Update on Interventional Radiology of the Spine

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Abstract

Interventional radiologists now perform spinal interventions routinely for diagnostic and therapeutic purposes. New technologies for the management of spine pathologies have emerged with promising results in terms of safety and efficacy. Interventional radiology techniques in the spine include percutaneous biopsy and therapies for intervertebral disk herniation or spinal stenosis, facet and sacroiliac joint pathologies, vertebral and sacral fractures, and metastases. These techniques can also be easily combined one with the other or to further therapeutic approaches including systemic therapies, surgical approaches, and radiotherapy. This review provides a comprehensive overview of current percutaneous imaging-guided interventional radiology techniques in the spine. It will help readers become familiar with the most common indications, learn about different technical considerations during performance, and review the available evidence. Controversies concerning new products and technical approaches are also addressed.

Keywords
► interventional radiology
► spine
► augmentation
► ablation
► biopsy

Surgical approaches in the spine increase morbidity and mortality while at the same time run the risk of destabilizing a pathologic segment. Interventional radiologists routinely perform spinal interventions for diagnostic and therapeutic purposes, such as percutaneous biopsy and therapies for intervertebral disk herniation or spinal stenosis, facet and sacroiliac joint pathologies, and vertebral and sacral fractures, as well as metastatic lesions. Pathologies in the spine managed by percutaneous approaches include pain and neuralgias, facet (with or without the presence of synovial cyst) and sacroiliac joint syndromes, intervertebral disk herniation, vertebral and sacral fractures, and benign as well as metastatic spinal lesions.[1–8] During the last decade, new products and technologies for the management of spine pathologies have emerged with promising results in terms of both safety and efficacy. These techniques can be easily combined with one to the other as well, to other therapeutic approaches including systemic therapies, surgical options, and radiotherapy.

The minimally invasive character of intervertebral radiology techniques in the spine is closely related to the products used as well as to the imaging guidance that contributes to the high safety and efficacy rates related to percutaneous or endovascular approaches. Factors governing the selection of the imaging-guided method include detailed visualization of the target lesion and surrounding sensitive structures, high contrast and spatial resolution, depiction of the exact location of the needle tip, real-time monitoring, safety of the approach access, and its contribution to avoiding damage of vital organs, as well as the operator's preference.[1]

The prerequisite for a safe and efficacious interventional radiology technique in the spine is a meticulous physical examination and medical record evaluation (including performance status and drugs uptake), as well as control of

preprocedural imaging studies. Informed written consent should be obtained in all cases after discussion with the patient about the procedure, the possible complications, and the available alternatives. Discontinuation of antiplatelet and anticoagulant therapy should be recommended according to standard international guidelines for percutaneous and endovascular procedures.[9–11] Standard laboratory testing including blood count and coagulation parameters should be performed and assessed before the biopsy, similar to all other minimally invasive interventional radiology techniques. Choice of anesthesia depends on the specific technique applied (including complexity and location) as well as the patient's and operator's preferences.

This review provides a comprehensive overview of percutaneous image-guided interventional radiology techniques in the spine, to familiarize readers with the most common indications, learn about different technical considerations during performance, and provide the current evidence. Controversies concerning new products and technical approaches are also addressed.

Percutaneous Biopsy

Open spine biopsy through surgical approaches can be complicated by skin/bone/soft tissue problems, as well as risks of diagnostic error or missing a small lesion.[12] Sampling in the spine can be classified as fine-needle aspiration and percutaneous biopsy. The former uses needles with a diameter thinner and is most often used for fluid collections in the disk, the spinal cord, or for cerebrospinal fluid (CSF) evaluation. The latter utilizes soft tissue or bone biopsy needles with a diameter larger than 20G.

Indications for percutaneous biopsy in the spine include histopathologic diagnosis (to identify the target lesion as benign or malignant and primary or metastatic), molecular profiling in case of recurring or new metastasis, confirmation of a hematologic diagnosis, or identification of specific pathogens in patients with an infectious process. Apart from molecular profiling, newer indications in the era of personalized medicine include identification of the optimal treatment required, prediction of the tumor response in advanced stages, and recognition of tumor recurrence that will provide data for estimates on the rate of recurrence.[1] Contraindications include the refusal of the patient to consent to the procedure, lack of secure access, and untreated coagulopathy. Significant spinal cord compromise at the level of the biopsy might be related to a theoretical risk of myelopathy due to tissue swelling and bleeding.[1]

Depending of the spinal level involved and the location of the target lesion, different percutaneous approaches for spinal biopsy include the transoral technique for the C2 vertebral body, anterolateral (most commonly) or posterolateral approaches for the remaining levels of the cervical spine, costovertebral, intercostal, transpedicular, and through the costotransverse joint approaches in the thoracic spine, and posterolateral or transpedicular access of the lumbar spine. All these approaches are usually performed under fluoroscopy or computed tomography (CT) guidance (►Fig. 1).
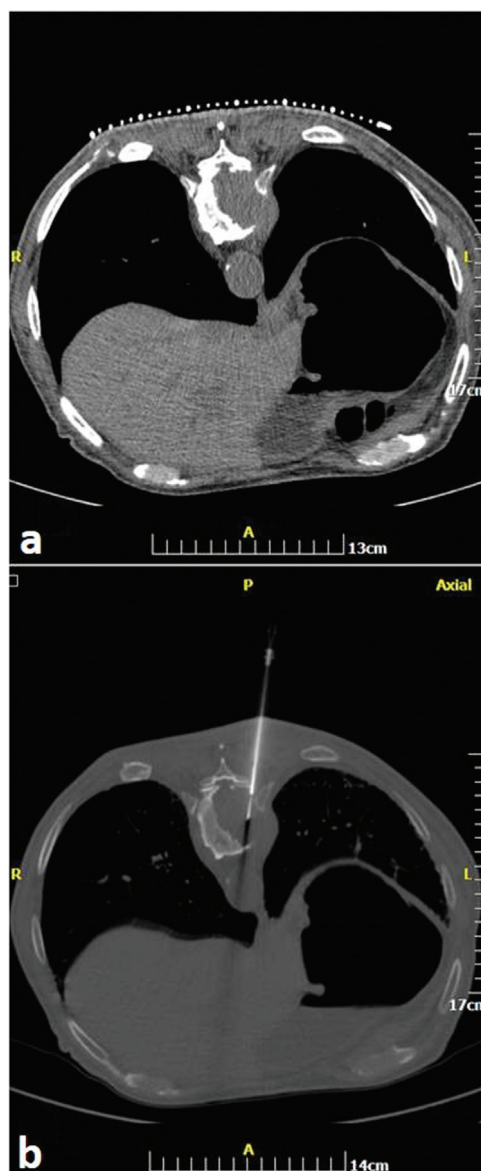
Fig. 1 (a) Computed Tomography axial scan in a 54-years-old female patient illustrating T11 vertebral body with a large – sized osteolytic lesion. (b) Through the costovertebral joint a trocar was placed in the vertebral body and coaxially a semi-automatic soft tissue biopsy needle was inserted.

In selected cases, magnetic resonance (MR) can be used as a guiding modality as well. Ultrasonography (US) as a stand-alone modality cannot serve for guidance because the vast majority of interventional radiology techniques are performed on the spine and involve intraosseous lesions, without a safe imaging window for the approach. Fusion software or the combination of US and endoscopic vision is being used and may become attractive alternatives. Targets for spine biopsy include the vertebral body, posterior vertebral arch, intervertebral disks, facet joints, paraspinal masses, epidural space, and the neuroforamen, as well as the spinal cord.

Decisive factors for a safe and percutaneous biopsy in the spine are an optimal imaging-guided method, appropriate needle trajectory to receive the greatest diagnostic yield, as well as selection of the biopsy system and anesthesia type.[1]

The diagnostic accuracy of percutaneous biopsy in the spine ranges from 70% to 96% with a suggested threshold of 70 to 75%. Three bone samples, the largest feasible biopsy needle, and osteolytic rather than osteoblastic lesions, as well as mixed lytic, compression fractures, and inflammatory bone lesions, are factors significantly increasing the diagnostic yield in a spinal biopsy.[13,14] In addition, aspirated blood clots should be considered as a tissue specimen because they have been shown to increase the diagnostic yield.[15]

In case of spondylodiskitis, percutaneous biopsy was shown to alter the clinical management of the patient in 35% of the cases.[16] Specifically for any infectious substrate, sampling of both the vertebral end plate and the intervertebral disk, as well as discontinuation of antibiotics before biopsy, were shown to increase the procedure's diagnostic yield and reduce the need for repeated biopsies.[17,18] The complications rate is < 5% including vascular injury, hematoma, myelopathy, nerve root damage and radiculopathy, thecal sac puncture, and fracture.[19]

Intervertebral Disk Therapies

Interventional radiology therapies for the management of intervertebral disk herniation and degeneration include diskography/diskomanometry, myelography, and spine injections, as well as decompressive/destructive or regenerative percutaneous approaches. For the intervertebral disk, indications for these percutaneous therapies include adult patients capable of providing consent, with from small to medium intervertebral disk herniation (occupying less than a third of the canal diameter at MR imaging) that is symptomatic (reporting leg pain with or without back pain; when these two coexist, leg pain should be of higher intensity). Finally, symptoms should be consistent with the segmental level where herniation is seen at MR imaging (e.g., an L2–L3 right foraminal herniation is expected to produce right L2 root neuralgia). Contraindications include sphincter dysfunction, extreme sciatica, and a progressive neurologic deficit that are considered surgical emergencies, as well as infection, sequestration, or asymptomatic herniation.

Percutaneous diskography can be performed in case of multilevel disk pathology to verify the intervertebral disk that acts as the source of pain. A subsequent CT provides imaging details concerning the dispersion of the contrast medium (►Fig. 2). Measurement of intradiskal pressure provides invaluable information not only for the degree of degeneration and the presence of ruptures/fissures but also can serve as a prognostic factor for both percutaneous and surgical therapeutic management. It can also be combined with artificial intelligence prognostic MRI software to define early degeneration. Percutaneous myelography with subsequent CT imaging can be used for symptomatic patients after fixation procedures in the spine with metallic instrumentation present that limits the visibility and diagnostic value of MR.

Spine injections can be performed intradiskally, transforaminally, or epidurally through either the flaval ligaments (interlaminar) or the sacro-coccygeal hiatus (caudal) (►Fig. 3). Most commonly used injectates include a mixture
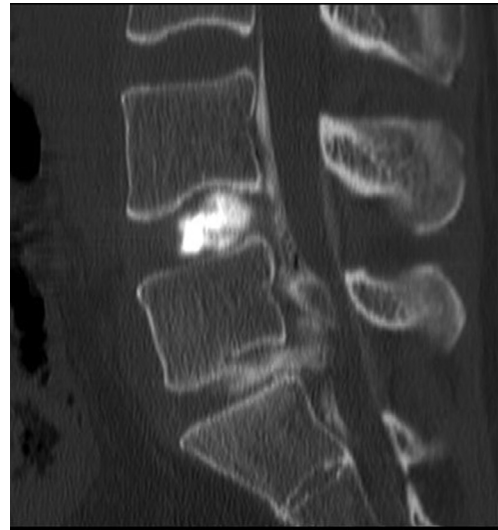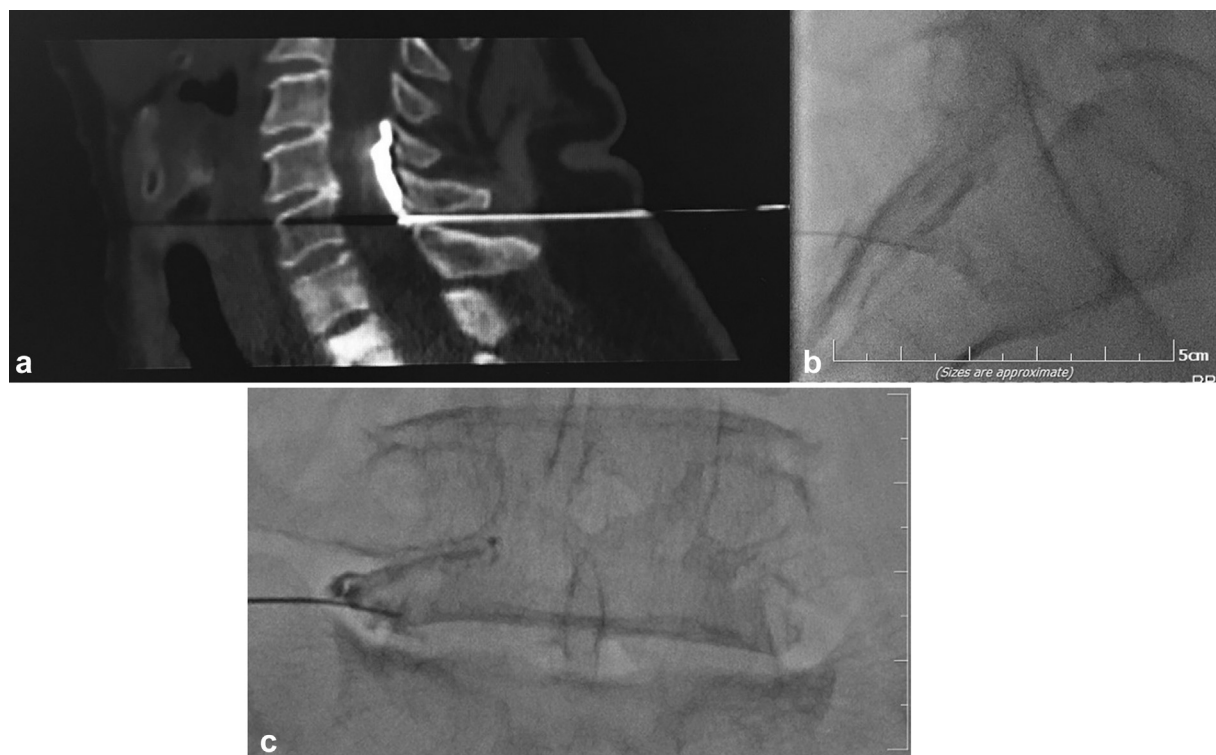

Fig. 2 Computed Tomography sagital reconstruction post percutaneous discography at 2 lower lumber intervertebral disc levels illustrating contrast medium in the epidural space through a hernia and a rupture / fissure of the L5-S1 intervertebral disc.

of corticosteroids with local anesthetic (or normal saline in case of injection in the cervical spine) and ozone. No matter the route of access, spine injections have been performed since 1901 using only local anesthetic; it was only in the 1950s that steroids were added to the mixture, changing the landscape and the therapeutic approach. Steroids act at the cellular level, and the resultant effect may take 3 to 5 days postinjection. Spine injections offer diagnostic and therapeutic advantages in the management of intervertebral disk pathology.

Transforaminal infiltrations are selective nerve route injections that can verify whether the target nerve acts as a pain source or not. On the contrary, translaminar and caudal approaches are not selective and cannot serve as diagnostic tests. Spine infiltrations can be either combined with conservative treatment of intervertebral disk pathology or performed as an intermediate step between conservative, percutaneous, or surgical therapies.

In a systematic review and meta-analysis evaluating the contents of the injectate as well as the routes of administration, Manchikanti et al concluded there is level 1 evidence for transforaminal and interlaminar approaches using local anesthetic and steroids versus level 2 evidence for the use of local anesthetic alone via the same routes.[20] For caudal infiltrations, there is level 2 evidence for using local anesthetic and steroids or local anesthetics alone.[20]

However, imaging guidance seems to be a decisive factor for the safety and efficacy of spine injections. Filippiadis et al compared blind versus fluoroscopy-guided translaminar epidural infiltrations in a group of patients with a severe degenerative lumbar spine, concluding that blind approaches lack the accuracy of exact needle location that imaging guidance offers in ∼ 40% of cases, placing the needle elsewhere, whereas in 30% of the cases, the needle was placed in a nontarget level.[21] Specifically for lumbosacral stenosis, a comparative trial between intramuscular ozone

Fig. 3 (a) Sagital Computed Tomography reconstruction during a cervical spine trans-laminar epidural infiltration. Contrast medium injection verifies correct needle position in the epidural space. (b) Lateral fluoroscopy view during a S1 infiltration. Contrast medium injection verifies correct needle position in the S1 foramen. (c) P-A fluoroscopy view during an L5 infiltration. Contrast medium injection verifies correct extra – vascular needle position in the L5-S1 foramen.

injections and caudal infiltration concluded that both techniques reduce pain at 8-week follow-up; however, ozone injections significantly outperform regarding a decrease of pain intensity.[22]

Complications after spinal infiltrations are rare and include infection, dural puncture, hypertension, or increased blood sugar related to the steroids injected or epidural hematoma. Paraplegia is an extremely rare complication most probably related to a radiculomedullary artery puncture and intravascular injection of a particulate steroid where the particles clog, causing arterial embolization that results in cord ischemia.[23] Prior surgical operations resulting in scar tissue with abundant vasculature from neoangiogenesis is a recognized risk factor.[23] Real-time monitoring of a contrast medium injection to verify correct extravascular needle location is a prerequisite for a safe session. In case of CT-guided injections, the absence of contrast media pooling should be a red flag and suggestive of an intravascular needle placement.

Another type of spine injection involves rupture and/or gluing of a symptomatic Tarlov's cyst. Through an image-guided needle puncture approach, the operator can deliver treatment to a symptomatic Tarlov's cyst, thus provoking shrinkage that liberates the compressed neural structure from the volume effect. Finally, image-guided injection of blood patches, in case of CSF leakage, can be performed under fluoroscopy or even more accurately under CT on the precise location of the leakage, as seen from the MR sequence. The technique increases the precision and target delivery of the blood patch because the whole procedure is monitored. Contrast media is injected initially to verify the epidural location, followed by the local injection of up to 20 mL peripheral blood. Because the delivery is on target, usually a smaller volume of peripheral blood is administered. The injection is immediately stopped if there are any signs of discomfort.

Percutaneous decompressive/destructive approaches for intervertebral disk herniation can be further classified into mechanical, thermal, and chemical types based on the product used.[3] All these techniques are based on the fact that the intervertebral disk is a closed space governed by the principle that removal of a small tissue volume results in significant pressure changes with subsequent decrease of the mechanical pressure and the irritation at the nerve root or pain receptors located in the annulus fibrosus and peridiscal space. Therefore, by destroying a small part of the nucleus pulposus, there is major intradiskal pressure reduction with a resultant withdrawal of the herniated fragment.

Mechanical decompression techniques use high-rotation-per-minute devices or water/pneumatically driven suction-cutting probes to remove disk material most commonly from the nucleus pulposus or the hernia itself (►**Fig. 4**). Thermal disk decompressive techniques include coblation, radiofrequency, and laser ablation (applied in pulsed or continuous modes). In general, pulsed application of radiofrequency or laser energy keeps tissue temperature < 42°C; in continuous ablation, coagulative necrosis occurs at temperatures between 60°C and 80°C. Coblation refers to low-temperature
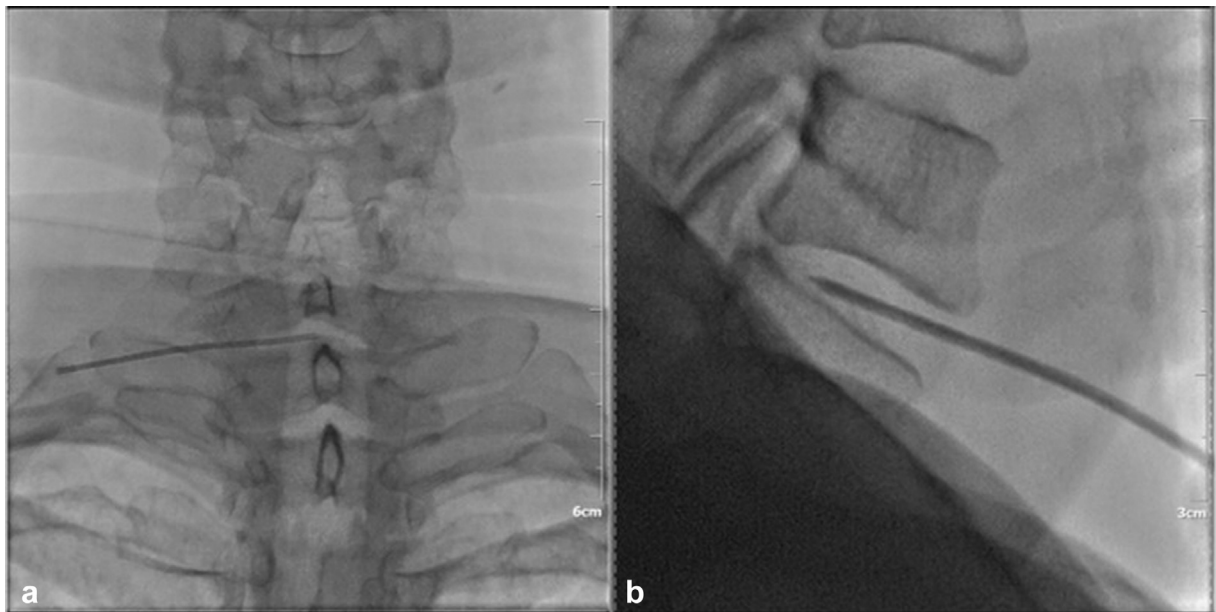
Fig. 4 Percutaneous cervical discectomy: Fluoroscopy A-P (a) and lateral (b) views illustrating correct trocar's intradiscal position at the midline in A-P and at the anterior third in lateral projection half way between the end plates of the vertebral bodies.

plasma field-controlled ablation (50–70°C) that creates intradiskal channels. Continuous laser heats the tissue, provoking coagulation necrosis and shrinkage of the tissue. Chemical decompression techniques utilize an oxygen-ozone mixture or radiopaque gelified ethanol to dehydrate the intervertebral disk with an additional anti-inflammatory response.

Efficacy rates for all types of percutaneous decompressive techniques range between 75% and 80%.[3] When compared with conservative therapies, percutaneous techniques show improved amelioration of symptoms at the 12- and 24-month follow-up.[24] In the most recent noninferiority randomized controlled trial, intradiskal application of the oxygen-ozone mixture met the noninferiority criteria to microdiskectomy; approximately two thirds of the patients of the percutaneous arm were able to avoid surgery.[25] In addition, percutaneous approaches are related to minimal damage of the surrounding structures and have been proven more cost effective when compared with an open surgical options.[26] Iatrogenic complications, such as hemorrhage, dural puncture, or nerve root damage, are extremely rare; spondylodiskitis is the most severe complication (0.24%).[3]

Historically, intradiskal biologics for intervertebral disk therapies included fibrin adhesives (such as fibrinogen and thrombin to seal annular tears), bone morphogenic protein, growth differentiation factor, α2-macroglobulin, platelet-rich plasma, and mesenchymal cell-based therapies (autologous or allogeneic). In addition, hydrogel-based compounds have been used that aim to restore nucleus pulposus height and water absorption in case of an intact annulus fibrosus.[3,27] These products are either biologically derived or synthetically produced. A platelet-rich plasma intradiskal application currently has the most data in the literature; it was shown to exert an anti-inflammatory effect combined with tissue regeneration and angiogenesis promotion.[28] At

present there is no definitive evidence regarding the safety and efficacy of intradiskal biomaterials; further trials are necessary to support noninferiority criteria regarding percutaneous decompressive or surgical approaches.

Facet and Sacroiliac Joint Therapies

Pathology of the facet and sacroiliac joints accounts for ~40% of patients with low back pain. The pathologic substrate varies including degenerative, arthritis, inflammatory arthropathy, infection, or trauma.[29,30] Interventional radiology therapies for facet and sacroiliac joints pathology include injections, neurolysis or neuromodulation, and fixation (arthrodesis) techniques. These percutaneous techniques are considered first-line therapeutic approaches due to the high complications rate of open surgical therapies. Level 1 evidence supports the application of fluoroscopy or CT for all facet and sacroiliac joint interventions.[30]

Most commonly used injectates include a mixture of corticosteroids with local anesthetic (or normal saline in cases of injection in the cervical spine), plasma rich in growth factors, and hyaluronic acid derivatives.[30] Facet or sacroiliac joint injections can be used for diagnostic purposes (as a positive test before neurolysis) or a therapeutic objective (aiming at pain reduction) (►Figs. 5 and 6). For facet joints, specific target locations include intra-articular needle placement or on the median branch nerve. Similarly, for sacroiliac joint injections, targets include intra- or periarticular locations. Hypotheses to explain therapeutic impact post median branch or periarticular infiltration include deep trigger points injection during the infiltration, adhesion lysis, desensitization of hypersensitive medial branch nerves, a diminishing pain threshold, and chemical neurolysis through the local anesthetic.[31] For facet joint injections, there is a moderate strength of recommendation (level 2) for
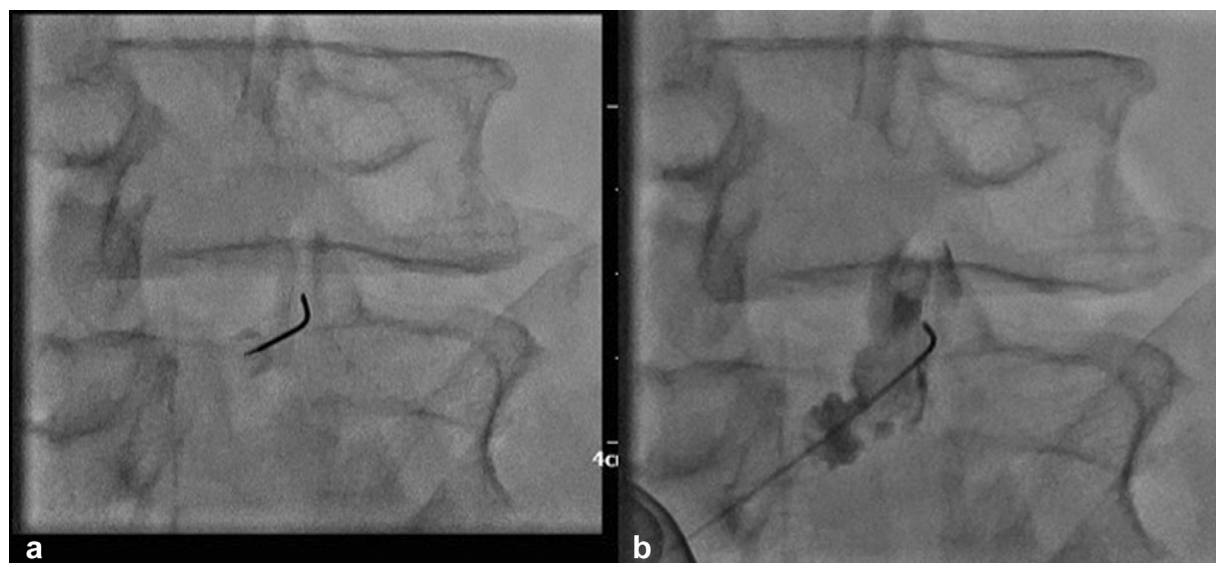
Fig. 5 (a) Fluoroscopy oblique view (Scottie dog projection) illustrating the 22G spinal needle inside the L4-L5 right facet joint. (b) Fluoroscopy oblique view (Scottie dog projection) illustrating contrast medium which verifies correct intra-articular needle placement.

therapeutic efficacy in the cervical and lumbar spine.[30] For the sacroiliac joints, when compared in a double-blind randomized clinical trial, intra-articular injection of corticosteroids was shown to result in a significantly better outcome than a platelet-rich plasma injection in terms of both pain and improvement of function.[32]

Neurolytic techniques are aimed at joint denervation and include the application of continuous radiofrequency energy using standard or cooled electrodes or cryoablation (►**Fig. 7**). In contrast, neuromodulation uses application of pulsed radiofrequency energy with the temperature remaining below 42°C. The target point for joint denervation or neuromodulation is the junction of the transverse process and the superior articulating process where the median branch nerve runs and turns posteriorly to innervate the facet joint. In addition, pulsed radiofrequency for neuromodulation can also be performed intra-articularly. A comparative trial with steroid injection showed that intra-articular stimulation is as effective as a steroid injection.[33]

For facet joint neurolysis, there is a moderate strength of recommendation (level 2) for therapeutic efficacy in the cervical and lumbar spine.[30] Recent sensitivity analyses showed that facet joint denervation is a cost-effective therapy meeting the criteria for high priority treatment.[34] As a totally noninvasive approach, MR-guided high-intensity focused ultrasonography (HIFU) can be applied as a neuro-destructive/neurolytic approach for facet and sacroiliac joint denervation with similar reported rates of pain reduction and functional improvement as those of percutaneous techniques. However, due to the nature of the technique, the duration of the therapeutic session is significantly longer for MR-guided HIFU, potentially requiring general anesthesia.[35]

Arthrodesis techniques use fusion devices to stabilize the joints to become immobile and, in theory, not to act as a pain source. They are minimally invasive procedures aiming to avoid patients undergoing open surgical approaches.[36] Specifically for synovial cysts originating from the facet joints,
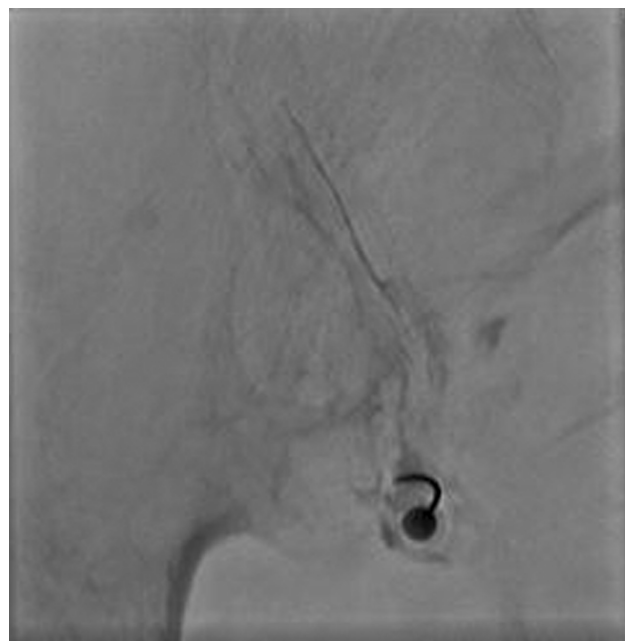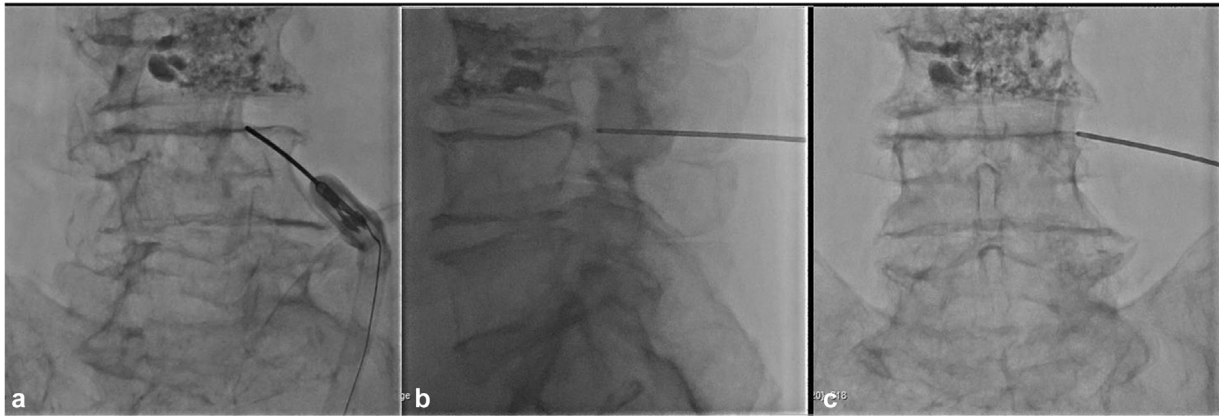

Fig. 6 Posteroanterior fluoroscopy view illustrating the 22G spinal needle inside the left sacroiliac joint. Contrast medium injection was used to verify correct intra-articular needle placement.

image-guided percutaneous rupture or evacuation combined with a steroid injection can be performed. The technique was shown to be a safe and efficacious therapy that can eliminate the need for surgery.[37]

Percutaneous Implants for Spinal Stenosis

Older adult patients with symptomatic spinal stenosis may be noncandidates for open surgical approaches due to comorbidities and the need for general anesthesia. Interspinous implants that can be placed percutaneously under local anesthesia or mild sedation have been introduced with reported pain palliation, reduced disability, and significant

Fig. 7 (a) Oblique, (b) lateral, and (c) posteroanterior fluoroscopy views during positioning of a cryoprobe for facet joint neurolysis.

Fig. 8 Posteroanterior fluoroscopy view after cement injection during percutaneous vertebroplasty illustrates bilateral dispersion of the polymer in the vertebral body from the upper to lower end plate and crossing the midline. Next step: In the lateral view, both needles are removed.

increases in spinal canal and foraminal cross-sectional areas at the treated level.[7] When compared with conventional surgical techniques (bony decompression with or without fusion), the percutaneously placed interspinous spacers, although more expensive and with higher reoperation rates, have met the noninferiority criteria in terms of pain reduction and quality-of-life improvement with a lower postoperative complication rate and hospitalization length of stay.[7] However, it is questionable if these spacers can be considered the primary treatment for spinal stenosis or a solution for patients unfit for open surgery.

Vertebral Augmentation Techniques

Percutaneous vertebral augmentation techniques for pain reduction and structural support include vertebroplasty (►**Fig. 8**), balloon augmentation, as well as the application of spinal implants.[2] Indications for vertebral augmentation include osteoporotic, pathologic, and traumatic (stable) fractures, benign lesions (such as hemangiomas), as well as cancer-related cases with lytic, blastic, or of mixed appearance metastatic lesions or lesions related to hematologic malignancies (multiple myeloma, leukemia, etc.). Additional indications include Kummel's disease and the need for anterior stabilization before surgery is performed on the spine's posterior elements.[2,38] Contraindications include improvement of symptoms after a 4- to 6-week course of conservative treatment, asymptomatic patients, uncorrectable coagulopathy, severe cardiorespiratory disease, cement allergy, and systemic and especially local infection.[2,38]

The most common polymer used is polymethylmethacrylate; alternatives include a synthetic bone substitute such as calcium phosphate cement aiming for new bone formation or elastomeric polymers.[38] Spine implants that can be placed percutaneously for the management of a vertebral fracture include stents, jacks, polyetheretherketone (PEEK) cages, cannulated screws, and fracture reduction systems.[7] Implants aim to provide restoration of vertebral height and long-term improvement of the kyphotic angle.[7] At the present time, there is no proven superiority of one implant or technical approach over the other in terms of efficacy, safety, and biomechanical evaluation. Regarding cost, however, implants are significantly more expensive when compared with standard augmentation techniques such as percutaneous vertebroplasty and balloon augmentation.[7] The vast majority of implants are placed as a couple bilaterally in the vertebral bodies according to the guidelines provided by the manufacturer. The PEEK cage is the only implant that can be placed singly through a unipedicular approach (►**Fig. 9**). An alternative technical approach includes the stent-screw-assisted internal fixation or the transpedicular fixation by PEEK polymer implants combined with cementoplasty (that can reduce the fracture, reconstruct the vertebral body, and fix it to the posterior elements).[39,40]

Efficacy and complication rates depend on the pathologic substrate of the treated fracture. In the osteoporotic substrate, efficacy rates (in terms of pain reduction) are up to 90% for acute and 80 to 100% for chronic fractures with a complications rate between 2% and 5%.[2,38] Efficacy and
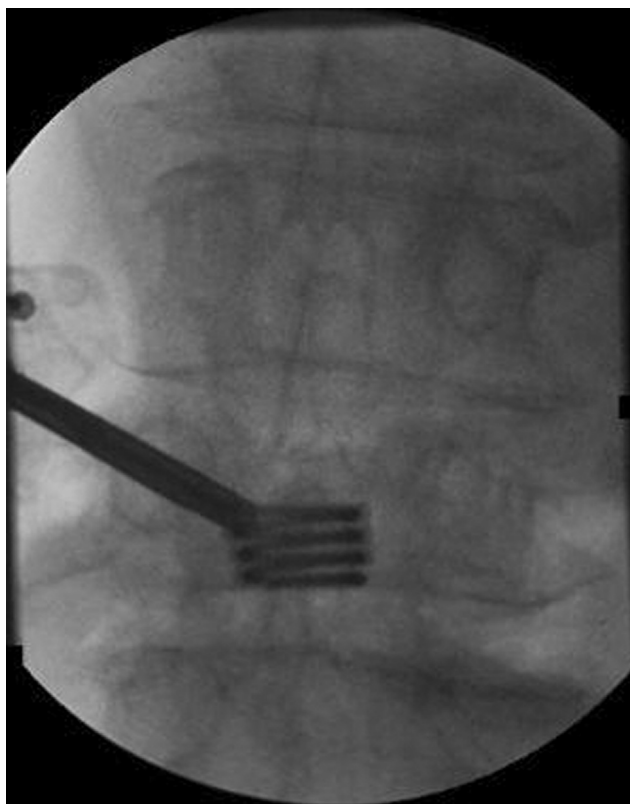
Fig. 9 Posteroanterior fluoroscopy view during polyetheretherketone cage placement verifying midline position of the implant in the vertebral body.

complication rates for malignant substrate are 60 to 85% and < 10%, respectively, whereas for aggressive hemangiomas, the rates are 80 to 100% and 2 to 5%, respectively.[2,38] Complications include cement leakage, infection, pedicular or rib fracture, bleeding, and allergic reaction.[2,38] Adjacent vertebral body collapse has not been proven to be related to prior vertebral augmentation techniques. Randomized controlled trials comparing vertebral augmentation techniques with conservative or placebo therapies showed neither any relation nor any risk increase of new adjacent and distant fractures.[41]

Vertebral augmentation techniques have been proven to prolong survival and prevent morbidity in patients with vertebral compression fractures. Risk of complications from performance of these therapies is significantly less than conservative management of a bedridden population. Percutaneous management of vertebral fractures is associated with significantly reduced or discontinued opioids prescription, having a respective impact on opioids-related harms and payer costs.[42] In a meta-analysis of > 2 million patients with osteoporotic vertebral fractures, those treated with vertebral augmentation were 22% less likely to die at up to 10 years after treatment than those who received conservative management.[43]

The data in the literature comparing percutaneous vertebroplasty and balloon augmentation techniques are controversial. At present there is no clear superiority of one technique over the other.[2,38] It is evident, however, that a single-session multilevel (more than three) vertebroplasty is equally safe and efficacious as management of less than three fractured levels, no matter the pathologic substrate.[44,45] When compared with balloon augmentation, spine implants have met noninferiority criteria with similar efficacy and rates of adverse events. In addition, spine implants were associated with a favorable difference of adjacent new fractures.[46,47] In the future, cements, biologics, and implants may serve as drug delivery platforms for antibiotics, anticancer, and other systemic therapies.
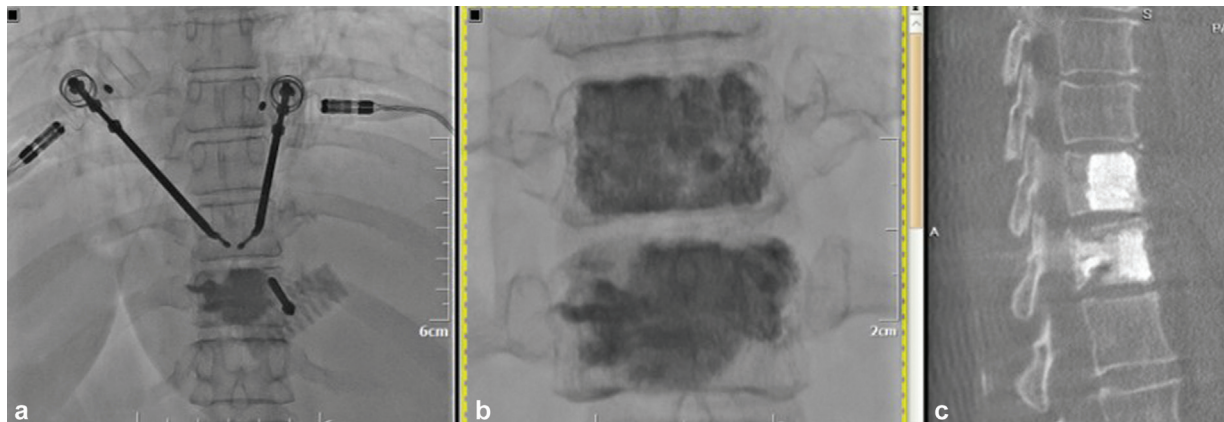
Percutaneous Ablation

Due to its proximity to sensitive neural structures, the spine is considered a challenging location for percutaneous ablation. Specifically for cancer patients, multidisciplinary input is a prerequisite. When compared with open surgery, percutaneous ablation is less invasive, easily repeatable, governed by lower morbidity, and lower cost with high rates of technical and clinical success rates, minimal blood loss and tissue injury, as well as a significantly shortened hospitalization.[4,48] Percutaneous ablation techniques that can be applied in the spine include laser interstitial therapy, radiofrequency, microwave, cryoablation, and HIFU under MR guidance. Of these, radiofrequency and cryoablation are related to the highest level of available cumulative data in the literature. Recently, bipolar radiofrequency systems either with straight electrodes and separate thermocouples or with navigational electrodes and build-in thermocouples became available for spine ablation. Technical factors (such as location, size, lytic or blastic characteristics, proximity to spinal cord or nerve roots), as well as operator's preference, determine the selection of ablation modality. In addition, for cancer patients, tumor histology, patient clinical-functional status, risk of pathologic fracture and collapse, and life expectancy should be considered.[4,48–51]

Percutaneous ablation in the spine currently plays a pivotal role in the therapeutic management of benign and malignant lesions, and it can be performed either solely or in combination with other interventional radiology procedures, radiation therapies, and systemic therapies. With few exceptions (e.g., osteoid osteoma), whenever ablation is performed in the spine, it should be followed by cement injection for structural support. The Spine Instability Neoplastic Score, which assesses the risk of a secondary pathologic fracture and vertebral collapse, is an interesting tool to categorize vertebral fractures before therapy.[49] Indications for percutaneous ablation in the spine include benign lesions (such as osteoid osteoma, osteoblastoma, aneurysmal bone cyst, hemangioma, etc.), and primary malignant (hemangiopericytoma), as well as metastatic lesions, in a vertebral body.[4,48]

Specifically for cancer patients, goals of ablation in the spine include either local tumor control or pain reduction with or without functional restoration. According to the 2020 National Comprehensive Cancer Network guidelines for adult cancer pain management, indications for percutaneous ablation include pain reduction and prevention of

Fig. 10 Female breast cancer patient with metastatic lesions in thoracic spine: one year post percutaneous ablation of T11 vertebral body follow-up imaging with MRI illustrated a recurrent lesion in the same level as well as a new lesion in T10. Bipedicular simultaneous radiofrequency ablation was performed with navigational bipolar electrodes at T10 and unipedicular approach was performed at T11 level (a) followed by cement injection (b). Cone beam CT 3D reconstructions (c) were used for evaluating the dispersion of the polymer in the vertebral bodies treated.

serious reportable events in patients without an oncologic emergency or symptomatic patients with symptoms refractory to systemic pharmacologic therapy.[50] Contraindications include unstable pathologic vertebral compression fractures and metastatic epidural spinal cord compression.

Osteoid osteomas in the spine constitute a challenging group for both surgical and percutaneous approaches. High safety and efficacy rates are related to the choice of ablation modality, ancillary techniques for thermoprotection, adequacy of treatment, and postablation imaging. Tsoumakidou et al reported a 98.2% and 100% primary and secondary success rate, respectively, after percutaneous CT-guided laser photocoagulation of osteoid osteoma in the spine with a 5.3% total recurrence rate and no major complication rates.[52] In general, efficacy and safety rates of spinal osteoblastomas, although comparable, are somewhat lower than those for the ablation of osteoid osteoma.[53] Efficacy rates of spinal ablation for curative and pain palliative effect range up to 87% and 96%, respectively.[4,5,8,54] Simultaneous bipedicular radiofrequency ablation in the spine results in a more thorough ablation of the vertebral body and pedicles by producing confluent, coalescent, and overlapping ablation zones (►Fig. 10).[4,54]

The most fearsome complication of spine ablation is nerve or cord injury that can result in radiculopathy, paresis, and paralysis. The vast majority of these neural complications are transient and may be managed by spine injections (transforaminal or translaminar epidural infiltrations using steroids and local anesthetics).[4,55,56] Infection, aseptic meningitis syndrome, and pathologic fracture or injury to the surrounding tissues are other complications related to ablation in the spine.[4,55,56] Ancillary techniques aiming to increase safety and augment the efficacy of percutaneous ablation in the spine include temperature measurement by thermocouples, placed close to sensitive neural structures, neurophysiologic monitoring by means of evoked potentials or local electrostimulation of specific peripheral motor nerves, as well as hydro- or gas dissection.[55–58] Specifically, monitoring of transcranial electrical motor and somatosen-

sory evoked potentials during spine ablation has been proven efficacious on reporting abnormal activity changes that correlate with postprocedural neurologic sequelae.[58]

Contrast-enhanced MRI is the modality of choice for the evaluation of spine ablation in the follow-up period through a comparison of nonenhancing zone of necrosis with the enhancing tumor as illustrated on the pretreatment imaging. At present there is no clear algorithm for follow-up imaging. The first follow-up examination is ideally performed at 6 to 8 weeks, and then further imaging is conducted in case of new or worsening symptoms.[57] Apart from MRI, positron emission tomography (PET)/CT or PET/MRI can be used for follow-up of spine ablation, offering invaluable information and differential diagnosis among tumor remnant or recurrence, vascular fibrosis, or granulation tissue.[57] But all imaging evaluation techniques have the innate issue of posttreatment inflammation. As such, they must either be performed immediately posttreatment (in the first 24 hours) or 3 to 6 weeks posttreatment to avoid postablation inflammation tissue interference.

Transarterial Embolization

Endovascular approaches in the spine include spinal angiography and transarterial embolization. Spinal angiography is indicated for the diagnostic evaluation of spinal vasculature, enabling visualization of anatomical variants or of a lesion's arterial feeding. Transarterial embolization is indicated for preoperative application to reduce intraoperative blood loss, improve visualization of the tumor, and facilitate complete removal. Other indications include palliative pain reduction or curative goals in well-selected cases of benign (osteoblastoma, hemangioma, aneurysmal bone cyst, giant cell tumor) or primary malignant (hematologic malignancies, sarcomas) tumors as well as of chordoma.[59]

Preoperative transarterial embolization can be performed before surgical removal of primary or metastatic hypervascular spinal lesions. Ideally, complete embolization is the objective of the session; however, due to the risk of spinal

cord stroke with serious neurologic consequences, partial approaches are considered more preferable and safer. Surgery post transarterial embolization should be performed on the next day or at the maximum within 72 hours to benefit from the optimal devascularization effect and at the same time observe for any possible complications.[60]

Complications of preoperative spinal tumor embolization range between 2% and 10% and include neurologic sequelae, muscle pain, skin abscess, and vertebral body infarcts.[59,60] The palliative pain reduction effect after transarterial embolization in the spine is based on devascularization that reduces the size of the tumor and a slowdown of the periosteal destruction with resultant relief of symptoms. Reported efficacy rates are up to 89%.[59] Most commonly used materials for palliative embolization in the spine are N-2-butyl cyanoacrylate or polyvinyl alcohol.

In the palliative setting, transarterial embolization can be performed alone or in combination with radiotherapy. In any case, addition of a chemotherapeutic agent (transarterial chemoembolization) can be considered an alternative approach as well. Curative indications of transarterial embolization in the spine for primary benign and malignant lesions are questionable. Up until now, enough data have been reported only for an aneurysmal bone cyst.[59]

Conclusion

Spinal interventions are now performed routinely by interventional radiologists for diagnostic and therapeutic purposes including disk and nerve evaluation, percutaneous biopsy, therapies for intervertebral disk herniation or spinal stenosis, facet and sacroiliac joint pathologies, and vertebral and sacral fractures and metastases. Technological and imaging evolution, together with new material technologies for the management of spine pathologies, are showing promising results in terms of safety and efficacy. Interventional radiology techniques can be considered either as first-line therapies or as attractive alternatives with a central and pivotal role in the therapeutic algorithm. They can be easily combined together as well as used to further therapeutic approaches including systemic therapies, surgery, and radiotherapy. Specifically for cancer patients, multidisciplinary input should be mandatory.

Conflict of Interest
None declared.

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