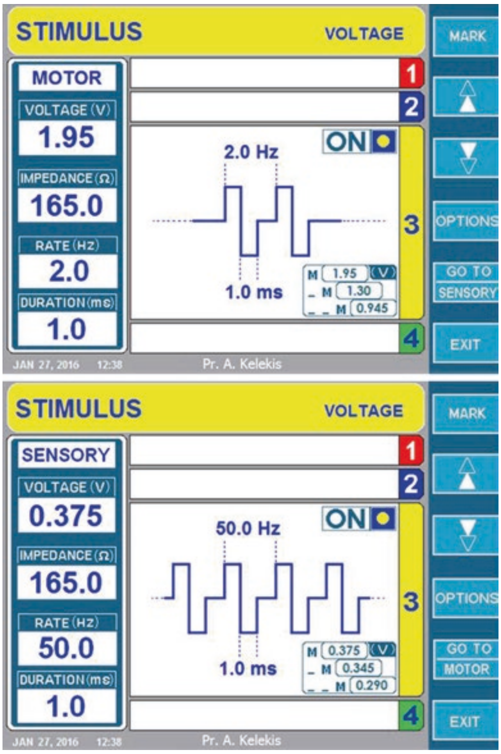

Fig. 7.7 Image of the generator's screen during motor (*upper image*) and sensory (*lower image*) stimulation tests

7.3.3 Post-procedural Care

Post facet joint denervation patient remains bedridden and hospitalized for 30–60 min. Patient exits the hospital with an accompanying person in order to avoid driving. Bed rest for 24 h is recommended. Clinical follow-up is advised 1 week later.

Conclusion

Percutaneous facet joint neurolysis in the lumbar spine using radiofrequency ablation is a safe and cost-effective technique which is performed under imaging guidance and local anaesthesia as outpatient procedure. Extensive and strict sterility is a prerequisite. Radiofrequency neurolysis is a feasible and reproducible, efficient (70–80 % success rate) and safe (>0.5 % mean complications rate) therapy for the treatment of symptomatic facet joint syndrome. Imaging guidance increases technical and clinical success and decreases potential complications rate. Percutaneous diagnostic infiltration contributes to proper patient selection by recognizing a specific facet joint as the potential pain source enhancing thus efficiency rates. Clinical results of facet joint denervation seem to provide better and longer-lasting results (pain reduction and mobility improvement) when compared to percutaneous infiltrations.

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8 Radiofrequency Ablation for Sacroiliac Joint Pain

Christopher Gilligan, Obaid S. Malik, and Joshua A. Hirsch

The sacroiliac joint (SIJ) is the largest axial joint in the human body. It is a unique joint, with significantly decreased and unconventional motion compared to other synovial joints. Along with its curved shape, these characteristics make it a difficult joint to study. It is an important source of chronic low back pain, which is the leading cause of disability in the United States [1–3]. An estimated 15–25 % of low back pain patients may have SIJ pain as the cause of their symptoms. Furthermore, according to several sources, this figure may be an underestimate [4–10]. The anatomy and physiology of SIJs are unique, which makes accurate diagnosis and management very challenging.

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8.1 Anatomy and Innervation of the Sacroiliac Joint

Historically, SIJs were thought to be mobile only during pregnancy in women. However, eighteenth-century studies revealed that they have a synovial membrane and are mobile in both men and women [11]. The SIJ is the largest axial joint in the human body. It is formed by the articulation of the medial surfaces of the Ilium and lateral sacral segments S1, S2, and S3 (Fig. 8.1). SIJs have a rigid structure with tight fibrous ligaments that are essential for load transfer between the spine and legs. SIJ movements such as forward and backward tilting are not independent and directly influence lumbar joints such as L5–S1 and higher spinal levels [11].

The innervation of the SIJ is variable, complex, and controversial. The lumbosacral plexus provides sensory innervation for the SIJ. A recent cadaveric study found that the *posterior* SIJ is innervated by the lateral branches of the posterior rami of L5–S4. The lateral branches of S1 and S2 contribute to the innervation in 100 % of specimens, S3 88 %, L5 8 %, and S4 in 4 %. The lateral branches of S1–S4 exit the sacral foramina and traverse the sacrum in an unpredictable fashion [12]. Other sources claim that the medial branches of L4 and L5 may also provide innervations to the posterior SIJ. The S1 level likely provides the greatest innervation to the posterior SIJ [13].

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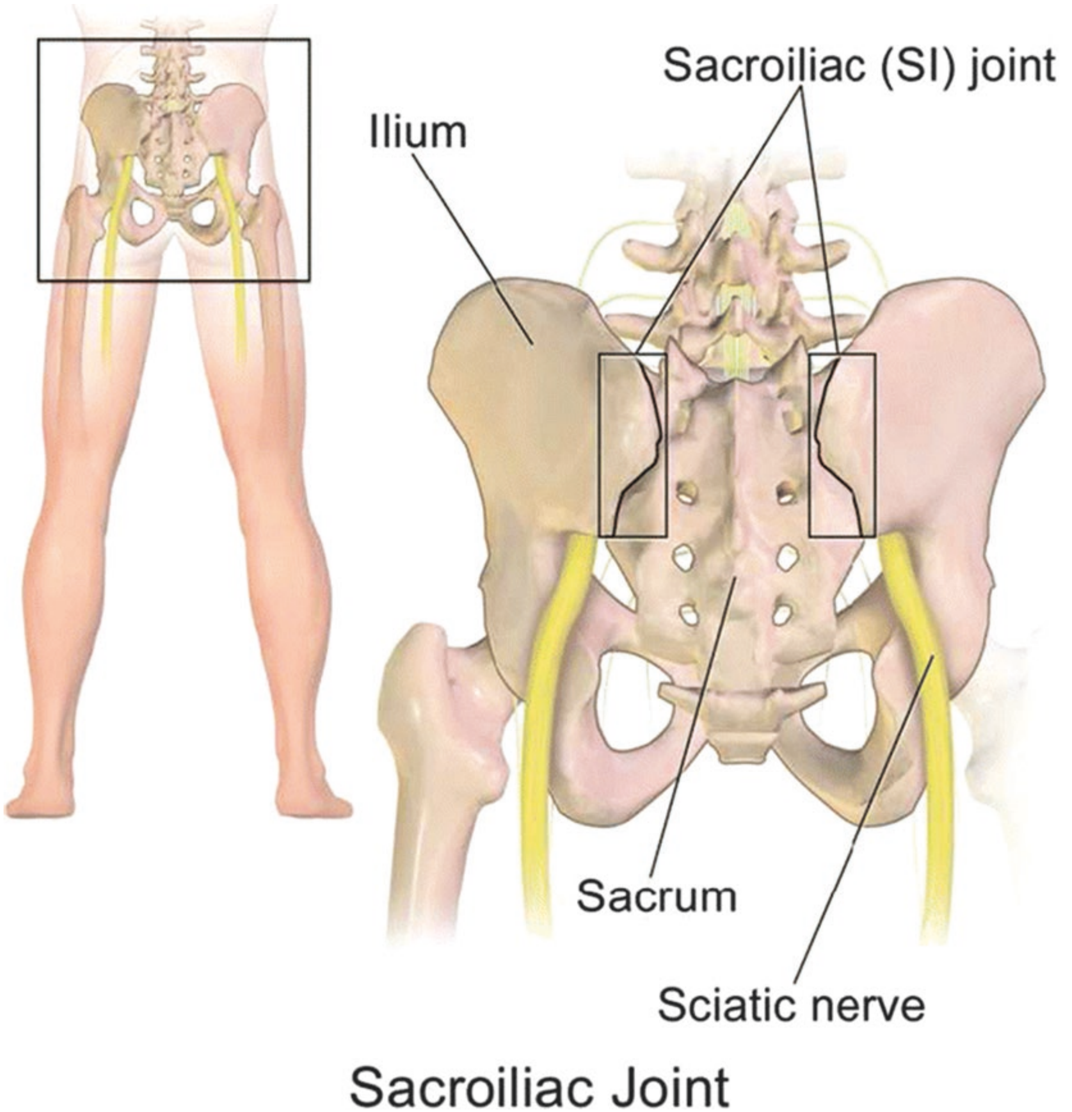

Fig. 8.1 Anatomy of the sacroiliac (SIJ) joint (Blausen.com staff. "Blausen gallery 2014." *Wikiversity Journal of Medicine*)

The *anterior* SIJ is innervated by the posterior rami of L1–S2 and by the superior gluteal and obturator nerves. It is important to note that SIJ pain originating from the anterior SI joint line cannot be effectively targeted by radiofrequency ablation (RFA). There are no reliable SIJ-specific RFA targets for obturator and superior gluteal nerves. This may, in part, account for the ineffectiveness of some RFA interventions for SIJ pain. Although imaging findings do not necessarily correlate to pain, one study revealed that 69 % of SIJ pathology on computed tomography (CT) was in the anterior/ventral aspect of the SIJ in 13 patients with block-confirmed SIJ pain [14].

8.2 Pathology, Clinical Symptoms, and Diagnosis of Sacroiliac Joint Pain

Acute and chronic axial or rotational overloading can lead to SIJ injury. In 40–50 % of cases, SIJ pain is associated with a specific inciting event such as a motor vehicle collision and fall onto the buttocks. Other causes include cumulative injuries such as lifting and running [15]. Intra-articular pathology, extra-articular ligamentous damage, and inflammation can cause pain. Common causes of SIJ pain include osteoarthritis, repeated athletic endeavors leading to joint stress, and HLA B27 seronegative spondyloarthropathies such as psoriatic arthritis. SIJ pain also occurs in peri- or postpartum patients. Pain in the gluteal and/or paraspinal regions below the fifth lumbar vertebrae are the most common complaints. SIJ pain may radiate to the thigh. Nearly one fourth of the patients may have referred pain distal to the knee. SIJ pain may be worsened by transitional movements such as rising from a sitting position [16].

Unique characteristics, which are typically not seen in other diarthrodial joints, make diagnosing SIJ pathology difficult and elusive. Anatomic abnormalities may not be present on imaging. Previous studies have shown that no single test can reliably identify SIJ pathology. Therefore, multiple studies have been done to improve the diagnostic accuracy of SIJ pain including local anesthetic blocks, combinations of physical maneuvers, and imaging techniques [4–8]. Szadek et al. [17] conducted a systematic review and concluded that three or more positive stressing tests, the compression test, and the thigh thrust have enough discriminative power that they can be used for diagnosing SIJ pain. However, Song et al. [18] later reported that this is of limited value in establishing sacroiliitis. Multiple Cochrane review publications indicate that there is moderate evidence for the accuracy and validity of local anesthetic injections to establish SIJ as the cause of pain [19]. Other sources such as the Centre for Reviews and Dissemination at the University of York from the National Institute for Health Research cite a lack of evidence for diagnostic local anesthetic injections [20]. Despite the differing opinions, clinicians typically diagnose SIJ pain by one or two intra-articular local anesthetic blocks with a greater than 50 % decrease in pain [14]. Alternatively, selective blocks of the S1, S2, and S3 lateral branches may be used for diagnostic purposes.

8.3 Radiofrequency Targets in Sacroiliac Joint Pain

Radiofrequency ablation (RFA) is appropriate for patients with a positive diagnosis of SIJ pathology as the cause of their symptoms and insufficient duration of relief after inadequate SIJ injections. Appropriate patient choice is of paramount importance; patient selection is the silent partner of success. Typically, this consists of one or two intra-articular local anesthetic blocks. Establishing an accurate diagnosis of SIJ pain remains a point of controversy among practitioners. Contraindications to RFA include coagulopathies, ongoing sepsis, therapeutic anticoagulation, or presence of nearby invasive lesions such as tumor or infection. Relative contraindications include previous failed RFA to same target, unoptimized psychiatric conditions, target site deafferentation/neuropathic disorders, alteration of target anatomy with prior surgical intervention, and unrealistic expectations of pain relief. Patients with spinal cord stimulators and pacemakers need special care as RFA devices may interfere with their function. The grounding pad should be placed away from these devices so that current may be drawn away.

Interestingly, RFA is more effective for extra-articular rather than intra-articular joint pain [21]. RFA for SIJ pain poses unique challenges to the practitioner. Conventional RF lesions are prolate ellipsoidal in shape [22]. In conventional RFA, the bulk of the lesion's volume is spread circumferentially around the long axis of the uninsulated tip of the probe (Fig. 8.2). Therefore, optimal positioning of a conventional RFA probe lies parallel to the path of sensory nerves. Perpendicular positioning is not optimal and carries a higher probability of unsatisfactory nerve ablation. SIJ innervation is variable and includes nerves that travel laterally from the sacral foramina toward the SIJ. It is not practical to place the RFA probe parallel to the horizontal path of these nerves due to the flat posterior plane of the sacrum. Therefore, the location for proper RFA probe placement is unclear, and various techniques have been studied.

RFA after diagnostic SIJ local anesthetic blocks has inherent limitations. Not all patients

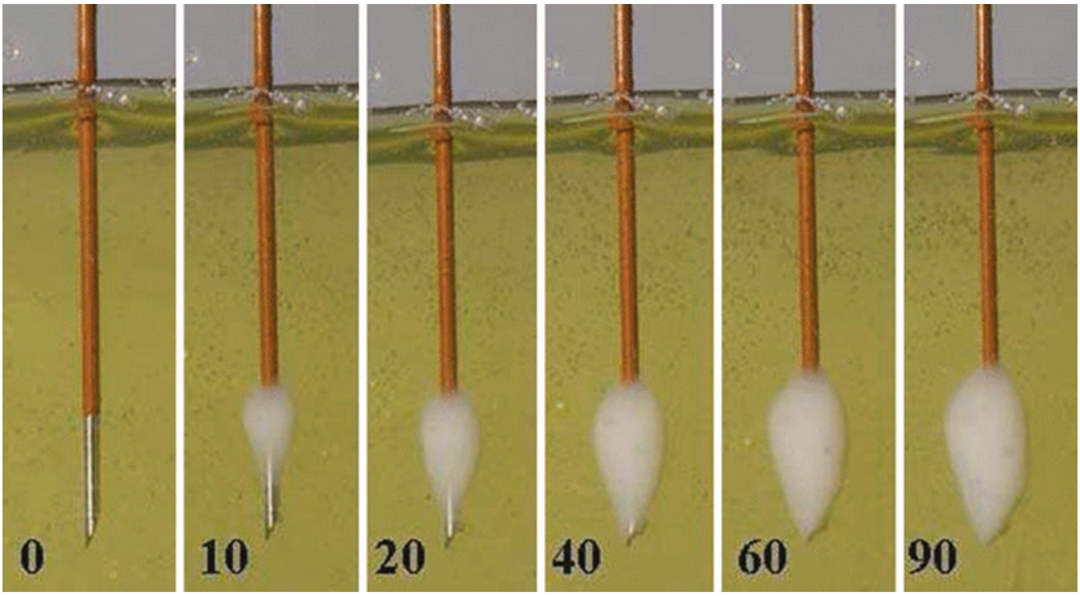

Fig. 8.2 Conventional radiofrequency is prolate ellipsoidal in shape. The bulk of the lesion's volume is spread circumferentially around the long axis of the uninsulated tip of the probe. Figure shows the spread of the lesion over 90 seconds

with SIJ pathology as the source of their pain and with >50 % pain relief after diagnostic local anesthetic blocks will benefit significantly from RFA. It is not possible to reproduce a local anesthetic block with RFA. RFA is limited to neurotomy of posterior SIJ innervation, but local anesthetic solution spreads within the joint and has the potential to block sensation from intra-articular surfaces and surfaces innervated by ventral nerves. Variety in SIJ anatomy due to the bony contours of the sacrum and varying paths of the sacral nerves make it technically challenging to perform RFA parallel to the target nerves. Consequently, it is difficult to denervate the entire nerve network that contributes to SIJ pain. In addition, guidelines for facet joint RFA are based on 100 % pain relief with local anesthetic blocks. As a result, it may be difficult to replicate the results of facet joint RFA for SIJ pathology.

Larger gauge electrodes (size 14–16) have a higher likelihood of mechanical injury, bleeding, and deafferentation pain. However, SIJ RFA targets are not adjacent to major vessels or important functional nerves. Therefore, larger gauge electrodes may be used for SIJ RFA. In addition, SIJ RFA target sites are not excessively vascular, and they are well insulted by the bony structure of the sacrum. Dissipation of heat away from the contacted tissue (i.e., heat washout) is less of a concern except if the active tip is close to the skin. It is important to monitor the rate of temperature change because raising temperature too quickly risks unpredictable lesions and cavitations.

8.4 Nerve Localization with Electrostimulation for Sacroiliac Joint Radiofrequency Ablation

Multiple approaches to SIJ RFA have been published. There is no literature consensus over which approach is best [24–26]. Undeniably, more randomized controlled trials are needed to strengthen the evidence for SIJ RFA. Several studies have localized RFA sites lateral to the sacral neural foramina by using provocative electrical stimulation. Neurotomy is performed at sites that produce pain with minimal electrical stimulation. Selective targeting of symptomatic nerve branches is theoretically attractive. Yin et al. performed stimulation-guided mapping of the dorsal sacral plexus and subsequent neurotomy in 2001 [27]. They applied 50-Hz, 1-ms stimulation at 0.4–0.7 V termed "searching voltage." An RF lesion generator with advanced stimulation capabilities (model RFG-3C +; Radionics, Burlington, MA) was used with 100-mm, 20-gauge, 10-mm active tip, curved, blunt RF electrodes (model RFK-100; Radionics). The RF electrodes were finely manipulated until reproduction of usual pain or paresthetic somatic or cutaneous sensation was elicited with electrical stimulation. RF lesions were created at 80 degree Celsius (C) for a period of 60 s. They defined a successful block as greater than 50 % consistent decrease in visual integer pain score, maintained for at least 6-month post-procedure. If the dorsal sacral area was viewed as a clock face, they applied stimulation to 6 o'clock to 10 o'clock on the left and 2 o'clock to 6 o'clock on the right. 64 % of patients experienced a successful outcome.

Similar studies report 60–89 % of subjects achieving >50 % relief after 4–9 months of follow-up. Albeit theoretically appealing, localization with stimulating may be technically demanding, associated with prolong procedure times and patient discomfort. Patients may also need to be premedicated with parenteral analgesic medications. Furthermore, once the sensory nerve is found, local anesthetic must be given so that the patient may tolerate the ablation. However, the spread of local anesthetic precludes the identification of other symptomatic nerves.

8.5 Traditional Radiofrequency for Sacroiliac Joint Pain

Gevargez et al. recruited 38 patients with SIJ pain who had >50 % improvement of their pain with local anesthetic injections [23]. This study was unique because of *direct* RF application to the SIJ. The rationale behind this approach was numerous clinical and anatomical papers showing that the SIJ is thoroughly innervated, and there are excessive sensory innervations in the ligamentous SIJ structures [28–31]. Monopolar CT-guided RF lesioning was performed at one L5 posterior ramus site and at three intra-articular/posterior interosseous sacroiliac ligaments. CT imagery was used to position the cannula with the most suitable access to the posterior interosseous sacroiliac ligaments (Fig. 8.3). A 10- or 15-cm, 23-G-insulated RF cannula with a 5-mm uninsulated tip (Leibinger) was used. The probe was placed in a satisfactory position in the ventral portion of the ligamentous SIJ component, and this location was confirmed by CT. Three overlapping RFA lesions were produced by applying heat for 90 s and withdrawing the cannula 5 mm each time. They used an RFA temperature of 90 °C, and the total average coagulation time was 7.2 min. At 1-month follow-up, approximately 70 % of patients reported no pain or substantial pain reduction. At 3-month follow-up, about 65 % of patients reported no pain or a substantial reduction in pain.

Cohen et al. studied the outcome predictors for SIJ RFA in 2009 [32]. They recruited 77 patients with refractory, injection-confirmed SI joint pain at two academic centers. Patients underwent conventional RFA lesioning at the L4 and L5 dorsal rami with 22-gauge SMK-C10 (Radionics, Burlington, Mass) 5-mm active tip cannulae parallel to the course of the nerves until bone was contacted at the junction between the superior border of the transverse and superior articular processes for L4 and in the groove of the sacral ala for L5. Electrostimulation was used at 50 Hz at 0.5 V or less to confirm target nerve location. 90 s 80 °C lesions were made. However, S1 to S3 lateral branch block denervation was performed with either cooled or conventional RFA based upon availability, physician preference, and reimbursement considerations. Either 17-gauge cooled electrodes with 4-mm active tips (Baylis Medical, Montreal, Quebec, Canada) or 22-gauge SMK-C10 electrodes were inserted at the S1–S3 foramina in 1 and 5:30 o'clock positions on the right and 6:60 and 11 o'clock on the left. 90 s, 80 °C lesions were used for SMK electrodes to make approximately 3–4-mm lesions. For the 17-gauge electrodes, 2.5-min lesions were made using a water-cooled heating system leading to 8–10-mm lesions. Successful outcome was defined as greater than 50 % reduction in

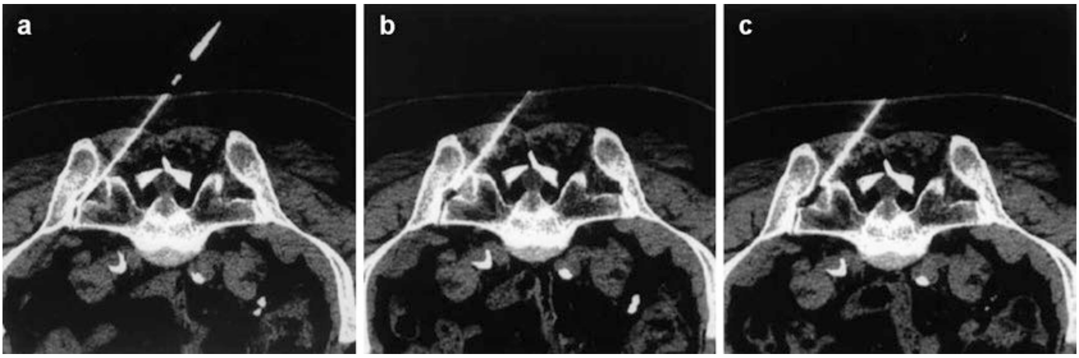

Fig. 8.3 (**a**–**c**) CT image of positioning of the cannula. (**a**) Cannula is placed in ventral portion of ligamentous SIJ component. Then, it is withdrawn by 5 mm to produce an overlapping lesion (**b**, **c**) (Gevargez et al. [23])

pain lasting at least 6 months coupled with a positive global perceived effect. 52 % of patients obtained a positive outcome. Although statistically insignificant, they noted a trend toward improved success with cooled RFA when compared to conventional RFA. They attributed this increased success to the larger lesions created by cooled RFA.

Preprocedure pain intensity, age over 65 years, and pain radiating below the knee were predictors of failure. An inverse correlation between duration of symptoms and difficulty in controlling pain has been described for RF and other procedures [33–35]. This may be due to neuroplasticity that develops with long-standing pain. Elderly patients are more likely to experience progressive arthritic SIJ pain rather than pain from peri-/extra-articular causes seen in younger patients – these may be self-limited and may explain improvement of symptoms. Opioid use had a trend toward negative outcome; this may be due to subclinical nociceptor sensitization, secondary gain issues, or higher incidence of overlying psychopathology [36–39].

Mitchell et al. conducted a large prospective, observational study of 215 patients undergoing conventional radiofrequency. Only patients with a positive response to SIJ blocks with local anesthetics were recruited for this study [40]. In this study, the L5 descending branch of the dorsal ramus and S1 to S3 lateral branches were targeted. RFA needles were placed parallel to the targeted S1–S3 lateral branch nerves. This was facilitated by lateral views with the C-Arm. Subsequently, lesions were made from the inferolateral corner to the superolateral corner of the S1 to S3 foramen. RFA lesions were made at 90 °C for 90 s. They demonstrated a decreased pain score, reduced analgesic use, and improved employment capacity in approximately 25 % of patients and satisfaction of outcome in two thirds of patients. There is a relative paucity of literature regarding analgesic use after SIJ RFA. This study found a trend for decreased opioid analgesic use in 47.5 % of patients, with nearly half of these patients reporting an extreme decrease in opioid consumption. Limitations of this study included the lack of an independent control group and weak outcome parameters.

8.6 Pulsed Radiofrequency for Sacroiliac Joint Pain

Instead of a continuous flow, pulsed RFA delivers short bursts of RF current. This results in considerably lower maximum temperatures, which allows the tissue to cool. This reduces the risk of neighboring tissue destruction. It is also less painful than conventional RF because it does not rely on tissue destruction [41]. In pulsed RFA, the needle should be placed perpendicular to the nerve because the greatest electric field is created in front of the needle. Due to the anatomic nature of the SIJ, and the technical difficulty of placing the probe parallel to the sacral nerves, pulsed

RFA offers a theoretical advantage of creating more efficient lesions than conventional RFA. However, there is a paucity of data on pulsed RFA for SIJ pain.

Vallejo et al. published a case series for pulsed RFA for SIJ pain syndrome in 2006 [42]. Investigators chose to perform pulsed RFA in patients who had pain relief after at least one diagnostic local anesthetic block. Furthermore, only patients who failed conservative management including two consecutive injections, physical therapy, repeated SIJ injections, and/or analgesics were recruited for pulsed RFA. 22 patients underwent pulsed RFA of medial branch of L4, posterior rami of L5, and the lateral branches of S1 and S2. A 22-gauge, 10-cm-long, 10-mm active tip RFA needle (Radionics, Burlington, MA) was used. Pulsed RFA parameters were 45 V for 120 s and temperatures ranged from 39C to 42C. Primary outcomes were visual analog scale (VAS) and quality of life assessments. Of the patients treated with pulsed RFA, 72.7 % (16/22) patients experienced >50 % reduction in VAS. 26.1 % (6/22) of patients did not respond to pulsed RFA. This study did not include a control group, and the sample size was rather small. The interventionists did not treat nerve roots originating from the S3 foramina, which may account for some failed therapies. Overall, this study establishes that pulsed RFA is safe and an effective treatment for patients with SIJ pain refractory to other treatments.

8.7 Cooled Radiofrequency for Sacroiliac Joint Pain

Water-cooled RF prevents proximal tissue from reaching excessive temperatures because the cooled cannula acts as a heat sink to absorb energy. This allows distal tissue to reach high temperatures while preventing excessive proximal tissue damage from extreme temperatures. The overall advantage of water-cooled RF is that it can produce larger lesions (Fig. 8.4). The SIJ is the most significant application for water-cooled RF [43]. Currently, there are only two random controlled trials published for SIJ RFA, and both have been performed with cooled radiofrequency.

Cohen et al. conducted the first randomized controlled trial using water-cooled SIJ RFA in 2008. They recruited 28 patients with positive response to SIJ blocks (i.e., >50 % pain relief). Fourteen patients were included in the placebo

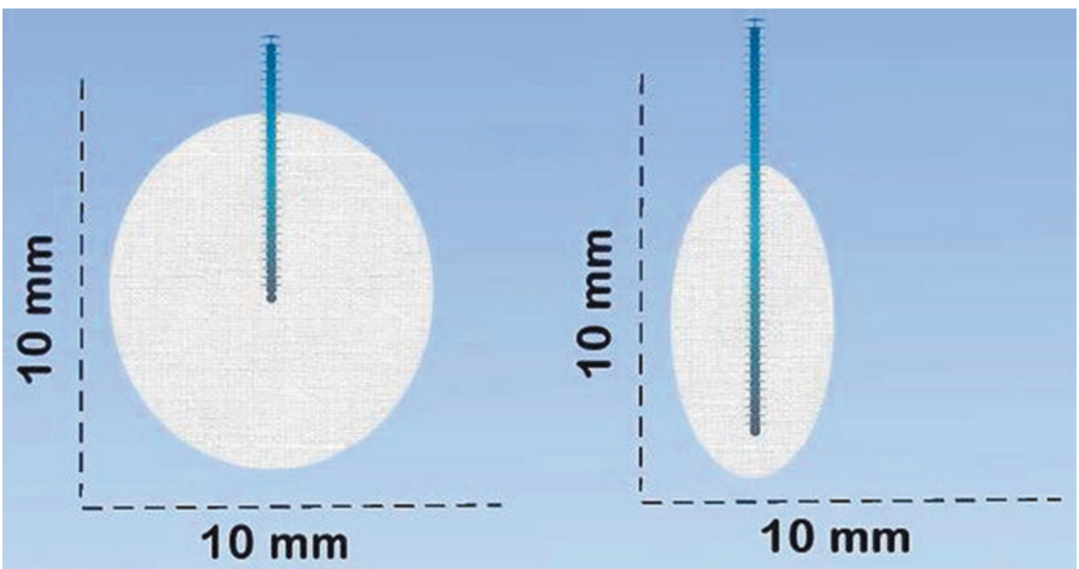

Fig. 8.4 Cohen et al. demonstrated the differences in lesion sizes between cooled RFA (*left*) and conventional RFA (*right*) (Pain Management SInergy System: Baylis Medical) (Cohen et al. [44])

group and received local anesthetic injection followed by placebo radiofrequency. Intervention consisted of cooled radiofrequency of L5 primary dorsal ramus and S1 to S3 lateral branch RFA after local anesthetic block. For L4 and L5 dorsal ramus lesioning, 22-gauge SMK-C10 cannulae (Radionics, Burlington, MA) with 5-mm active tips were inserted parallel to the course of the nerve. For S1–S3 lateral branch RFA, 17-gauge, 75-mm cooled electrodes with 4-mm active tips (Baylic Medical, Montreal, Quebec, Canada) were placed in 1, 3, and 5:50 o'clock positions on the right and 6:30, 9, and 11 o'clock positions on the left. At S3, needles were placed at 1:30 and 4:30 on the right side and at 7:30 and 10:30 on the left side (Fig. 8.5). 80 °C lesions were made for 90 s. At 1, 3, and 6 months after the procedure, 79, 64, and 57 % of patients experienced pain relief of 50 % or greater and significant functional improvement. In the control group, 14 % of patients experienced significant pain relief at 1 month. No patients in the placebo group had significant pain relief at 3 months of follow-up. This was the first placebo-controlled study evaluating SIJ RFA and provided some of the strongest evidence for the efficacy of SIJ RFA. However, critics have argued that the control group may have been an active control [20, 44].

Patel et al. conducted the second randomized, double-blind, placebo-controlled cooled RFA trial for SIJ pain in 2012 [45]. Fifty-one patients were randomized on a 2:1 basis to lateral branch neurotomy and sham neurotomy,

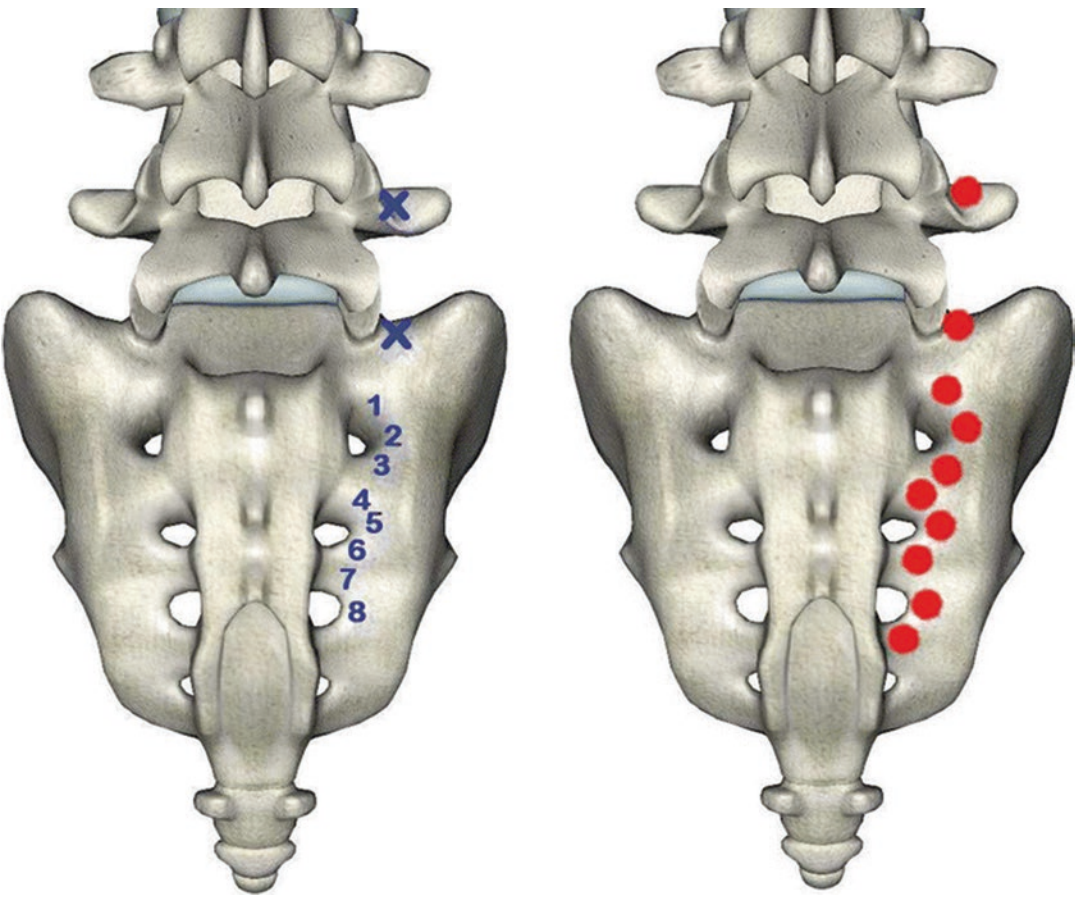

Fig. 8.5 Cohen et al. used a "leap-frog" technique with cooled RFA for S1–S3 lateral branch neurotomy. On the *left*, the sequence of probe placement is numbered around the sacral foramina (Cohen et al. [44])

respectively. Patients in the placebo group received local anesthetic injection followed by sham RFA. The control group received cooled RFA with ablation of the S1 to S3 lateral branches and L5 dorsal ramus. Equipment sounds, probe placements, procedure durations, and visual indications to the patients were identical in both groups. L5 dorsal ramus was lesioned with a cooled RF Synergy probe (Kimberly Clark Health Care, Roswell, GA, USA). RFA was applied for 150 s at a temperature of 60 °C using a pain management radiofrequency generator (Kimberly Clark Health Care). Sacral lateral branches of S1–S3 were targeted by 17-gauge, 75-mm cooled electrodes with 4-mm active tips (Kimberly Clark Health Care). The 17-gauge cannulae were positioned 2 mm from the surface of the sacrum. Impedance was confirmed between 100 and 500 ohms. RFA was applied for 150 s at a temperature of 60 °C. The principal outcomes were changes in numeric pain scale, physical function, disability, quality of life assessment, and treatment success. Authors found statistically significant changes that favored the lateral branch neurotomy group at 3-month follow-up and included decreased pain, improved physical function, decreased disability, and improved quality of life. At 3, 6, and 9 months, 47 %, 38 %, and 59 % of patients in the treatment group achieved treatment success, respectively. Similar to the randomized controlled trial by Cohen et al. in 2008, critics have argued that the place group may have been an active control.

Steltzer et al. retrospectively evaluated 126 patients treated with water-cooled RFA in 2013 [46]. Patients were selected based upon a positive response to an intra-articular SIJ block with 50 % pain relief and physical exam findings consistent with SIJ pain. Water-cooled RFA neurotomy of L5 dorsal ramus, and S1 to S3 lateral branches was performed after lidocaine and bupivacaine infiltration. Optimal tissue impedance was optimized between 300 and 500 ohms. A total of nine lesions were created using the Pain Management SInergy System (Kimberly Clark Corporation, Roswell, GA, USA) (Fig. 8.6). RFA energy was delivered for 2 min and 30 s at a target temperature of 60 °C. Outcome measures included visual analog scale (VAS), quality of life, medication usage, and patient satisfaction. Authors noted improvement in quality of life and a 50 % or greater reduction in VAS in 86 % of patients after 4–6-month-follow-up and 48 % after 12-month follow-up. Although retrospective, this was a much larger study than the previous randomized controlled trials of SIJ RFA.

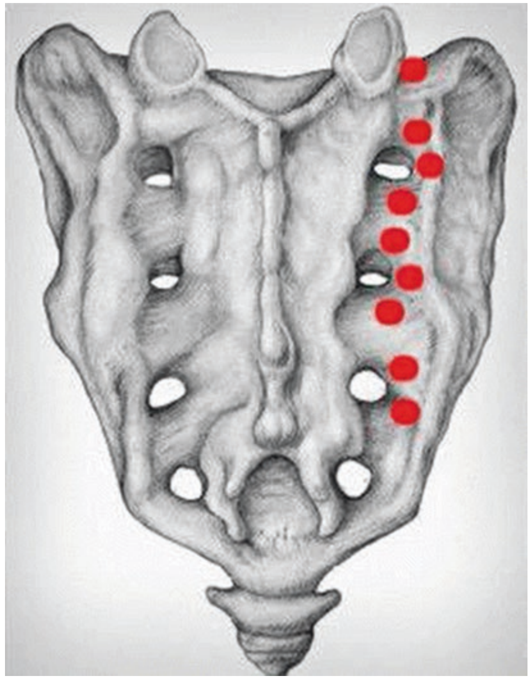

Fig. 8.6 Stelzer et al. created a total of nine lesions. L5 dorsal ramus and S1–S3 lateral foramina were targeted. No lesion was created at L4 dorsal ramus (Stelzer et al. [46])

8.7.1 Cooled Versus Conventional RFA

Cheng et al. performed a retrospective assessment of patients with 58 patients receiving cooled radiofrequency and 30 patients receiving traditional radiofrequency [47]. All patients had at least 3 months of pain and achieved >50 % pain relief after two SIJ blocks with local anesthetic. Nerves were localized using sensory electrostimulation at 50Hz. Nerves from L5 to S3 were lesioned. For conventional RFA, nerves were lesioned with a 22-G SMK-C10 (Radionics, Burlington, MA) cannula with a 5-mm active tip. Conventional RFA lesions were made for 90 s and at 80 °C. Cooled RFA lesions were made by using a water-cooled heating system (Pain Management SInergy System, Baylis Medical Company, Montreal, Canada) that used 17-G, 75-mm electrodes with 4-mm active tips. In both groups, 50–60 % of patients had >50 % pain relief. The authors concluded that the relief after treatment was comparable and that there was no significant difference between the two groups.

There are notable shortfalls of this study. A 50 % pain reduction without any functional outcome was used as the outcome measure. The procedures were performed by different clinicians, and the techniques may not have been consistent. The retrospective nature of this study resulted in several demographic differences between the two groups. Patients in the cooled RFA group were significantly younger, had more spine surgeries, and had more post-RFA steroid injections. This study has also been criticized by Patel and Cohen [48] noting that the sample size was inadequate and that prospective randomized studies are necessary to infer differences between the two techniques. Experts in the field continue to believe that cooled RFA may be the better option.

8.8 Bipolar Radiofrequency for Sacroiliac Joint

In monopolar RFA, a large grounding pad is placed on the patient's skin, and the circuit is completed by electrical current passing form the active electrode through the surrounding tissue. In contrast, bipolar RFA consists of two electrode tips placed alongside each other. This allows current to pass from one electrode to the other (Fig. 8.7). The current density and electric fields are focused between the two electrodes, and when optimally spaced, the result is a lesion larger than that created by two monopolar electrodes alone [14]. Bipolar lesions are optimal at an interelectrode distance of 4–6 mm. Other factors that influence the size of lesions include the composition of tissue, energy used, and the gauge of cannulae [49, 50].

Burnham et al. described a "leap-frog" technique of using bipolar RFA for SIJ pain. Nine patients with SIJ pain for over 6 months were

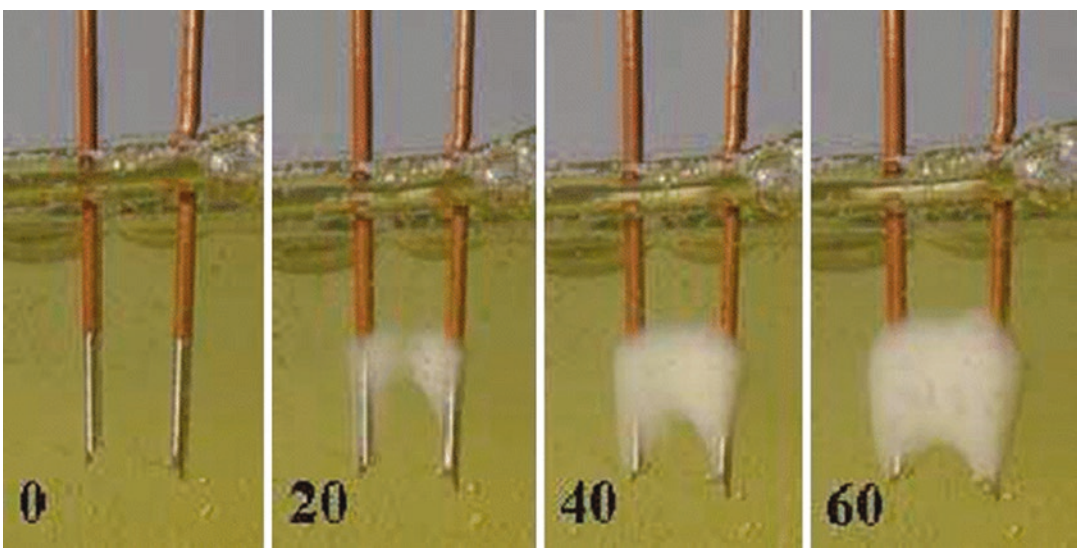

Fig. 8.7 Bipolar RFA consists of two electrode tips placed alongside each other. This allows current to pass from one electrode to the other. With bipolar RFA, it is possible to create lesions larger than monopolar RFA. Bipolar lesions are optimal at an interelectrode distance of 4–6 mm

recruited [51]. Participants had at least >50% relief of index pain on at least one fluoroscopy-guided local anesthetic injection. They ablated the L5 posterior ramus at the junction of the sacral ala and the root of the superior articular process of S1. Subsequently, for a right sacral foramen, a lesion was made between the 12 and 2 o'clock positions. Then the 12 o'clock needle was removed and placed at the 4 o'clock position. After this, the 2 o'clock needle was removed and placed at the 6 o'clock position. These "peri-foraminal strip RF lesions" were completed for sacral foramina S1–S3. A 20-gauge, 10-cm-long, 10-mm exposed curved-tip cannula (model PMC 20-100-10CS; Baylis MedicalCompany, Montreal, Quebec) through which an active probe (model PMP-20-100C, Baylis Medical Company) was passed, which was attached to an RF generator (model PMG-115, Baylis Medical Company). The RF cannulae were placed 4–6 mm apart. The RF lesions were made at a temperature of 80 °C for a duration of 90 s. The percentage of patients who were "very satisfied" during this pilot study at 1-, 3-, 6-, 9-, and 12-month post-procedure was 78, 67, 67, 89, and 67%. However, satisfaction is subjective and may not equate to pain relief. Therefore, this study is difficult to compare to others. A similar method of successful SIJ RFA has been described by Ferrante and Cosman.

8.9 Multilesion Probe RFA for Sacroiliac Joint Pain

Schmidt et al. conducted the first retrospective SIJ RFA study with a *multilesion* probe in 2014 [52]. Simplicity III (Neurotherm, Middleton, MA) is a curved probe with three electrodes. It has the ability to generate three monopolar and two bipolar lesions, which create an overall 9×52.5-mm lesion [53] (Fig. 8.8). Two separate institutions performed 77 RFAs in a total of 60 patients. Included patients had previously positive responses to diagnostic intra-articular injection with >50% improvement in pain, and these patients had physical exams consistent with SIJ pain. Under fluoroscopic guidance, the probe was inserted through the skin to contact the bony margin lateral to the S4 foramen and then advanced to lie over the posterior sacral plate. Patients who were not fused at L5–S1 also had RFA lesions (80 °C, 90 s) performed of the L5 dorsal ramus. Fifty-five out of sixty patients had greater than 50% pain relief at 6 weeks, and about thirty-two patients had pain relief 6 months. This was the first study with a multilesion probe with promising results.

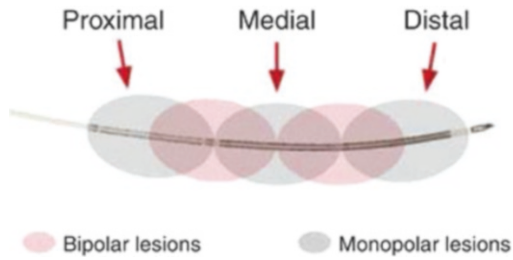

Fig. 8.8 The simplicity probe has three independent, active electrodes with the capability to create monopolar and bipolar RFA lesions (St. Jude Medical. St. Paul: St. Jude Medical, MN. Simplicity Medical. St. Jude Medical, 2 June 2015. Web. 22 June 2016)

The clear advantage of using a multilesion (Simplicity III) probe is one needle-entry site, which can decrease patient discomfort and obviate the need for cannulae and introducers. Recently, Gilligan et al. [54] have described a Seldinger technique for multilesion probe RFA that allows the probe to be placed precisely along the anesthetized track with a single percutaneous puncture. RFA at 85 °C for 1.5 min with impedance in the range of 100–300 ohms was applied. The single-stick approach has the potential to decrease the risk of bowel perforation, patient discomfort, and procedure time. In contrast to the "leap-frog" technique described for bipolar RFA, multilesion probes can produce a continuous "strip" lesion, which may have a higher likelihood of capturing lateral branches of S1–S3 (Fig. 8.9). This technique has some limitations. Aligning the multilesion probe over the sacral plate may be technically challenging in patients with a large body habitus. Neurolysis by multilesion probes occurs at a single depth, and this may not account for SIJ nerves that travel at different depths.

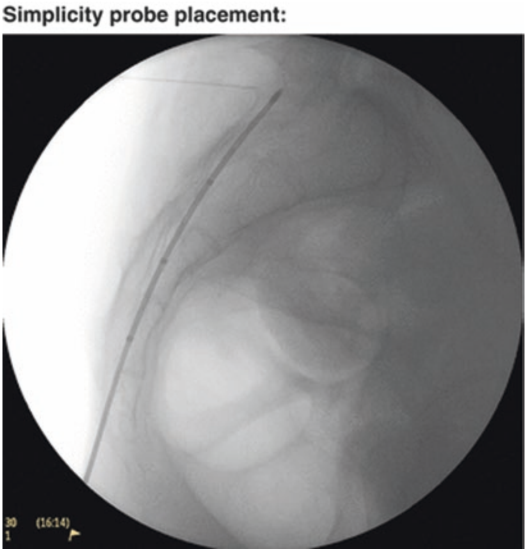

Fig. 8.9 The Simplicity III (St. Jude Medical) probe is flexible and replicates the natural curvature of the SIJ (Gilligan PPT)

8.10 Sacral Insufficiency Fractures as a Cause of Low Back Pain

Sacral insufficiency fractures (SIF) were first described in 1982 and are a significant source of debilitating back pain. SIF diagnosis is challenging because of inconclusive imaging and nonspecific signs. Similar to sacroiliac joint pain, SIF can present with pain radiating from low back to the buttocks. This makes the differentiation between SIF and SJI difficult [55, 56]. Historically, there were limited approaches to treating sacral pain resultant from sacral insufficiency fractures. As a result RFA of the SIJ has been tried, anecdotally, for these types of lesions. Borrowing from more traditional vertebral augmentation techniques, the percutaneous injection of polymethyl methacrylate has also been used to stabilize these fractures and thus reduce pain. Both prospective and retrospective studies suggest promise of this technique [57–59].

8.11 Future Directions

At present, there are only two randomized control trials of SIJ RFA, and these have been performed with cooled RFA only. Further studies need to be performed regarding cost–benefit analysis that compares RFA to conservative management such as analgesics, serial injections with steroids or local anesthetics, and physical therapy. Another important area that remains to be studied is whether SIJ RFA interventions can delay or prevent progression surgical intervention for SIJ pain.

SIJ pain continues to be a significant burden. Functionality in a large number of patients is limited due to SIJ pain. SIJ pathology is expensive to diagnose and treat. Currently, there are no clear published guidelines or recommendations for the diagnosis of SIJ pain, indications for SIJ RFA, or for the optimal technique of SIJ RFA. As evidence for sacroiliac joint radiofrequency accumulates [20], it will be important to reach a consensus and establish a cohesive strategy against this challenging problem.

Conclusion

RFA neurolysis is safe and modestly effective for a number of chronic pain syndromes, including SIJ pain. The SIJ remains difficult to study with variable anatomy between individuals. There is also variability in the path sacral nerves travel between the left and right sides of the body. Patient selection for SIJ RFA remains empiric. Further large randomized trials demonstrating efficacy are lacking. Information regarding RF treatment for SIJ is accumulating, and there is a growing body of information that testifies to its effectiveness.

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9 Discogenic Low Back Pain and Radicular Pain: Therapeutic Strategies and Role of Radio-Frequency Techniques

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9.1 Pathogenesis and Diagnosis

9.1.1 Discogenic Low Back Pain

In 1970 Crock referred to IDD as a painful condition due to alteration in the internal structure of the intervertebral disc [9]. The intervertebral disc is composed by the nucleus pulposus and annulus fibrosus. The nucleus pulposus has an extracellular matrix of proteoglycans and collagen. The proteoglycans have the ability of attracting and retaining water [10]. The extracellular matrix tolerates axial forces and gives to the disc the abilities of a semifluid during the various movements of the vertebral column. However the nucleus pulposus obtains its nutrition from the vertebral body end plates and from blood vessels in the annulus fibrosus by diffusion [11]. Annulus fibrosus is composed by a complex network of collagen fibers, which acts as a strong shell of the nucleus pulpous and allows some degree of movement of the superior and inferior vertebrae. The posterior third of the annulus fibrosus has a smaller thickness condition which is the basis of the more frequent posterior annular tears [2, 12]. Especially nerve fibers of the sympathetic system are present in the vertebral disc [13] (Figs. 9.1 and 9.2).

IDD is characterized by dehydration of the nucleus pulpous and disruption of the inner lamella of the annulus fibrosus by radial fissures [2]. In the healthy disc only the outer third of the annulus fibrosus is innervated. When radial fissures occur, nerve endings are exposed to enzymes and breakdown products involved in degradation processes. It has been studied in this way nerve endings extend in the inner third of the annulus fibrous and in the nucleus pulposus [14].

9.1.2 Radicular Pain

Pathogenesis of radicular pain is a complex mechanism, which leads to molecular and cellular changes of the herniated disc and peripheral axons [15]. The extrusion of material from the nucleus pulposus leads also to reduced blood flows of the nerve roots with secondary edema [16]. Production and release of cytokines as TNF-α change the local microenvironment of the DRG and the spinal dorsal horn. In this way the production of neurotrophins started with following sensitization of the synaptic transmissions of the compressed nerve roots and neighboring uncompressed ones [17] [18]. The Wallerian degeneration of the involved axons is the final results, with alteration on electromyography examination [19]. As above explained, these mechanisms cause also ectopic response from

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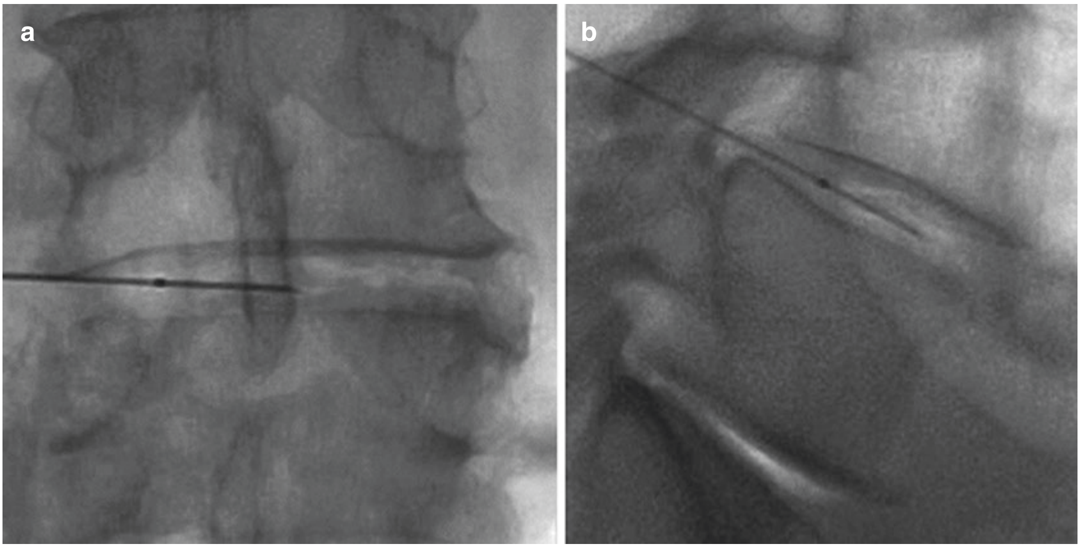

Fig. 9.1 Under anteroposterior (**a**) and lateral (**b**) fluoroscopic control, a 20-G RF needle with a 20-mm active tip is placed in the center of the intervertebral L4–L5 disc

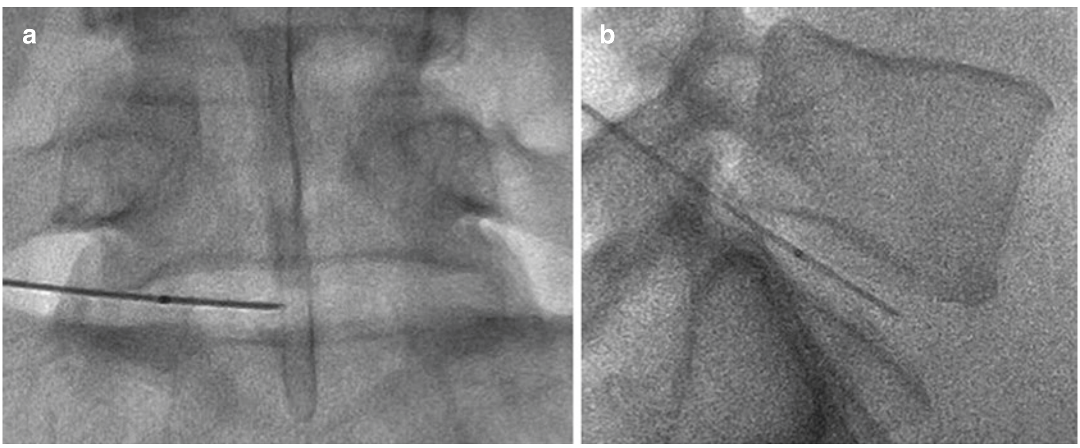

Fig. 9.2 Under anteroposterior (**a**) and lateral (**b**) fluoroscopic control, a 20-G RF needle with a 20-mm active tip is placed in the center of the intervertebral L5–S1 disc

neighboring nerve roots, with following difficult in precise diagnosis and treatment of involved nerve roots [20].

9.1.3 Diagnostic Strategies and Role of Imaging

There are not specific clinical tests or blood examinations for discogenic LBP. Currently the diagnosis is made only by a provocative discography. There are precise criteria for positive discography: abnormal morphology of the examined disc, presence of "concordant" pain by provocation, no pain experienced by provocation of the nearest healthy discs, and less than 3 mL of injected contrast agent [21]. Studies established discography is painful only in the abnormal disc, while voluntary patients well tolerated the procedure in the normal disc without symptoms [22]. Discography requires injection of contrast agent into the center of the disc, usually less than 3 ml, after a needle has been positioned under fluoroscopic guidance. This procedure, via chemical stimulation and mechanical stimulus resulting from fluid-distending stress, may evoke pain in the patient, who should refer it as its usual or "concordant" pain [23]. A recent technique considers the introduction of pressure-controlled contrast agent into the disc, which is needed to distinguish real painful disc from the healthy nearest ones [24].

Magnetic resonance imaging (MRI) allows the assessment of multiple disc levels in a single examination. In 1992 April and Bogduk first described the high intensity zone (HIZ) in the posterior annulus fibrosus, separated from the nucleus pulposus [25]. It is suggested inflammation of the annular fibrosus fissure causes the HIZ, and this inflammation also provokes nerve fiber irritations. Some studies recorded high values over 70–80 % of sensitivity, specificity, and positive predictive value [26] [27]. Anyway, other studies described normal MRI findings in patients with surgically proven IDD and abnormal discography [28].

Disc herniation can be categorized as central, involving the lateral recess of the spinal canal, foraminal, or extra-foraminal. MRI provides these informations, but physicians usually meet patients who have radicular pain with one or more disc protrusions. Electromyography plays an important role in the research of the more damaged nerve roots and, therefore, helps to decide which disc level should be treated [29].

9.2 Treatment

9.2.1 Therapeutic Strategies of Discogenic Low Back Pain

In early stages physicians treat discogenic LBP with conservative therapies as pharmacological (analgesic and anti-inflammatory drugs) and physical therapies, with variable results [30, 31]. To provide an alternative to failed conservative therapies, in the years, several percutaneous intradiscal procedures for discogenic LBP have been introduced in clinical practice.

Intradiscal injection of steroids is a therapeutic option used by discographers with the aim of inflammation suppression [32].

Intradiscal injection of ozone gas has been proposed in the 1980s as a treatment for disc herniation. Ozone is a strong oxidizer and its application to the nucleus results in cleaving of the proteoglycans, which bind hydroxyl groups from water molecules [33]. A reduction of the herniation volume is finally obtained [34].

Intradiscal thermal procedures (ITP) have the rationale of applied heat to the posterior annulus of the degenerated disc, where usually radial fissures occur and nerve endings evoke pain. Sluijter first introduced percutaneous intradiscal heating in 1993 with a standard RF needle inserted into the center of the disc and heated 90 s at 70 ° C [35].

ITP include intradiscal electrothermal therapy (IDET), percutaneous intradiscal radio-frequency thermocoagulation (PIRFT), radio-frequency annuloplasty, intradiscal biacuplasty (IDB), percutaneous (or plasma) disc decompression (PDD) or coblation, or targeted disc decompression (TDD). The inclusion criteria for ITP typically are axial low back pain with or not radicular symptoms with a duration over 6 months, failure to conservative therapies, concordant pain and abnormal disc morphology on discography, MRI negative for a neural compressive lesion, <30 % decrease in disc height, and no prior surgery [36]. Spinal instability, local or systemic infection, progressive neurological defects, coagulation disorders, and canal stenosis are considered as exclusion criteria [36].

During the IDET procedure, a thermal catheter is placed under fluoroscopically control in the posterior annulus fibrosus through a 17-G introducer needle [37]. Then the coiled active tip (1,5 or 5 cm length) is electrically heated to 90 °C for 16 to 17 min, leading to thermocoagulation of nociceptors and unmyelinated nerve fibers. Treatment may be achieved with unilateral catheter deployment [37]. Risks include infections and damage to neural structures of spine and neural roots, if the tip of the catheter is positioned posterior to vertebral margin or in close proximity to the dura and nerve fibers. Some studies investigated the clinical outcome of patients treated with IDET: good results were recorded in terms of pain relief and quality-of-life improvement with a very low rate of complications [38–40].

PIRFT differs from IDET because thermocoagulation is due to a radio-frequency current, which is generated by a needle positioned in the center of the disc. The device is activated for 90 s at a temperature of 70 °C [37].

TDD is similar to IDET, but the device has an active tip 1.5 cm shorter than that of IDET catheter [41, 42]. Both PIRFT and TDD techniques have the final effect of thermocoagulation of targeted tissues, than no importance is given to dehydration of the disc [42].

PDD or nucleoplasty is a mini-invasive treatment for symptomatic contained disc herniation [43]. PDD uses an electrical current to generate a high-energy plasma field at the tip of the device placed in the disc. This molecular plasma ablates tissue with minimal damage to surrounding structures. When the catheter enters the disc, the coblation creates a 1-nm-thick region of high-energy ionized plasma filed at the tip of the device, which excites the electrolytes in the nucleus and breaks down the molecular bonds. When the catheter moves backward, the coagulation acts, by developing temperatures between 50 °C and 70 °C at the tip of the catheter with degeneration and shrink of the collagen fibers [43]. The rationale of PDD is the removal of nuclear tissue, leading to a reduction in intradiscal pressure. An important exclusion criteria is the dehydrated disc at MRI, where the ionized plasma could not arise [42].

Some prospective research trials and review manuscripts highlight the efficacy of nucleoplasty in terms of pain relief and quality-of-life improvement [44–47]. Anyway, PDD seems to be better in cervical than lumbar segments. An anatomic theoretical explanation affirms that the cervical nerve root is confined to a relatively smaller space than its lumbar counterpart [48, 49].

IDB applies cooled RF energy to cause necrosis of nerve fibers in the posterior annulus fibrosus [50, 51]. Under fluoroscopic or computed tomography (CT) guidance, an RF bipolar electrode is placed obliquely within the posterolateral aspect of the intervertebral annulus. This device has two serially non-insulated metallic surfaces at the tip electrode which act as double poles [50, 51]. In the literature there are not many studies which investigated the efficacy of IBD, however with promising results [50, 52].

9.2.2 Therapeutic Strategies of Radicular Pain

Some trials showed intramuscular injection of anti-inflammatory drugs, steroids, or muscle relaxants is no more effective than sham control groups in the long period treatment of the radicular pain [53, 54]. Authors also documented as interlaminar or caudal injections of steroids are not significantly more effective than sham treatment [55, 56]. These results prompted investigators to the development of other techniques as epidural or trans-foraminal injection of steroids (TFIS) under radiographic control. In the literature there are a lot of studies, which investigated effectiveness of TFIS [57].

TFIS consists in applying the medication directly onto the affected spinal nerve in the intervertebral foramen under radiographic control. The literature does not agree about the kind of corticosteroid preparation which should be used [57]. Studies with successful outcomes from TFIS used different agents at different doses. The volumes injected, however, ranged between 1 mL and 2 mL [57].

The number of injections varied according to the several published trials. Anyway, a high success rate was recorded with a single injection protocol in that studies which documented a successful outcome [57].

Some authors reported collateral events as headache, post-procedure pain, vasovagal reactions, rash, transient leg weakness, and nausea [57]. Trans-foraminal application of RF current developed in recent years with lower rates of complications.

9.3 Intradiscal and Trans-foraminal Radio Frequency

9.3.1 Principle, Technique, and Mechanism of Action

An electrode placed in the site of interest delivers an electrical current in order to generate heat at the specific area. The original interventional pain management with RF method was the continuous radio-frequency (CRF) technique [5]. During the CRF procedure, the constant output of RF energy is delivered through the electrode onto the specific nerve or into the adjacent soft tissues. The aim is to increase the temperature in the area between 60 and 80 °C, with necrosis of the targeted tissues. Thus, the permanent damage causes the consequent interruption of painful signals.

Pulsed radio frequency (PRF) was introduced in 1998 as a non-lytic alternative to CRF. Sluijter et al. in fact published preliminary clinical trials with the aim to use radio-frequency currents to alter the electrical field, but insufficient to cause permanent damage in the targeted tissue [58]. The PRF technique applies short RF pulses in the targeted area with intervals of pauses [5, 6]. The pauses or silent phases between the RF pulses permit the temperature to be kept under the limit of tissue necrosis of 42 °C. Since then PRF has been used for various pain conditions [5, 6].

Pulse-dose radio frequency (PDRF) is a technical development of PRF [59–61]. In PRF as in PDRF techniques, the temperature on the targeted tissue has the same value of 42 °C. In PRF, if the tissue temperature is over that value, the next pulse parameters are modified, usually amplitude or width. In PDRF the generator stops the emission of pulses until the temperature decreases: all of the pulses have the same amplitude and width.

In 2015 a manuscript was published by Masala et al. about the clinical efficiency of PDRF in patients with chronic pain due to trapezio-metacarpal osteoarthritis [61]. Good results were obtained in the mild period (3–6 months), and then the treatment was again performed with similar results. The same authors' group recorded good results in the management of chronic pain in the mild period in athletes with chronic pubalgia, a feasible cause of abstention from any physical activity. In 2014 Masala S. et al. documented PDRF clinical effectiveness (pain relief) and safety (absence of complications) when this technique is performed as a palliative care in knee osteoarthritis, hallux valgus, and pudendal neuralgia [60, 62, 63]. In all of these studies, the RF pulses have an amplitude of 45 V and a duration of 20 ms; a silent phase of 480 ms follows each pulse.

The biological effects of PRF are not well known, but authors believed PRF has neuromodulatory and anti-inflammatory effects. Microscopic damages were discovered after exposure to radio waves, as abnormal membranes and morphology of mitochondria, interruption, and disorganization of microfilaments and microtubules [64]. These ultrastructural injuries interest largely C fibers and A delta fibers, the principal sensor nociceptors [64]. Authors documented how radio waves influence immune cells and inhibit arrest production of pro-inflammatory cytokines as interleukin-1b and interleukin-6 [65]. No long-lasting effects were found [58].

9.3.2 Intradiscal Radio Frequency: Technical Considerations and Clinical Effectiveness

Intradiscal RF has been recently introduced in clinical practice as a mini-invasive therapeutic approach for discogenic LBP. To perform RF techniques, it needs an RF generator with two electrodes in order to form a close circuit [5]. An electrode is placed in the center of the disc to be treated and acts as the active electrode. The active electrode is insulated and only a small tip is left spare with high field densities around it. The second or the dispersive electrode is connected to a large surface plate and is positioned onto the patient's skin. The precise location of the cannula is controlled with fluoroscopy or with computed tomography (CT) guidance. The spindle of the cannula is then removed and the RF probe is inserted with a coaxial technique. The most commonly used sequence is a pulse frequency of 2 Hz, a pulse amplitude of 45 V, and a pulse lasting for 20 ms, followed by a silent phase of 480 ms. Physicians may decide the number of pulses; usually 800–1200 pulses are employed.

Some studies investigated the efficiency of PRF in treatment of discogenic LBP with controversial results. Kapural et al. published a prospective controlled trial which compared PRF with IDET: the IDET group recorded better results than the PRF one at 1-year follow-up in terms of pain relief [66].

Fukui et al. performed intradiscal PRF on 23 patients with discogenic LBP, by using discoblock for diagnosis: low volume (≤1.25 ml) of contrast medium evoked concordant pain, and administration of 1 ml of lidocaine 2 % diminished pain more than 70 %. At 1-year follow-up, 19 of 23 patients demonstrated pain relief on a numeric range scale, and 15 of 23 had >50 % pain reduction [67].

Rohof et al. investigated the role of intradiscal PRF in 76 patients with follow-up to 12 months after the treatment. 28.9 % (22) of patients had no effect after 3-month follow-up, 30 % (23) had >2 points improvement in pain intensity, 38 % (29) had >50 % improvement, and 2 patients were operated. The first two groups of patients were investigated and treated for additional pain foci. At 1-year follow-up, 56 % (43/76) of the patients had more than 50 % improvement in pain intensity [68]. These results pointed out the important role of a clinical examination to perform the correct therapeutic choice and showed PRF as an efficient and repeatable technique.

Teixeira and Sluijter experienced the role of high-voltage, long-duration, intradiscal PRF in eight patients [69]. They started from the hypothesis PRF has no clear mechanisms. Researchers supposed the RF effect is due to exposure to electrical fields or to the production of heat. In the first case, the authors suggested that the controversial results obtained in different studies may be due to the short duration of the procedure and to the reduced voltage [51, 67, 68]. Teixeira and Sluijter then performed intradiscal PRF with pulses of 20 ms, a voltage of 60 V, and a duration of 20 min. All patients had over 50 % in terms of pain reduction at 3-month follow-up. At 12-month follow-up, significant pain relief was referred by five patients; four had no recurrence of pain. Other patients were lost in the follow-up. Author supposed the combination of high voltage and low impedance inside the nucleus pulposus may cause electric fields with biological effects on nerve endings.

9.3.3 Trans-foraminal Radio Frequency: Technical Considerations and Clinical Effectiveness

Anterior motor root and posterior sensitive one take origin from the spinal cord and meet in the DRG near the intervertebral foramen (IVP); then the corresponding nerve exits the spinal canal and goes to its territory of innervations. Usually the posterior root or the DRG are the target of various treatments [70]. Under fluoroscopic or CT guidance, an RF needle is positioned in the IVP. Proximity to DRG is investigated with high-frequency and low-voltage (50Hz and 0.1–0.5 V) pulses of electrical current, which elicit paresthesia. Motor stimulation (pulses of 2 V) was employed to exclude damage to motor [70]. A radiculogram may be performed to delineate the position of the needle tip related to the DRG. As a general rule, during the CRF application, the electrical current density is greatest around the electrode tip, and the lesion has an elliptic form: therefore the electrode tip should be placed parallel to the targeted nerve [70]. During PRF application, the electrical current density is greatest distal to the electrode tip; therefore the needle should be positioned perpendicular to the target nerve [70].

Some published clinical trials investigated the effectiveness of RF applied to the DRG. A randomized placebo-controlled trial failed to demonstrate the effect of CRF for the treatment of chronic lumbar radicular pain compared with the placebo group [71].

PRF treatment near the cervical DRG has been recently analyzed. Physicians documented at 3 months a greater pain relief in the treated population than in the placebo group [72].

Some studies have been published about the results of single PRF treatment or PRF technique in combination with CRF one for the treatment of chronic lumbar radicular pain [8–11]. Van Boxem investigated the single PRF treatment with the following results: after 6 months 50 % pain relief was still present in 22.9 % of the cases and, after 12 months, in 13.1 % of the cases [73].

Simopoulos et al. enrolled 76 patients with chronic lumbosacral radicular pain refractory to conventional therapies. The first group was treated with a single PRF treatment, while patients of the second group underwent a combined PRF and CRF application. 70 % of the patients treated with PRF and 82 % treated with both procedures had a significant reduction in pain intensity. The average duration of analgesic response was 3 months in the single PRF treatment group and 4 months in the group treated with combined therapies [74].

In a retrospective study of 13 patients, Teixeira et al. highlighted the effectiveness of PRF on lumbar DRG in the treatment of sciatic pain due to a disc herniation [75].

Van Zundert et al. performed a retrospective review of 18 patients, who underwent PRF of the DRG for chronic cervico-brachial pain [76]. 72 % of the patients reported more than 50 % pain relief at 2 months, 56 % of the patients had pain relief for 3–11 months, and in 33 % of the patients the pain relief continued for more than a year.

Transient pain and dysesthesias for some weeks were reported in a small number of patients treated with CRF applied to DRG [71, 77]. No studies about the application of PRF to the DRG reported significant side effects or complications [73–75].

Conclusions

In recent years the use of radio-frequency techniques has been introduced in clinical practice for management of chronic back and radicular pain. In this chapter technical aspects of intradiscal and trans-foraminal radio frequency have been analyzed. Clinical trials for intradiscal radio frequency did not document concordant results, showing a better outcome in applications for cervical pain than back one. Trans-foraminal procedures reported good results in the mild period, even if not all studies had big samples of patients. Anyway, RF techniques are promising, repeatable, and safe applications for management of chronic back and radicular pain in patients refractory to conservative therapies.

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10 RF for Treatments of Benign Lesions

Giovanni Carlo Anselmetti and Mariangela Marras

10.1 Introduction

The benign primary tumors of the spine are a rare entity, with an incidence between 2 and 4 %. The ossifying benign symptomatic neoplasms are osteoid osteoma and osteoblastoma, both are histologically characterized by mature bone formation [1].

The symptoms are nonspecific and non-differentiable because of cross-links plurimetameric innervation of nociceptive spinal-thalamic pathways; pain may be related to some vertebral spinal levels away from its anatomical site of origin [2].

The imaging techniques have an important role in the characterizing and in the identification of the lesions, moreover in follow-up after treatment and evaluation of relapse.

10.2 Osteoid Osteoma

Osteoid osteoma (OO) is a benign lesion and constitutes 4 % of primary bone tumors and 12 % of benign bone tumors; it's more frequent in children, adolescents, and young adults (8–35 years), with male predilection (M/F 3–4:1). OO has no malignant potential; some cases of spontaneous regression have been described [3].

OO is characterized by osteoblastic central mass, the "nidus," with limited growth potential (<1.5–2 cm); the nidus has marginal area of sclerosis, which is only a reactive and reversible process.

The nidus consists of osteoid or of mineralized immature bone; it is a focal lesion well circumscribed with microtrabecole and matrix islets of osteoid/bone surrounded by a vascularized fibrous stroma with osteoblast activation and osteoblast. The perilesional sclerosis is composed of dense bone in various degrees of maturation.

Very rarely, an osteoid osteoma has more of a nidus, in which case it is called osteoid osteoma multicentric or multifocal [1].

It's usually a cortical lesion but can occur anywhere within the bone medullary level, subperiosteal, and intracapsular.

Metaphysis and diaphysis of long bones are the most frequent localizations (65–80 %).

The spinal localization is observed in 9 % of cases (lumbar 59 %, cervical 27 %, thoracic 12 %, and sacrum 2 %) with involvement of the posterior elements in 90 % of case and with involvement of the vertebral body in 10 % of cases [3].

The vertebral body involvement is rare, prevalent posteriorly at level of rear wall, where the periosteum is absent or poor, and the lesion takes a superficial position, between the wall and the longitudinal posterior ligament [2].

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10.3 Clinical Presentation

Inside the nidus, E2 prostaglandins are elevated (100–1000) and are released via COX 1 and COX 2; they are the cause of pain and vasodilatation, more acute at night; generally nocturnal pain is relieved by the use of salicylate [4].

In more than 75 % of cases, patients with spine involvement may present painful scoliosis with concavity of curvature toward side of lesion; local soft tissue thickening and tenderness point may be associated [2, 4].

10.4 Pathology

OO is composed of three parts: a central nidus with a meshwork of dilated vessels, osteoblasts, and osteoid and mature bone, sometimes with a central focal mineralization; a peripheral fibrovascular connective rim; and perilesional reactive sclerosis with lymphocytes and plasmocytes [3].

10.5 Imaging

Plain film evaluation may be normal or may show a solid periosteal reaction with cortical thickening; the nidus is often obscured by reactive sclerosis. Sometimes the nidus is visible as a well-circumscribed lucent region, occasionally with a central sclerotic focal area.

X-rays show a cortical lesion characterized by radiolucent central nidus (<1.5 cm) marginal sclerosis and mild reactive sclerosis in some cases. Periosteal reaction and soft tissue swelling may be observed. Cortical bone can be slightly prominent or may be thickened [2, 4, 6].

Computed tomography (CT) is the study of choice for identifying small, well-defined, round, or oval nidus surrounded by sclerosis, with periosteal reaction, sometimes with calcific or sclerotic central area. Furthermore CT study has the advantage of giving the exact measure of the size of the nidus.

The central nidus may have a different degree of ossification, sometimes it can be sclerotic; the periosteal reaction, if present, is unilaminar. The calcification of ligamentum flavum has been observed in some cases. After contrast agent infusion, OO shows variable enhancement.

CT study is necessary not only for the diagnosis but also for therapeutic planning [2, 3, 7].

Magnetic resonance imaging (MRI) is certainly sensitive, but nonspecific and often unable to identify the nidus. The hyperemia, bone marrow edema with soft tissue edema, may mimic an aggressive pathology or the extension of an infection process across disks. Moreover the extensive reactive bone edema and soft tissue suffusion can obscure the nidus, especially if it is small.

In all sequences the nidus signal intensity is variable as the degree of contrast enhancement.

MRI shows isointense lesion on T1WI and radiolucent areas of nidus intermediate-high signal intensity on T2WI [3, 6, 7].

The surrounding reactive area shows hyperintensity signal on T2WI may be much larger than the tumor and may extend to contiguous vertebrae, ribs, and soft tissue [3].

“Nidus target sign” may be present, with low central signal from nidus calcification on all pulse sequences, surrounded by high signal of non-mineralized nidus signal and outer low signal rim of sclerosis [1, 4].

MRI dynamic study is helpful for localizing nidus; OO shows a peak of enhancement during arterial phase and early partial washout; slower, progressive enhancement of adjacent bone marrow is seen. Moreover MRI may be useful in the follow-up after treatment and in case of relapse lesion; presence of edema in the treatment site is often indicative of relapse.

Nuclear medicine bone scan examination is the earlier method of identifying an osteoid lesion; OO shows increased uptake, with characteristic “double density sign” that consists in a small focus nidus of increased activity surrounded by an area of less-intense activity of reactive sclerosis; this sign if present is highly specific [1, 3].

Moreover this diagnostic method is useful in identifying the level of the lesion, being the little evocative clinic because of the wide irradiation of back pain.

PET study is useful to detect osteoid osteoma in some anatomic complex areas such as posterior elements of spine [2].

Osteomyelitis, osteoblastoma, stress fracture of pedicle or lamina, unilateral spondylolysis, sclerotic metastasis, lymphoma, and Ewing sarcoma are the main differential diagnoses.

The distinction between osteoma osteoid and osteoblastoma can be very difficult, if not impossible. In general, OO is larger than osteoid osteoma (>2 cm) and shows lower reactive sclerosis, but the reaction periosteal can be more significant [1, 3].

Sequestrum or focal abscess in osteomyelitis can mimic nidus, but generally vertebral bodies are involved with end plate destruction.

In case of stress, fracture of pedicle or lamina sclerosis around fracture mimics reactive marginal sclerosis of OO; CT or high-resolution MRI will show clearly fracture line [3].

10.6 Osteoblastoma

Osteoblastoma (OB) is also defined as a giant osteoid osteoma, from which it differs for the larger size (>1.5–2 cm). OB represents about 1 % of all bone primitive tumors and 3 % of all benign bone tumors [1].

In 90 % of cases, the age of onset is between 20 and 30 years, with male prevalence (M/F 2.5:1).

It is a benign osteolytic tumor with osteoblastic activation, characterized by slow growth, with an osteoid matrix that can be mineralized [1, 3].

Spine location occurs in 40 % of cases (40 % cervical, 25 % lumbar, 20 % thoracic, 15–20 % sacrum); OB originates from the arch neural and can invade the vertebral body. It was described osteoblastoma multifocal, very rare condition [3].

10.7 Clinical Presentation

Clinical manifestation is different from osteoid osteoma; generally patients are symptomatic, but the pain is less intense than OO and not readily resolved by salicylates. Also their natural histories differ: while the osteoid osteoma sometimes tents to regression, the osteoblastoma tends to progression and also to malignant transformation, although the possibility of the last event remains controversial [1].

Painful scoliosis concave inside of tumor and neurologic symptoms due to compression of nerve roots may be present [1, 3, 6].

Prostaglandins released by tumor cause broad marginal edema.

A rare variant of the tumor was identified as toxic osteoblastoma, which is associated with systemic symptoms, including periostitis, fever, and weight loss [2, 5, 6].

10.8 Pathology

The lesion is histologically similar to OO, but it is characterized by larger size (more than 1.5–2 cm in diameter). Osteoblasts are prominent in lesion and vascular fibrous stroma is observed, while quantity of woven bone matrix is variable.

The histologic differential diagnosis of osteoid osteoma and osteoblastoma can be difficult, and, in a considerable number of patients, it may be impossible [1, 5, 6].

OO and OB are lesions that produce osteoid, but in a typical osteoblastoma, the bone trabeculae are wider and longer and seem less densely packed and less compact than those of OO.

10.9 Imaging

Plain film features are an osteolytic area with sharp margins, sometimes sclerotic, with enlargement of neural arch and widening profiles of the vertebral body, without ever involving soft tissue.

Soft tissue invasion may be present in aggressive forms of OB and borderline form called “osteosarcoma osteoblastoma-like,” which requires biopsy screening [2].

CT is more sensitive than plain film in highlighting the detail of the intralesional bone matrix as well-circumscribed lesion of neural arch often extends into vertebral body, with sclerotic rim, periosteal reaction, and ligamentum flavum ossification; small irregular trabeculae may be seen. After contrast agent administration, enhancement is intense, sometimes inhomogeneous [1–3, 7].

Aggressive OB is characterized by cortical breakthrough.

MRI features of OB are low-intermediate signal intensity lesion on T1WI and intermediate-high signal intensity lesion, with low signal of bone matrix on T2WI [3, 6, 7].

MR shows in detail any secondary aneurysmal bone cysts and perilesional bone edema and soft tissue edema "flare phenomenon" that can partially hide the tumor.

Contrast enhancement is variable, and peritumoral edema may enhance.

Nuclear medicine bone scan three phase is positive.

When the tumor infiltrates the cortex and extends in soft tissue, MRI can document these aspects.

The osteoblastoma has four typical radiographic aspects:

1. Giant osteoid osteoma: the lesion usually has a diameter over 2 cm; it shows less reactive sclerosis and periosteal reaction more conspicuous than OO.
2. Massive expansion similar to aneurysmal cyst with small radiopaque center. This framework is particularly common in the lesion involving the spine.
3. An aggressive injury that simulates a malignant tumor.
4. A periosteal lesion which lacks bony sclerosis but shows a perifocal thin shell of periosteal bone newly formed [1, 2].

OB differential radiological diagnosis should include osteoid osteoma, aneurysmal bone cyst, metastasis, infection, chordoma, osteogenic sarcoma, and fibrous dysplasia [3].

10.10 Treatment

Several image-guided, minimally invasive interventions have been developed to treat benign bone tumors such as OO and OB, including image-guided radio-frequency ablation (RFA), which has been used to treat soft tissue tumors in the liver, breast, gallbladder, and lung. RFA has been applied to the treatment of osteoid osteoma for about 10 years [8]. The technique is one of the growing numbers of minimally invasive alternatives to conventional operative procedures, and the literature includes several clinical studies on RFA [9–16]. RFA can provide patients excellent relief of pain and early return to function while minimizing hospital stay and morbidity. RFA is considered the "gold standard" in the minimally invasive treatment of OO and OB. Alternatively, percutaneous ablation techniques in the musculoskeletal system also include chemical ablation (i.e., injection of ethanol), laser ablation, microwave ablation (MWA), and cryoablation. In the latter techniques, one should also include MR-guided high-intensity focus ultrasound (HIFU), which is totally noninvasive [17–22].

Percutaneous RFA of OO is normally performed under CT guidance (for precise RF probe positioning within this small lesion), extended local sterility measures, and antibiotic prophylaxis. After access route and distance are evaluated with CT scan (Fig. 10.1), access to the nidus is achieved with a trocar that is either hammered or drilled through the intact bone (Fig. 10.2). Once inside the nidus, a bone biopsy needle can be inserted coaxially and a sample obtained to verify the osteoma diagnosis. Then the electrode is inserted coaxially through the trocar, and ablation is performed with a specific protocol resulting in

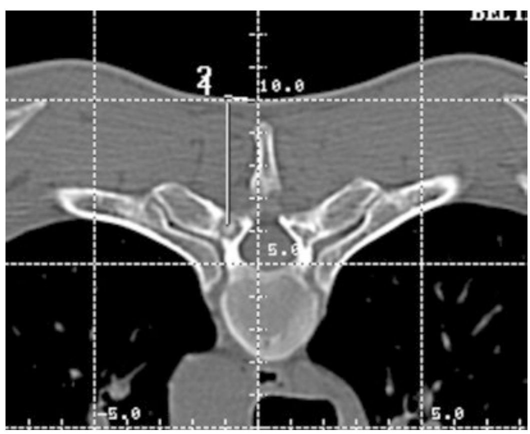

Fig. 10.1 Osteoid osteoma of the pedicle of 8th thoracic vertebra

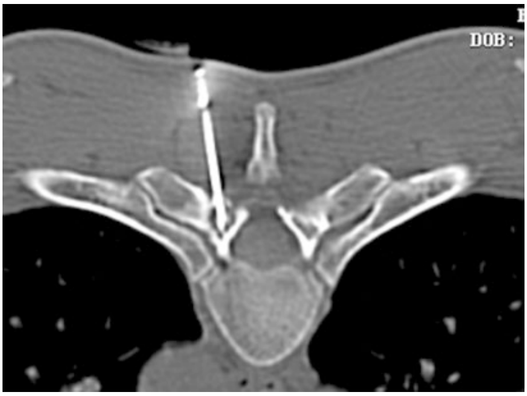

Fig. 10.2 Guiding trocar is drilled inside the osteoid osteoma

Fig. 10.3 RF probe is coaxially inserted to perform ablation

an ablation zone of 5–10 mm diameter (depending upon the probe tip dimension) (Fig. 10.3). Generally, ablation is performed for at least 6 min at a temperature from 90 to 100°C.

The procedure is painful and deep sedation or general anesthesia is always required. Post-procedural pain control by anesthesiologist is mandatory as all the patients reported high-grade pain immediately after the ablation lasting around 2–3 h. Overnight stay in the hospital of the patient is preferable, and, generally, the patient can be discharged from the interventional radiology unit the day after the procedure.

Potential complications are rare and include iatrogenic damage to the surrounding nerve root or tissues due to the electrode placement, heat effect, and size of the bone necrosis [23]; protective measures include techniques of insulation and temperature or nerve function monitoring to protect vulnerable structures. Passive thermal protection techniques include continuous monitoring of the temperature in the area of interest by thermocouples or of nervous function by monitoring systems such as neurodiagnostic EEG and EMG and evoked potential electrodes [23, 24]. Measurement of the temperature in proximity to a neural structure or of the nerve's functional ability during the ablation provides valuable information for a safe and efficient session.

Active thermal protection techniques include gas dissection, water dissection, and cooling media for skin protection (application of a sterile glove with iced saline, subcutaneous saline injection).

During gas dissection, CO_2 or air is injected for dissecting vulnerable structures from the ablation zone; generally CO_2 is insulated better than air, which is less soluble.

With precise CT guidance that allows multiplanar reconstruction (MPR) and protection techniques (i.e., evoked potential electrodes), very difficult OO can be treated safely (Fig. 10.4a–c). Follow-up of successful ablation is performed clinically, and there is no need for imaging follow-up in asymptomatic patients [18].

Traditional surgical treatment for osteoid osteoma includes wide excision with removal of a bone block, marginal resection of entire nidus, and curettage or high-speed burr techniques [25]. Comparison of these techniques to percutaneous imaging-guided ablation favors the latter in terms of minimal trauma, reduced functional restriction, and significantly lower cost [25].

RFA can be used as a treatment of larger benign tumors such as osteoblastoma (OB) (<3 cm in diameter) (Fig. 10.5); depending upon the diameter, a multipolar probe (allowing a larger ablation) and a longer ablation time can be required (Fig. 10.6).

While throughout the literature, there are reports of ablation in cases of eosinophilic granuloma, chondromyxoid fibroma, cystic hydroma, and aneurysmal bone cyst [18]. State-of-the-art reviews affirm that "essentially any small well defined lesion at imaging can be treated with RF ablation" [18].

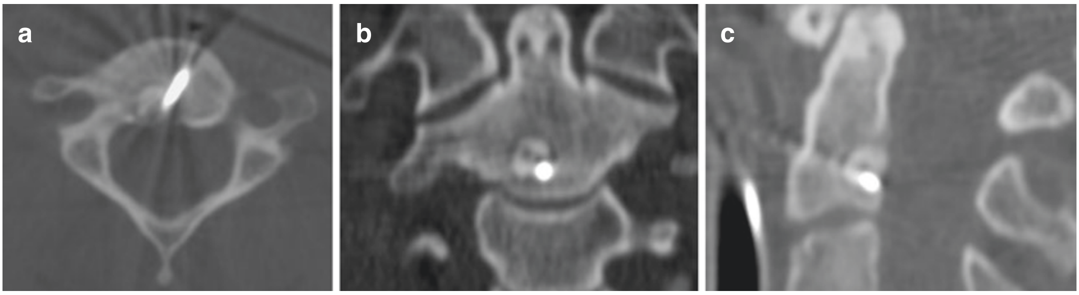

Fig. 10.4 Osteoid osteoma localized in the second cervical vertebra; CT multiplanar reconstruction (**a** axial, **b** coronal, **c** sagittal) allowed precise RF probe positioning within the lesion by means of a trans-oral approach

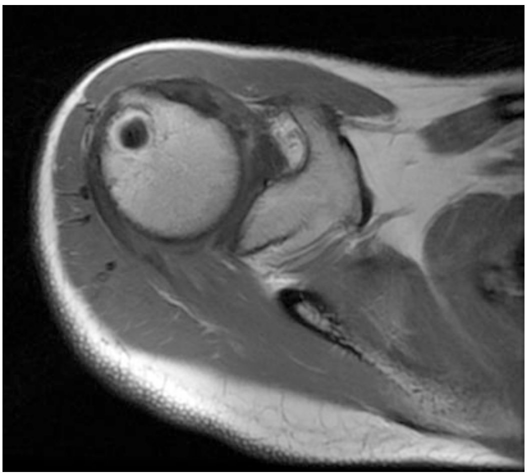

Fig. 10.5 Osteoblastoma of the left humerus

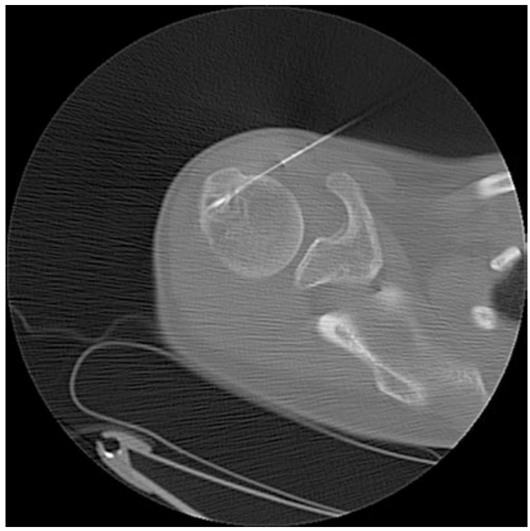

Fig. 10.6 Osteoblastoma RF ablation with multipolar probe

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11 RF for Treatments of Malignant Lesions

Bassem A. Georgy, Stefano Marini, and Emanuele Piras

11.1 Introduction

About 1.4 million patients are diagnosed with cancer annually in the USA alone, 70% of whom will eventually develop bone metastasis [1]. The spine is the most common site of osseous metastatic disease because of the presence of vascular red marrow and the communication of the deep thoracic and pelvic veins with valveless vertebral venous plexuses [2].

Vertebral augmentation has proven safe and effective in the treatment of primary and secondary vertebral malignant lesions [3]. Efficacious pain relief was demonstrated in 84–92% of cases, as well as improved quality of life compared to conservative therapy [4], in the multicenter randomized controlled Cancer Patient Fracture Evaluation study "CAFÉ" trial [5]. Patients with cancer who had vertebral compression fractures (VCFs) and were treated with kyphoplasty had a superior functional (RDQ) outcome at 1 month than patients who received nonsurgical management. At 1 month, patients in the kyphoplasty group also showed a marked reduction of back pain and improvement in quality of life, with fewer kyphoplasty patients using pain medications. Results for a wide array of pain outcome metrics (RDQ, SF-36 PCS, KPS) were also statistically and clinically significant at 1 month. Improvement in functional status, quality of life, and pain continued through the conclusion of the study (12 months) in patients randomly assigned to kyphoplasty. Since the early days of vertebroplasty, the technique has been characterized by a relatively safe profile even in advanced disease cases with known epidural extensions [3, 6].

11.2 Early Development

Dupuy et al. [7] measured differences in heat transmission for radiofrequency energy in cancellous and cortical bones and performed the first radiofrequency ablation on a metastatic hemangiopericytoma of L2 vertebra under CT guidance. Their early work showed that despite the use of internally cooled electrodes at maximum output, injurious elevations of temperatures in the epidural space did not occur. This work confirmed decreased heat transmission in cancellous bone and an insulative effect on cortical bone.

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They postulated that additional factors that may account for differences in heat distribution were the local heat sink from the rich epidural venous plexus and CSF pulsations. They also identified that a larger margin of safety could be gained by successfully preserving cancellous or cortical bone between the lesion and the spine. A vital point is that RFA that heats tissue to 45 °C is cytotoxic to the spinal cord and peripheral nerves [8]. Cortical bone insulates and protects the spinal canal, but an absent or lytic posterior vertebral body cortex or a widened neural foramen could increase the risk of thermal nerve damage.

The literature describes additional techniques for neuronal protection: Nakatsuka et al. [9] monitored spinal canal temperature in real time with thermocouples inserted in the epidural space between the tumor and the spinal cord. Buy et al. [10] introduced the practice of carbon dioxide dissection with thermocouples to protect vital structures. However, some authors have performed radiofrequency ablation of vertebral tumors with posterior wall defects followed by vertebroplasty with no significant complications [11].

Groenemeyer et al. [12] and Schaefer et al. [13] were among the first researchers to describe the combination of radiofrequency ablation and subsequent cement augmentation to achieve stability after tumor removal as a palliative treatment for metastatic spinal lesions. Both groups used commercially available radiofrequency systems employed routinely for ablation in other parts of the body, namely, the RITA system (RITA Medical Systems, Mountain View, CA), wherein the radiofrequency generator is connected to an expandable electrode catheter with multiple retractable arrays. The first group [12] reported a series of 12 patients where four of them underwent vertebroplasty few days after the ablation. The second group [13] reported a single case performed under CT guidance, where a 2 × 3 cm solitary lytic renal cell cancer metastasis of L3 was ablated using a 16-gauge LeVeen needle electrode and a radiofrequency generator (RF 3000; RadioTherapeutics, Sunnyvale, CA). A simple vertebroplasty immediately followed the ablation. The whole procedure was performed under general anesthesia.

Larger patient series were then published describing patients treated by combined radiofrequency ablation and cementoplasty. All papers reported pain relief despite borderline safety profile. Nakatsuka et al. [14] reported a series of 17 cases done under CT guidance with four major neurological complications. The authors used Cosman Coagulator-1 (Radionics, Burlington, MA). Gevargez et al. [15] reported 41 patients where ablation was performed using cool-tip electrodes (Radionics, Burlington, MA) and a RITA system (Mountain View, CA). Twenty-two patients underwent vertebroplasty after ablation, four of whom experienced radiculopathy as a side effect. All cases were also performed under CT guidance. Munk et al. [16] reported a group of 19 patients where they used biplane fluoroscopy and general anesthesia. They reported minor complications in seven patients related mainly to leakage. Lane et al. [17] reported performing the procedure in 36 patients under general anesthesia or with conscious sedation, with visualization aided by CT guidance or using a biplane fluoroscopy. Ablation was again performed using multiple RF machines not specifically designed for spine ablation but reporting only a few transient complications during the procedures.

11.3 Coblation Technology

In 2007, Georgy et al. [18] introduced the concept of performing plasma-mediated radiofrequency (pmRF) ablation before cement augmentation in metastatic spinal lesions. They presented a series of 15 patients with metastatic lesions presenting with posterior cortical disruption and/or epidural extensions. They hypothesized that creating a cavity by tissue removal, rather than displacement, before cement injection in this subset of patients would facilitate safer procedures, preventing possible leakage and tissue displacement in the spinal canal.

pmRF ablation operates by using radiofrequency energy to excite the electrolytes of a conductive medium, such as a saline solution, to create a precisely focused plasma field. The energized particles in this plasma field possess sufficient energy to break molecular bonds, excising or dissolving soft tissues at relatively low temperatures (40–70°C) [19]. The device (Cavity SpineWand; ArthroCare, Sunnyvale, CA) is a stronger version of the more commonly used nucleoplasty probe for disk material removal (Fig. 11.1). The device has a gentle curve to permit more medial directionality inside the vertebral body, but is not flexible, which limits its ability to precisely target particular lesions inside the vertebral body. It also requires continuous saline infusion during ablation.

The device was posited to be safer to use near the spinal cord and nerves due to its lower energy profile [20] compared to the standard RF probes originally designed for soft tissue ablation, which require a large safety zone. However, this resulted in weaker energy production that was unable to completely eradicate tumor masses.

The technique was marketed as a way of debulking tumors, and the same group [21] who introduced the technique later showed that decreasing the intravertebral pressure by creating a cone-shaped void through tissue removal and not displacement results in a predictable pattern of cement deposition in the anterior two thirds of the vertebral body away from the compromised posterior border (Figs. 11.2, 11.3, and 11.4).

Subsequent studies confirmed and duplicated the original work in Europe. Cianfoni et al. [22] reported a series of 48 patients (70 levels) with excellent short-term pain relief and epidural leakage in 14.2 % of cases (not clinically significant). In Germany, Dabravolski et al. [23] reported a series of 250 patients treated with the same technique over the course of 6 years. In 59 patients, posterior percutaneous instrumentation was added to the technique. After surgery, significant pain reduction, satisfaction, early mobilization, and

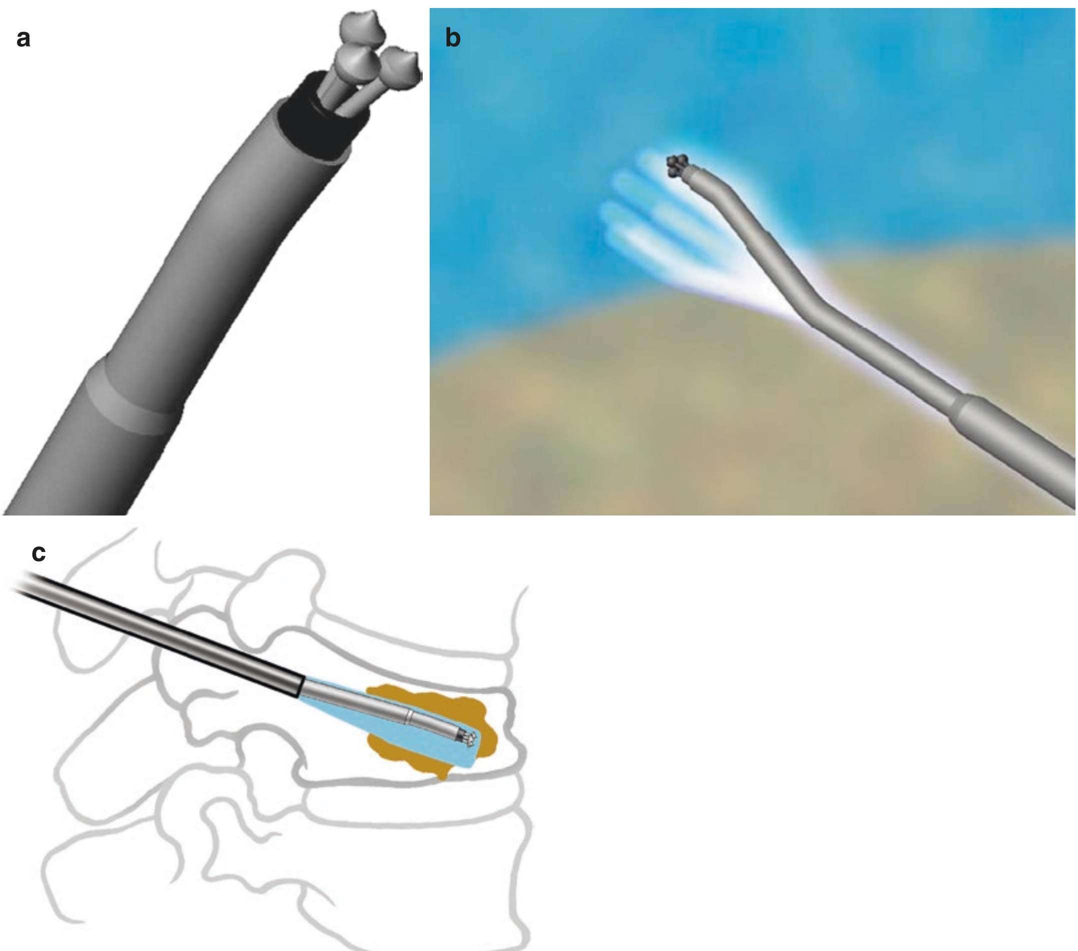

Fig. 11.1 Cavity SpineWand; ArthroCare, Sunnyvale, CA. The Wand has a bouquet of active electrodes at the tip (**a**). This is where the plasma is formed. It requires the presence of saline to create plasma and ablate tissue and has an 'S' shaped tip to maneuver off-axis. Multiple tracts with simple rotation allow the formation of cone of tissue void (**c**)

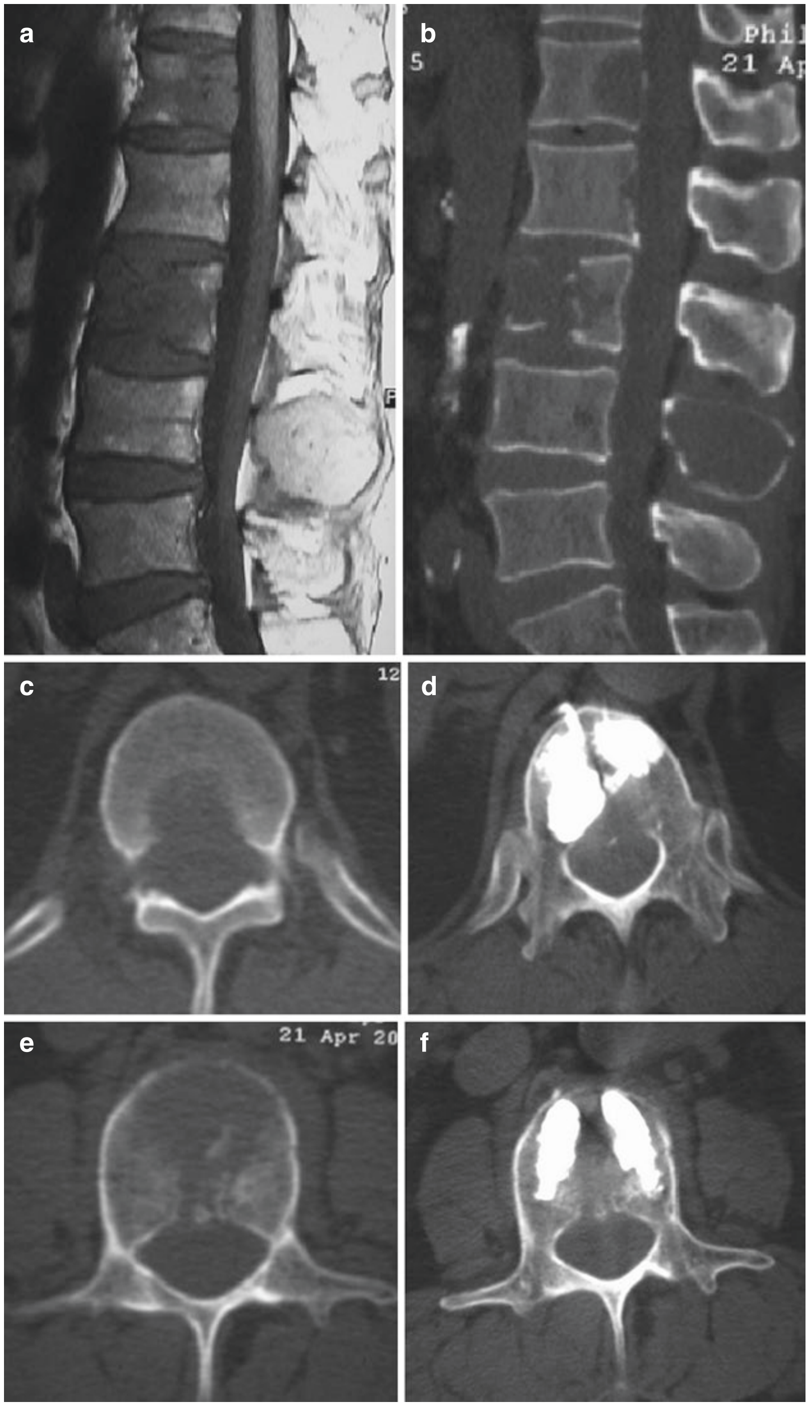

Fig. 11.2 Diffuse metastatic hepatocellular carcinoma in 76 years old man treated by Coblation and cementation. A and B are T1-weighted MRI images (**a**), and corresponding CT image (**b**) image of the lumbar spine showing destructive lesions in the posterior part of the L1 vertebral body and anterior part of L3 vertebra. C and D are axial CT images of L1 vertebral body before (**c**) and after (**d**) bi-pedicular Coblation and cementation. Note that the cement has conformed to the anterior part of the vertebra away from the compromised posterior border. E and F are axial CT images of L3 vertebral body before (**e**) and after (**f**) bi-pedicular Coblation and cementation. Note that in this level the cement has conformed to the anterior lytic lesion along the course of the cone of tissue removal created by the Wand

improvement in quality of life were demonstrated in all patients. Immediate radio- and chemotherapy could be carried out. In 38 cases, cement escaped laterally into the intervertebral space, but this had no clinical relevance. While the device does not have full technical and clinical support in the USA, it is widely used in Europe due to its ease of use and the wide safety profile.

Fig. 11.3 L2 Metastatic lung cancer in 84-year-old male. (**a**) is an axial CT image showing the destructive nature of the lesion as well as the epidural extension with no neurological deficit. (**b**) is post Coblation and augmentation, showing adequate cementation despite the presence of an epidural component causing anterior indentation of the mylogram column. (**c**) is a post procedure CT sagittal reconstruction image similar to **b**.

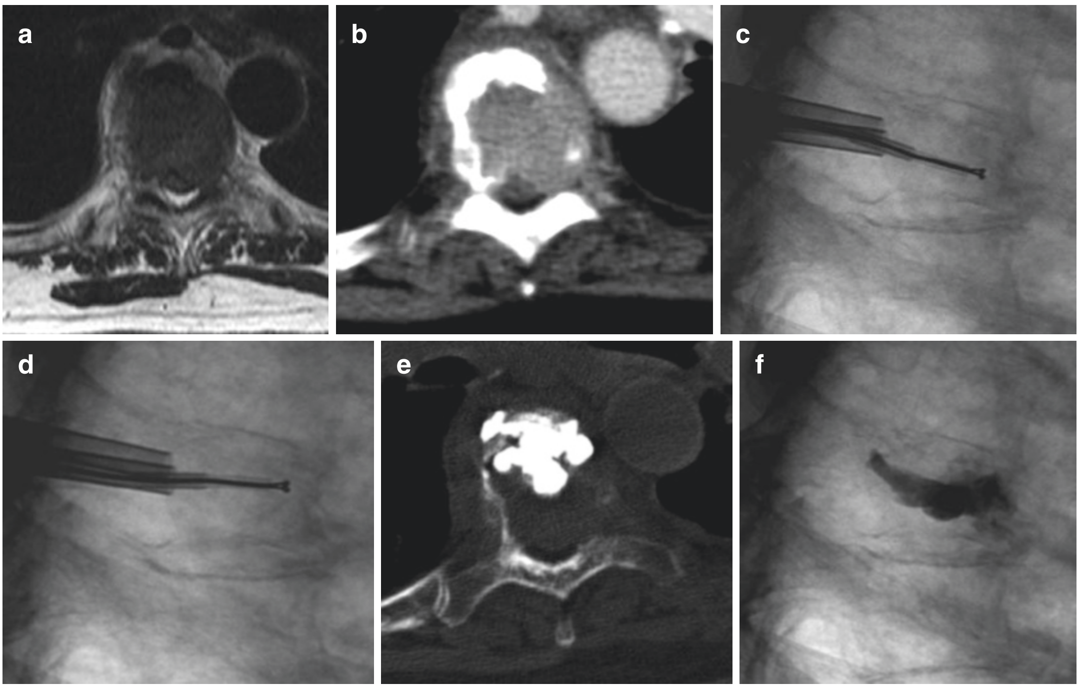

Fig. 11.4 77 year old female with T5 metastatic melanoma. (**a**) and (**b**) are axial T1-weighted images (**a**) of T5 vertebra showing a large metastatic lytic lesion with destruction of the posterior wall and epidural extension. (**b**) is the corresponding CT image. (**c**) and (**d**) are selected lateral fluoroscopy images showing the upside (**c**) and downside (**d**) movement of the Cavity Wand. (**e**) is CT image after cementation showing no posterior cement leakage. Note minimal anterior leakage, which is not significant. (**f**) is a lateral fluoroscopic image showing adequate cement distribution.

11.4 Specifically Designed RF Ablation Devices for Metastatic Spine Lesions

In 2014, Anchala et al. [24] reported the first multicenter retrospective study of radiofrequency ablation of spinal metastatic diseases using a novel navigational bipolar radiofrequency ablation device (STAR ablation device, DFine Inc, San Jose, CA) purposely built for bone lesion ablation. The STAR Tumor Ablation System (comprised of the SpineSTAR electrode and the MetaSTAR generator) contains a pair of active thermocouples positioned along the length of the electrode at 10 and 15 mm from the center of the ablation zone. The ellipsoid ablation volume is approximately 20 × 15 × 15 mm when the thermocouple located 10 mm from the center of the ablation zone reaches 50 C and 30 × 20 × 20 mm when the thermocouple 15 mm from the center of the ablation zone reaches 50 C. The generator displays the two thermocouple readings permitting real-time monitoring of the peripheral edge of the ablation. Two versions exist: a smaller one where the thermocouples are located at 5 and 10 mm from the center of ablation and a larger one where the thermocouples are located at 10 and 15 mm from the center of ablation. It is important to understand that in the larger variant, the distal end of the ablation zone extends distal to the electrode tip for about 5 mm. The system is designed in a way that once the temperature of the proximal thermocouple (the one that is located near the anterior epidural space) reaches 50 ^{0}C, the whole system will shut down completely as a major safety feature. Giving the articulating flexibility of the electrode, a unipedicular approach can be employed to cross the midline and reach practically any area in the vertebral body for targeted ablation. These navigational properties allow ablation of multiple overlapping zones to cover larger tumors. The MetaSTAR generator allows the use of four different power levels: 5, 10, 15, and 20 W settings. It also displays ablation time, impedance, and the two thermocouple tem-

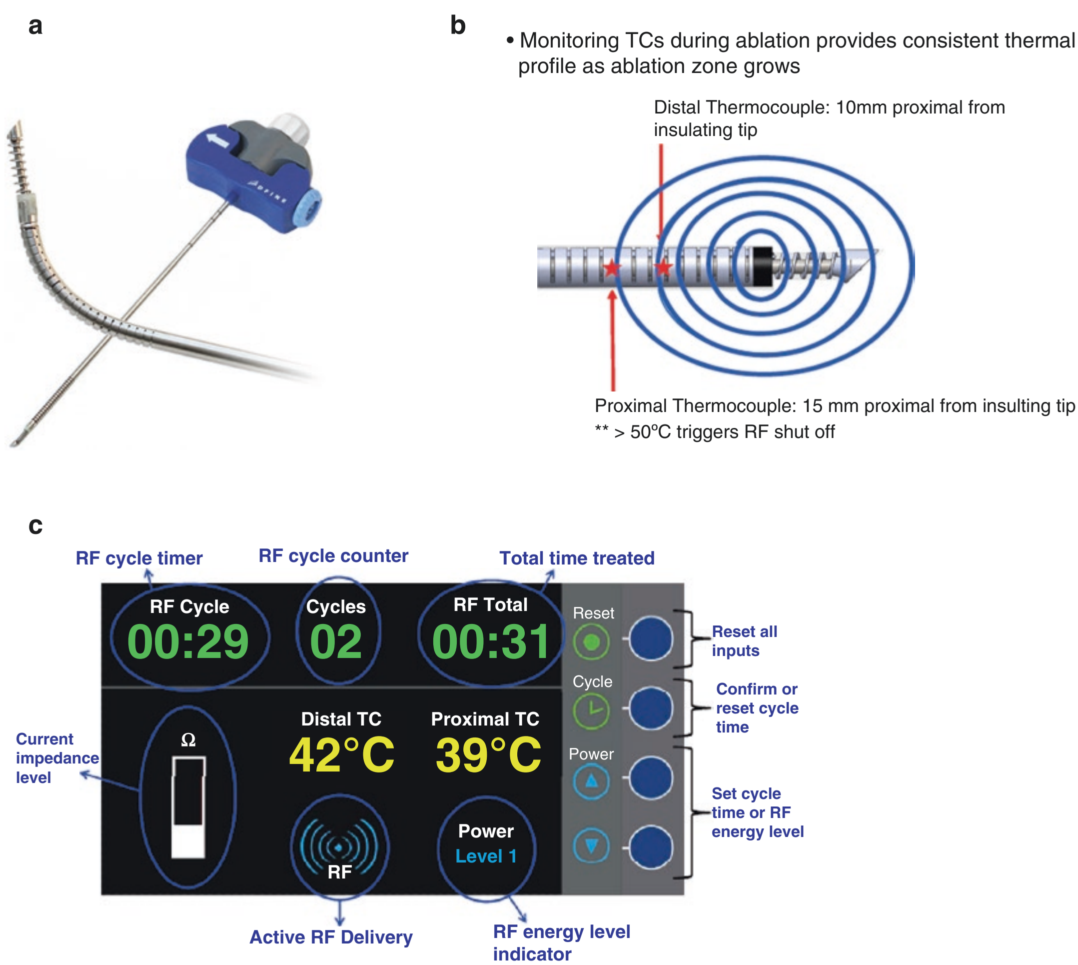

Fig. 11.5 The STAR, Spine Tumor Ablation with Radiofrequency. (Dfine Inc, San Jose, CA) (**a**) Spine STAR device, 10 gauge, articulating, expandable bipolar electrode. (**b**) Distal end of the Spine STAR containing 2 thermocouples (*red dots*), located at 10 and 15 mm from the center of the ablation zone which permit real-time monitoring of proximal peripheral edge of the ablation zone. (**c**) MetaSTAR Generator display, showing the temperature of both thermocouples, the impedance and time of ablation

perature readings that permit real-time monitoring of the peripheral edge of the ablation zone. Cement augmentation can be performed via the same guiding cannula (Fig. 11.5).

In this landmark study, the same authors (Anchala et al.) [24] reported a series of 92 patients with different metastatic diseases of the spine where tumor ablation was performed using the STAR system followed by vertebral augmentation when the vertebral body was at risk or had a pathological fracture. Visual analogue scores (VAS) collected at 1 week, 1 month, and 6 months postoperatively showed a statistically significant decrease before and after the procedures at different points of data collection. In the largest center group, 54 % of the patients experienced a decrease in pain medication, and 30 % had no change in medication postoperatively. Post-ablation imaging confirmed ablation zones of a size consistent with that measured by the thermocouples. The authors concluded that the STAR system was safe and effective for the treatment of spine metastatic osseous lesions. The new device allowed RFA treatment of previously untreatable lesions with a resultant reduction in pain that was not controlled by systemic radiation therapy. Later on, the same research group published on a smaller series of patients, showing that the STAR system is safe and effective in ablating posteriorly located lesions in the vertebral body [25]. Cement augmentation was not performed when the posteriorly located lesions were small (Figs. 11.6 and 11.7).

Another retrospective study [26] of 55 tumors treated with the same system was published

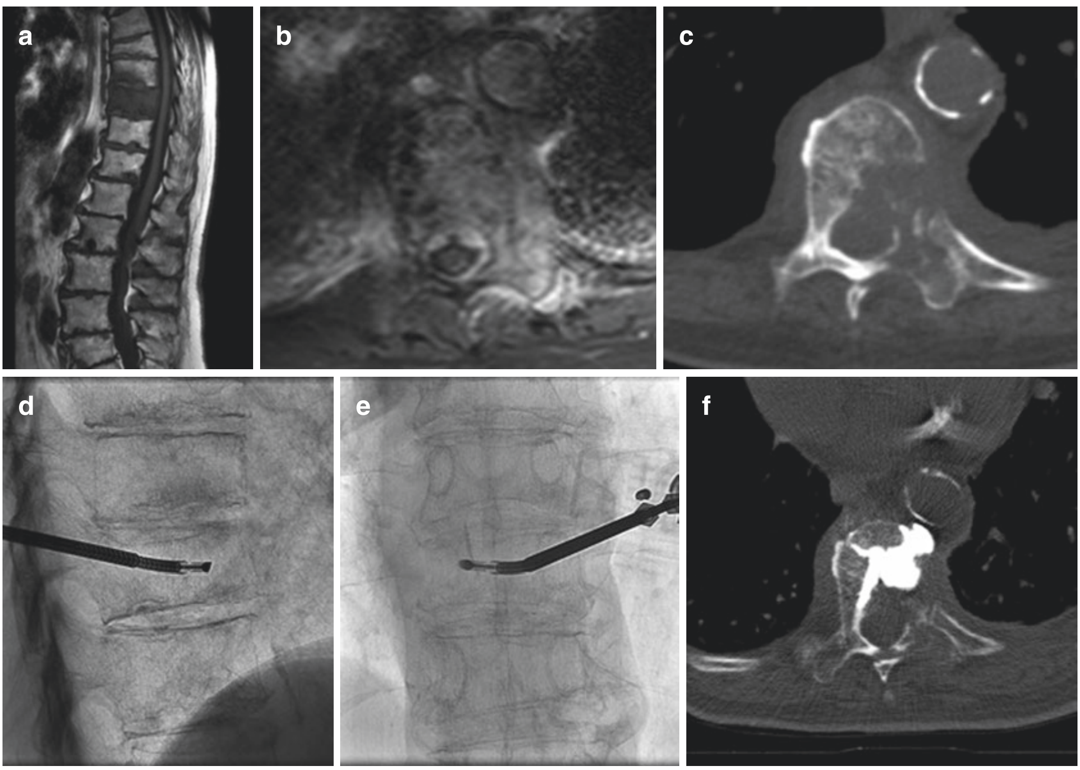

Fig. 11.6 84 year old women with metastatic adenocarcinoma of the lung. (**a**) is a sagittal T1-weighted images showing abnormal low signal intensity of T10 and inferior end-plate of T9. (**b**) and (**c**), Axial enhanced T1-weighted image with fat suppression at T10 level (**b**) showing an enhancing lesion in the left side of the vertebral body extending into the left pedicle with small epidural extension. A corresponding cortical disruption at the same level can be seen in CT image (**c**). (**d**) and (**e**), Radiofrequency ablation was performed on the lesion of T10 level using the contralateral pedicle for an access. The ipsilateral pedicle was not visualized under fluoroscopy during the procedure. The flexible STAR probe was used to cross the midline to ablate the lesion; (**d**) is a lateral view and (**e**) is A-P view (**f**) is a post-procedure CT image after cement augmentation showing no leakage into the spinal canal despite the posterior cortical disruption. No ablation was performed on T9 level since no specific lesion was identified

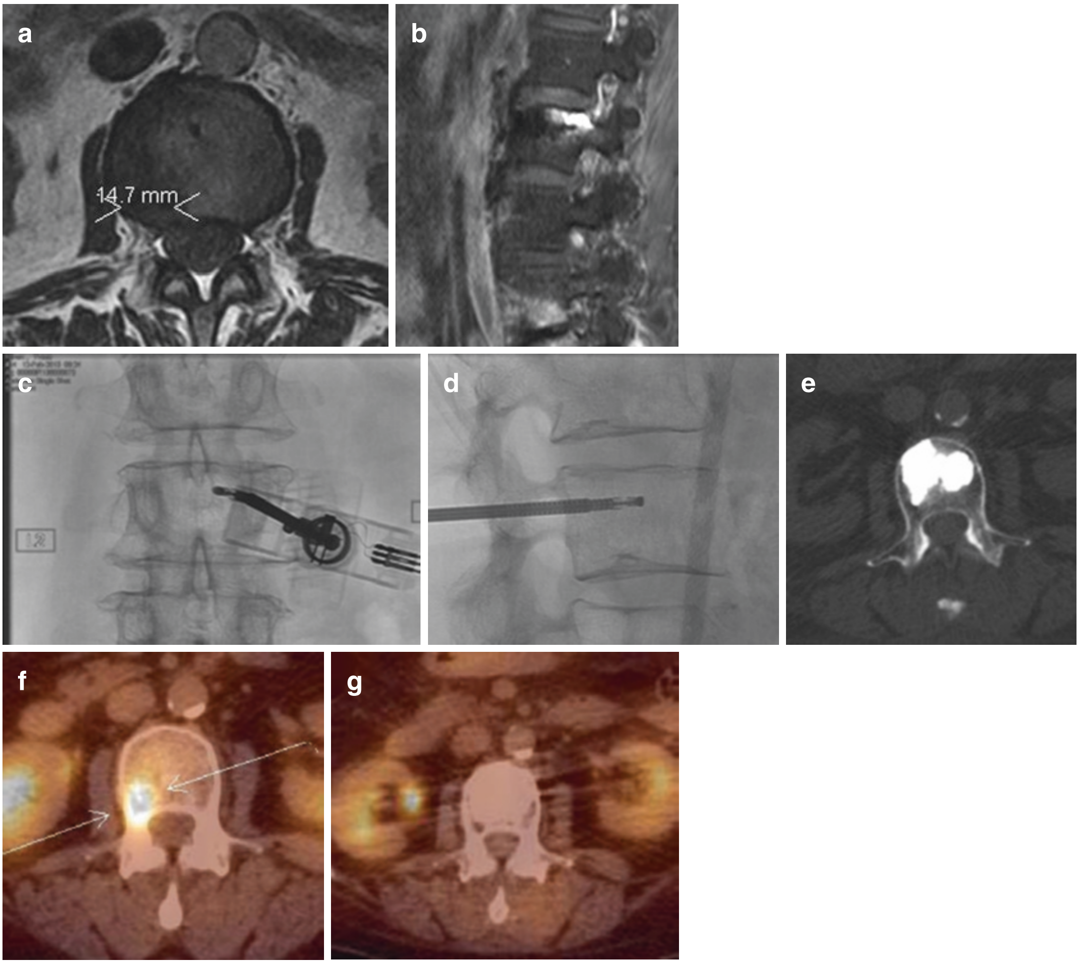

Fig. 11.7 Posteriorly located L2 metastatic breast cancer in a 76-year-old woman. (**a**) is an axial T1-weighted image showing a right posteriorly located metastatic lesion. (**b**) parasagittal T1-weighted image with fat suppression, again showing the enhancing posterior superior lesion. (**c**) and (**d**) are AP (**c**) and Lateral (**d**) fluoroscopic images showing adequate placement of the STAR device posteriorly and to the right of the midline to ablate the lesion. (**e**) post cementation axial CT image showing adequate filling of the vertebral body with cement. (**f**) Pre-procedure PET scan showing increased metabolic activity in the posteriorly located lesion. (**g**) Post-procedure PET scan showing absence of metabolic activity

recently. In this study Wallace et al. studied radiologic local tumor control rate in metastatic lesions after radiofrequency ablation and vertebral augmentation. Tumors treated in conjunction with radiation therapy were excluded. The researchers reported local tumor control (based on imaging) in 89 % of cases at 3 months, 74 % of cases at 6 months, and 70 % of cases at 1 year after treatment (Fig. 11.8).

Recently, Medtronic Inc. (San Jose, CA) introduced a new ablation system, the OsteoCool. The system is based on the cooled RF needles and generators by Baylis (Montreal, CA). The system is not flexible but comes in different lengths to control the ablation zone and can be used in a unipedicular approach, although a bipedicular access is desired to achieve a larger zone of ablation. A separate thermocouple is attached to the system and can be introduced into the epidural space via a Kambin's triangle approach, similar to what can be employed for transforaminal epidural steroid injections of the spine. There are no clinical publications currently available for that system [27].

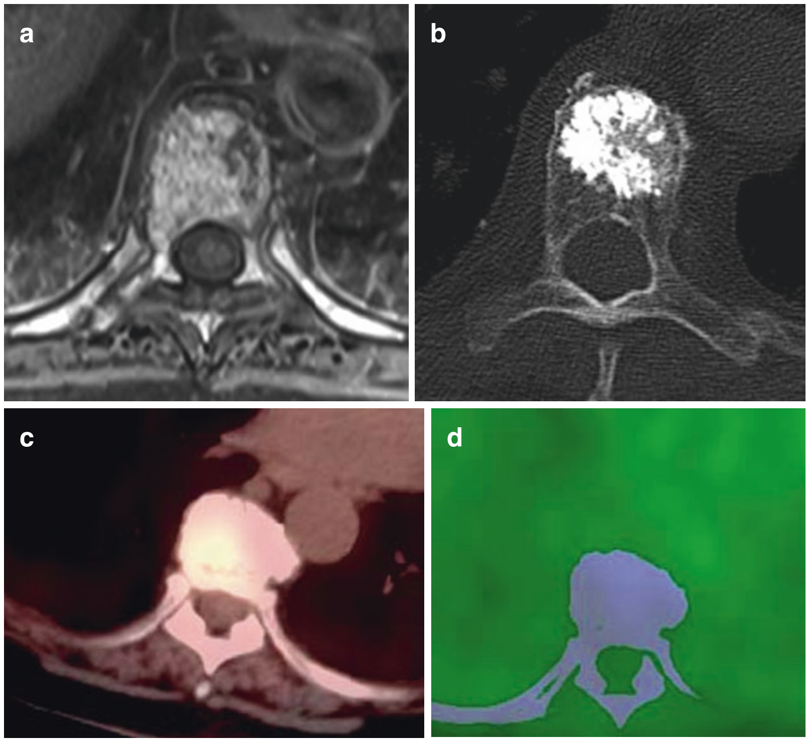

Fig. 11.8 T9 Metastatic breast cancer in a 65-year-old woman. (**a**) Axial T1-weighed image with fat suppression showing a large heterogeneous enhancing lesion involving most of the vertebral body on the right side. (**b**) Axial CT image of the same level after radiofrequency ablation and cementation using the STR ablation system. (**c**) axial PET scan immediately before the procedure showing increased metabolic uptake. (**d**) axial PET scans 2 months after the procedure showing no metabolic uptake with no other treatment in the interim

11.5 Current Status and Future Trends

Despite a wide range of publications covering the use of radiofrequency ablation devices to treat spine metastasis with or without vertebral augmentation, most of the literature is comprised of retrospective studies demonstrating the feasibility and safety of the technique and reporting improvement of different pain scores before and after the procedure. Although some data supports the fact that adding RFA to conventional radiation therapy might improve the rate and degree of pain relief in treatment of solitary bone metastasis [28], vertebral augmentation alone has been shown to produce pain relief in metastatic lesions [5]. Without a prospective study comparing the pain relief in cases treated with cement augmentation alone against a combination of cement augmentation and radiofrequency ablation, it is very difficult to justify the added risks and the costs only for the purpose of pain relief.

Although it had been shown that radiologic local tumor control can be achieved with radiofrequency ablation in a retrospective study [26], the exact role of this technique in a treatment algorithm had not been well defined, particularly its potential role in cases of oligometastasis.

According to the "metastatic spine disease multidisciplinary working group algorithm" [29], ablation is a reasonable therapeutic option for radioresistant spine tumors, in patients with persistent and/or recurrent pain who have reached their maximum radiation dose and in cases where radiation therapy cannot be offered due to concomitant chemotherapy or is ineffective giving the low risk and potential for local tumor control. The National Comprehensive Cancer Network (NCCN) guidelines recommend radiofrequency ablation as a commonly used interventional procedure for treating bone pain in non-oncologic emergencies [30]. Current indications include local pain control and local tumor control for radioresistant tumors and cases that reached maximum dose of radiation. The technique appears especially useful in cases of epidural tumor extension and compromised posterior cortex, in order to debulk tumor tissue and decrease intravertebral pressure to avoid cement leakage. Radiofrequency ablation may have a role in controlling local tumor recurrence [26]. Local tumor recurrence after augmentation alone has been described in the literature [31].

Conclusion

Fifteen years after the first reports, the technique has matured, with an array of devices and methods available for safe ablation and subsequent augmentation as necessary. Radiofrequency ablation is a complementary therapeutic method to current treatment modalities, in particular radiation therapy and surgery.

Over the next few years, the medical community should direct focus efforts toward more prospective studies to evaluate the potential role of radiofrequency ablation in local tumor control, rather than trying to achieve better pain control than augmentation alone. This would be particularly useful in cases of oligometastasis and smaller lesions, which bear greater similarities to our experiences ablating lesions in other parts of the body like the liver. This would serve to clearly define the proper role of radiofrequency ablation in the treatment algorithm of spinal metastasis, side-by-side with radiation therapy and surgical treatment.

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