52 The Diagnostic and the Therapeutic Utility of Radiology in Spinal Care

Matthew Lee and Mario G. T. Zotti

Contents

M. Lee (✉)
Western Imaging Group, Blacktown, NSW, Australia
e-mail: info@westernimaginggroup.com.au

M. G. T. Zotti
Orthopaedic Clinics Gold Coast, Robina, QLD, Australia

Gold Coast Spine, Southport, QLD, Australia

B. C. Cheng (ed.), *Handbook of Spine Technology*,
https://doi.org/10.1007/978-3-319-44424-6_83

Abstract

Advancements in technology have been a driving force in the development of medical imaging equipment. There are now multiple, varied, and intertwined imaging modalities which visualize the spine in many different formats and positions. This has facilitated an increase in accuracy of diagnosis, and then at the same time allowed medical imaging to be an essential tool, in treatment of spinal conditions. Multiple image-guided therapies are now available to assist physicians/surgeons with treatment regimens and pre- and postoperative surgical planning. This chapter will detail the above.

Keywords

Radiology · Spinal · Neuroradiology · CT · Computed tomography · MRI · Magnetic resonance imaging · Nuclear medicine · EOS · Myelography · Medial branch block · Discography · Intervention · Corticosteroid injection · Aspiration · X-ray · Fluoroscopy

Introduction

Radiology, or medical imaging, has advanced dramatically since the discovery of the X-ray by William Roentgen in 1895. Over the last 120 years, this scientific discovery has evolved from being a novelty nonmedical commercial and social photographic studio tool to a necessity, essential to physicians and surgeons throughout the world (American Society of Radiologic Technologists 2018).

The computer age and advancing technologies allowed the use of X-rays and then other forms of radiation to be progressed into more sophisticated imaging equipment. Thus, medical diagnosis has progressed well beyond the first point of physician-patient contact – history and examination – as the diagnosis or differential diagnoses can be radiologically narrowed or confirmed and the pathology directly viewed within the patient.

The radiology/medical imaging field has taken a dual role of diagnosing and treating. Radiology canbe a primary source of treatment or an adjunctive intervention to both surgical pre- and postoperative care.

Within the field of spine care, radiology has assumed such an important role in the detection, diagnosis, and treatment of spine and spine-related disorders. Thanks to the radiologists, the spine surgeon can deliver a precision diagnosis and with that therapeutic options. When combined with the quantification and prognostication afforded by imaging (e.g., the grade of spondylolisthesis or the amount of sagittal imbalance), this forms an invaluable trinity of diagnosis, quantification, and therapy (see Fig. 1).

The diagnostic and treating armamentarium available to the patient and physician from the radiology specialty is as follows:

- Diagnostic:
  - Noninvasive:
    - *X-ray*
    - *Fluoroscopy*
    - *CT*
    - *MRI*
    - *Nuclear medicine*
  - Invasive:
    - *Myelography*
    - *Medial branch block*
    - *Discography*
- Therapeutic:
  - *Facet joint/medial branch corticosteroid injections*
  - *Epidural/perineural corticosteroid injections*
  - *Synovial cyst puncture and aspiration*
  - *Sacroiliac joint corticosteroid injections*
  - *Coccyx injections*
  - *Facet joint denervations*
  - *Vertebroplasty and kyphoplasty*
  - *Insertion of stimulators*

Comments About Radiation

Plain radiographs, CT, and fluoroscopy all produce ionizing radiation and hence the ability to cause cancer or birth defects, via damage either

Fig. 1 The unity of diagnosis and treatment clearly shown in verification of deformity correction

to the reproductive organs or to the developing embryo directly. However, the use of radiation from medical imaging procedures when ordered prudently and for the specific benefit of diagnosis or treatment leads to minimal hypothetical risks especially in relation to cancer deaths and estimated cancers produced and even more so when the principles of ALARA (radiation dose as low as possible), ASARA (medical procedures as safe as reasonably achievable), and AHARA (medical benefits as high as reasonably achievable) are followed (Hendee and O'Connor 2012). With technologies improving all the time, the radiation dose from all forms of imaging is becoming less, and the major equipment suppliers make this a standard in design and development and market accordingly. Despite lessening radiation doses from improving technology, the link of abdominal radiation dose with solid organ malignancy mandates careful assessment of risks and benefits from the ordering of tests involving ionizing radiation.

Noninvasive Techniques

X-ray

The humble radiograph. With all the new modalities for imaging now available, the spine radiograph is of less diagnostic importance as CT and MRI provide far more detail. The fact the plain radiograph cannot show soft tissue details of the spine, only bone, and can only image in limited planes is its major drawback, and the radiograph provides a 2D representation of a 3D structure.

However it still does play an essential role in the investigative role of diagnosing spine and spine disorders and as such should not be dismissed as an irrelevant investigation but a useful investigation in the first line of the diagnostic pathway. Despite government detractors that criticize the plain radiograph from the point of view of ionizing radiation and the lack of benefit, the radiograph provides a positive yield in many situations, clinical and diagnostic, when applied specifically to the clinical situation.

Traditional images are AP and lateral views with oblique or functional views being added depending upon the request of the referrer or individual protocols of the radiology practice. The lateral view plain film will show alignment of the spine – confirming the normal or abnormal lordosis or kyphosis of the cervical, lumbar, and thoracic spines, respectively, and the AP film curvature or more scoliosis. Also disc space narrowing, i.e., degeneration and possibly foraminal stenosis, may also be revealed and of course a bony lesion. Oblique lumbar radiographs may be ordered in the case of spondylolysis to detect pars defects.

For a lumbar spine radiograph, the question of radiation to the reproductive organs is always of some concern. However, like with any radiograph, it must be balanced against its benefit, particularly in the younger person.

An exciting new technology, which has only become available in the last few years, is EOS™. It takes plain film spinal radiography to a new level. Firstly, the radiation dose is about 50% less than for digital radiography; hence the dose is almost negligible. Secondly, the entire skeleton – the chest, upper limbs, entire spine, pelvis, hips, and lower limbs – can be viewed in the weight-bearing position. Both frontal and lateral images are obtained, and from the images, 3D modelling is performed. This allows detailed analysis of the kyphotic and lordotic state of the spine and, of course, scoliosis (see Fig. 2). Hence, the normal distribution of weight, stresses, and angles throughout the axial skeleton can be assessed. Many parameters are measured including the C7 plumb line, kyphosis and lordosis, thoracic and lumbar vertebral and intervertebral rotations, spino-sacral angle, pelvic incidence/version and sacral slope, pelvic obliquity and rotation/tilt, Cobb angle, and scoliosis. Further measurements in relation to lower limb leg lengths and hip and knee angle and alignment parameters can be carried out. With all this additional

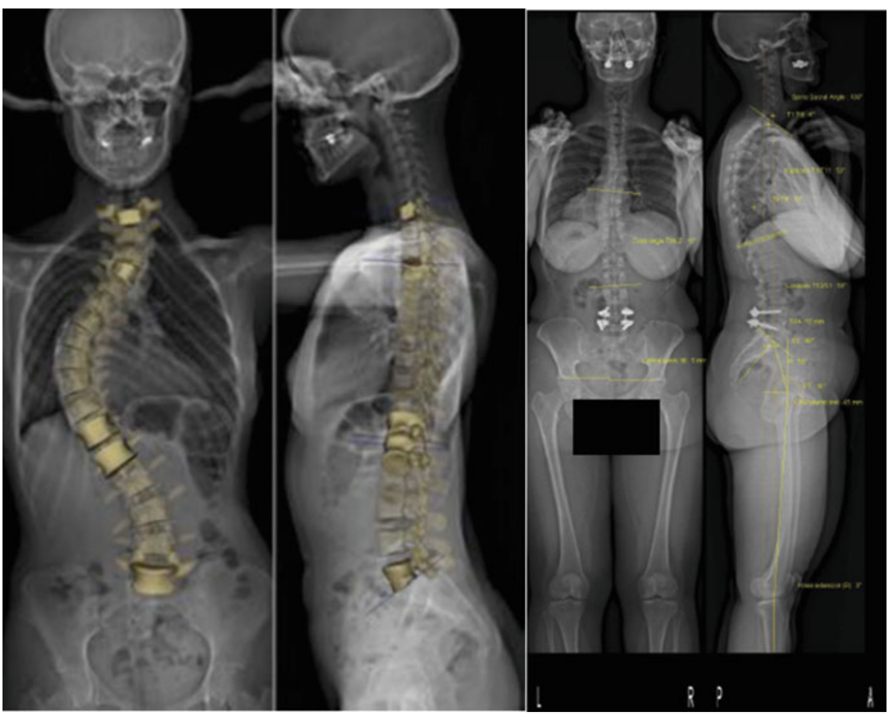

Fig. 2 EOS™ showing images of the whole spine – AP, lateral, and 3D reconstructions – with measurements for assessment of surgical balance as a forerunner to surgical treatment and planning

information, surgical procedures can now be planned (including types and requirements of reconstructions) to take into account the entire axial skeleton rather than solely the symptomatic area in question (Amzallag-Bellenger et al. 2014).

Fluoroscopy

This is using X-rays to allow real-time (i.e., dynamic) imaging. The machinery and technology have developed over time like that of the X-ray machine. It works on a similar principle to the traditional X-ray machine; however it is of low intensity (and hence low radiation) and therefore is coupled with an image intensifier which allows the image to be seen (without the need for a darkened room) (Amzallag-Bellenger et al. 2014).

The fluoroscopy unit has its main use as an adjunct to spinal procedures particularly aiding in needle placement for injections, both for diagnostic, e.g., discography and myelography, and treatment regimens, e.g., corticosteroid – *see below*. It is also used in theater for spinal level checks and aids in planning and confirming spinal surgical hardware placement and position. Such advancements have allowed reduction in malpositioned screws and cages that, if unrecognized, could present problems in the perioperative period for the patient (Amzallag-Bellenger et al. 2014; Goodbody et al. 2017; Deschenes et al. 2010; Laredo et al. 2010).

Computed Tomography

CT was part of the spinal imaging evolution, both diagnostically and therapeutically. The spine could now be imaged in much greater detail than was possible with the plain radiograph and fluoroscopy. The soft tissues, i.e., disc, ligaments, muscle, nerve roots, and CSF, could now be seen as could the size and state of the spinal canal (see Fig. 3). Tumors and fractures were depicted far more clearly. Further benefits were found as CT could image in multiple planes – coronal, sagittal, and axial – as well as oblique planes with rotation and 3D images. Hence, the name changed from computed axial tomography when it originated as a single-slice machine to now just computed tomography with the current cohort being multi-slice/multidetector up to 640. It remained the most accurate method of neural and soft tissue assessment until advancements in the mid-late 1980s made MRI feasible for routine use. CT remains superior to MRI, however, for assessment of bony structures and is still the gold standard for assessing fusion.

Continued refinements in CT have allowed faster, higher resolution and more accurate scans as well as significant reductions in radiation. CT now has the added benefit of CT fluoroscopy

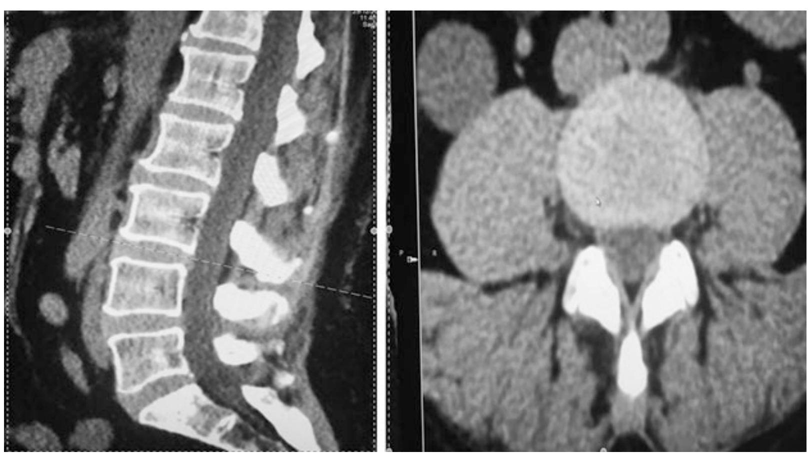

Fig. 3 Sagittal and axial CT of lumbar spine, showing bones, disc, canal, foramina, and nerve roots

– real-time imaging via the CT scanner in procedures.

Diagnostically, CT allows the disc (+/− disc osteophyte complex) to be analyzed, whether or not there is herniation or stenosis and to what degree – both foraminal and central canal. The origin and descending nerve roots can also be seen; hence nerve root compression and displacement becomes available allowing the clinician to diagnose and treat the symptoms with far greater accuracy. This is particularly important in cervical spine surgery where disc osteophytes and uncovertebral complexes need to be cleared to enable unimpeded passage of the nerves. Further diagnostic value is found with discography and myelography, both of which require specific needle tip placement, and this may be done with the use of CT alone or in conjunction with fluoroscopy. All spinal levels – cervical, thoracic, or lumbar – can be analyzed.

Therapeutically, CT (or fluoroscopy alone or CT fluoroscopy) allows the interventionist to perform numerous procedures to treat the patient with spinal pain. Biopsy of perispinal lesions in the case of suspected infection or tumor is an example of a procedure with diagnostic value but also important in planning therapy, e.g., identification of organism or tumor subtype. CT angiogram is particularly useful if an anterior lumbar or high cervical approach is planned and there is concern about vascular anatomy or if there is a thoracic lesion where the spinal cord blood supply is of particular importance when considering embolization of a high vascularity lesion.

MRI

Magnetic resonance imaging is the gold standard for spinal imaging. Like all diagnostic modalities in spinal imaging, it has advanced over time with technology. In particular the availability of high magnetic fields strength systems, increase gradient performance, the use of RF coiler rays and parallel imaging, and increase pulse sequence efficiency allowed for better acquisition speed and improved low signal-to-noise ratio. It provides detailed and conspicuous imaging of the spinal structures, showing greater detail than other modalities (see Figs. 4, 5, 6 and 7). There are categories of MRI available. First is the traditional tunnel lie down 3T MRI (Tesla, the magnetic field strength) which is the most widely used global static imaging tool. The alternative or adjunct to this is the open/upright MRI. The latter provides positional imaging – sitting, standing, flexing, and extending. Different positions can reveal dynamic pathologies that the supine tunnel MRI cannot demonstrate, e.g., instability, herniated discs, and annular tears that may not be detectable when in the unloaded, nonfunctional position (see Fig. 5a–b).

MRI imaging has the advantage of no ionizing radiation and clearly displays the type and extent of spinal pathology. Additional information can be realized with MR imaging. In particular:

(i) Degenerative state of the disc: It can be clearly characterized by MRI, unlike X-ray or CT where, unless there is a decrease in the disc height or a distinctive disc bulge,

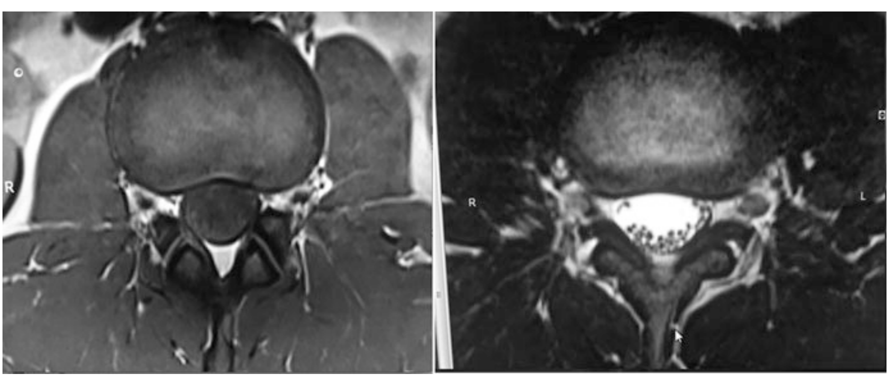

Fig. 4 MRI: note the far clearer delineation of all structures compared to Fig. 3; disc, canal, and nerve roots

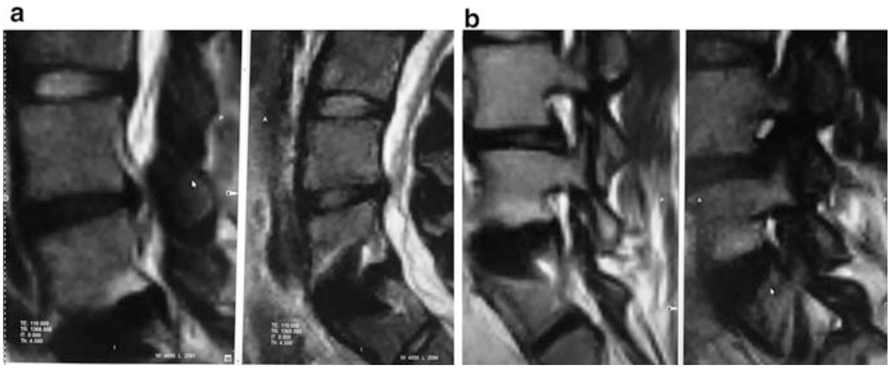

Fig. 5 Note in (**a**) the difference in the degree of herniation and in (**b**) the foraminal stenosis in the weight-bearing position comparing the static lie down images

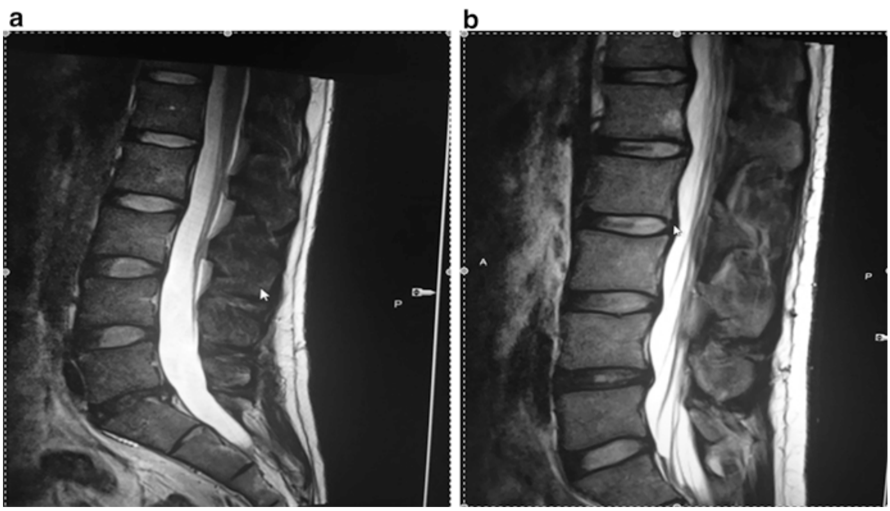

Fig. 6 (**a**) and (**b**) Note also the state of the discs: L1-4/5, all normal; L5/S1, degenerate grade 4, i.e., nucleus no longer white, loss of height, and with the high signal intensity zone/annular tear. a Note in b the degenerate L4/5 disc, grades 3–4

the morphology of the disc is not ascertained. An MRI classification of the disc degeneration has ensued – Pfirrmann grades I–V. The grading is based upon T2-weighted imaging with the low-signal changes to the nucleus pulposus becoming more pronounced and diffuse within the disc as well as loss of disc height as the degenerative process progresses.

(ii) Further markers of intervertebral disc degeneration shown on MRI are:

(a) High-signal-intensity zone (HIZ) located in the posterior annulus fibrosis, separated from the nucleus pulposus – a relationship between the HIZ and pain has been observed.

(b) Modic changes (Modic et al. 1988) – signal changes to the vertebral end plate and bone deep to the cartilage; these are graded I–III combining both T1W and T2W images. Type I, also known as the inflammatory phase, is denoted by inflammation of fibrous tissue, low signal intensity on T1W, and high signal intensity on T2W imaging. Type II, known as

Fig. 7 MRI lumbar spine sagittal slices. Note the detail of the study which enables differentiation of extruded and sequestered disc material in the canal contacting the thecal sac from the broad-based herniation present at L5/S1 and degenerate disc at L4/L5

the fat phase, is marked by a large deposition of fat cells in the end plate and the area underneath it, as well as a high signal intensity on T1W and an equivalent or mildly high signal on T2W imaging. Type III, also known as the bone sclerosis period because the bone becomes hardened in the end plate and the area underneath it, is also characterized by low signal intensity in T1W and T2W imaging (Rahme and Moussa 2008). It has also provided prognostic value for interventions for diagnosed discogenic back pain (Furunes 2018) and has been associated with increased vascular adhesions during anterior lumbar surgery (Malham 2018).

Other value in ordering an MRI includes:

(iii) The exact relation of the herniated disc to the nerve roots and whether or not direct compression is present.

(iv) The status and size of the paraspinal muscles. For example, severe multifidus wasting may suggest radiculopathy and be associated with poorer outcomes for decompression (Zotti et al. 2017) and disc replacement surgery (Le Huec et al. 2005; Storheim et al. 2017).

(v) Vascular pattern: particularly if anterior or oblique or lateral surgery is being considered, then vascular pattern including any anomalies should be studied to anticipate problems.

(vi) Assessment post-surgery for recurrent herniation, stenosis, and/or presence of fusion. This modality can be useful if a patient's leg symptoms recur to the point where intervention would be considered; then MRI with contrast can be of use in assessment to differentiate scar tissue from recurrent disc herniation. Recent studies suggest that MRI is comparable to CT for assessing lumbar spine fusion (Kitchen et al. 2018) (Fig. 7).

MR spectroscopy is an emerging technology whereby differential water and protein contents within the region of interest can be measured and correlated to the patient's symptoms allowing differentiation of painful from non-painful discs (Zuo 2012). This may in time and with maturity enable diagnosis of discogenic pain without invasive provocative discography. Intraoperative MRI can be performed (more in the setting of craniocervical or spinal cord tumor surgery) but is not routine or widespread.

Nuclear Medicine

Radionuclide bone scanning is a well-accepted and sensitive method for uncovering a variety of bony lesions including abnormalities of vertebral bodies or facet joints that may be contributing to spinal pain. It has a more functional basis than the other imaging modalities as it has the ability to detect the most avid area of "inflammation," seen as increased regional blood flow, as determined by the degree of tracer uptake. Single photon emission computed tomography (SPECT) is especially useful in such an evaluation because it allows for precise localization of a lesion to the vertebral body, disc space, or facet joint. Greater diagnostic accuracy is achieved with this dual technique – using both radionuclide tracer, e.g., technetium 99, and integrated CT – allowing the level and anatomical location of pain generation to be imaged. This anatomic distinction is necessary in order to accurately diagnose the underlying condition detected by the bone scan. Most bony abnormalities result in focal areas of abnormal tracer activity but do not affect all components of a vertebra with equal frequency nor have a random pattern of involvement. Vertebral diseases tend to conform to predictable patterns that can be more readily identified by SPECT scan compared to planar imaging (Gates 1988, 1998). In some applications, such as in symptomatic pars defects, SPECT has sensitivity at least equivalent if not superior to MRI (Fig. 8).

Fig. 8 SPECT scan of the thoracolumbar spine visualized in the coronal plane. Note tracer uptake most pronounced at the T12/L1 end plates asymmetrically which correlated with the patient's pain

Comments About Pain Generators

As with anywhere in the body, the causes and origins of pain are vast and extensive and include referral from extra-spinal regions. In the spine itself, the main pain generators are:

(A) The joints – facet and sacroiliac
(B) The intervertebral disc
(C) The nerve roots
(D) The bones
(E) The muscles

Biomechanical and Chemical Models for Disc and Facet Pain

Intervertebral disc degeneration has been reported to be a source of low back pain in adults. The intervertebral disc consists of the nucleus pulposus, surrounding annulus fibrosus, and the superior and inferior cartilage end plates. Collagen and elastin fibers are present in different orientations lying within a proteoglycan (most prominently aggrecan) and non-cartilaginous protein mixture, forming a complex matrix. Disc degeneration occurs with the breakdown of this matrix with replacement of fibroblasts with chondrocyte-like cells and alteration in the lamellar structure of the annulus and when the nucleus gel becomes fibrous. Annular tears have been strongly associated with the development of degenerative disc disease. In other words as the nucleus can no longer support the load, the annulus can buckle and tear promoting radial and circumferential tears. Neurovascular structures can migrate into these tears. Numerous biomechanical-biochemical studies have shown that following annular tears, the axial load that is normally carried through the center of the disc can shift posteriorly over the nerve concentrated posterior and posterolateral annular fibrosis. Therefore in addition to the painful inflammatory reaction, one can get mechanical irritation of these already inflamed and irritated *nociceptive* fibers in the peripheral annulus. The fundamental basis of this breakdown at the molecular level is the production of an abnormal matrix or an increase in the constituents which cause matrix degradation, e.g., IL-1 and TNF and matrix metalloproteinases (MMPs), and a reduction in the amount of tissue inhibitors of metalloproteinases. The normal disc posteriorly is innervated by branches of the sinuvertebral nerve (from meningeal branches) and sympathetic fibers. Only the outer aspect of the annulus is innervated, and the sensory fibers are primarily nociceptive and proprioceptive (although less so). In a degenerate disc, the number of nerve fibers increases, and nerve nociceptive fibers grow into the normally aneural part of the annulus and nucleus. Many factors may contribute to the degenerative process – genetics, mechanical load, trauma, and nutrition; however, the exact etiology and relationships still require further research.

Studies have linked pathological changes in facet joints with preceding disc degeneration. The intervertebral discs support most of the weight during flexed postures, but the facet joints bear an increasingly greater burden as the lumbar spine is ranged into extension. In addition to stabilizing the spine and guiding segmental motion, facet joints function as weight-bearing structures that support axial loading along with the intervertebral discs. Studies have shown that the facet joints can carry up to 33% of the dynamic axial load. Disc degeneration with associated narrowing of the disc space alters the mechanical load distribution and may result in a degenerative cascade with increased mechanical stress on the facet joint and joint capsule. Within the active range of the lumbar spine, the paraspinal muscles act as the principal contributors to vertebral stability. However, both cyclic and sustained flexion movements decrease the reflexive muscle activity of the paraspinal muscles such as the multifidus muscle. In theory, this may result in increased laxity across the facet joint leading to both decreased stability and increased stress on the facet joint capsule.

The role of the facet joint capsule in stabilizing the motion characteristics of these joints cannot be understated. Studies have suggested that disc degeneration results in increased range of axial rotation. It has been postulated that the increase in axial rotation and subsequent instability place additional stressors upon the facet joint capsules leading to a molecular response, which results in fibrocartilaginous metaplasia in the capsules of facet joints. Boszczyk et al. (2003) reported hypertrophic and fibrocartilaginous changes in the facet joint capsules of patients who had undergone lumbar fusion for degenerative instability.

The facet joint (or zygapophyseal joint) is innervated by the medial branch of the dorsal ramus of the nerve exiting at the same level and also the medial branch of the nerve one level above. The joint has a strong capsule, and hyaline articular cartilage is present.

Changes in load distributions (from a degenerative disc or from spinal malalignment or pelvic tilting or rotation) can lead to osteoarthrosis, osteophyte formation, and inflammation. The cartilage and synovium of facet joints are sources of inflammatory cytokines. It has been proposed that painful symptoms may arise not only from mechanical stress discussed previously but also from the associated inflammatory response involving cytokines such as tumor necrosis factor alpha, interleukin-6, and interleukin-1 beta, oxygen-free radicals such as nitric oxide and inflammatory mediators such as prostaglandins. Interestingly, some have suggested that inflammatory cytokines originating from inflamed synovium may spread to adjacent nerve roots and produce radicular lower extremity symptoms.

The sacroiliac joint (SIJ) is a true diarthrodial joint with unique characteristics not typically found in other diarthrodial joints. The joint differs with others in that it has fibrocartilage in addition to hyaline cartilage, there is discontinuity of the posterior capsule, and articular surfaces have many ridges and depressions. The sacroiliac joint is well innervated. Histological analysis of the sacroiliac joint has verified the presence of nerve fibers within the joint capsule and adjoining ligaments. It has been variously described that the sacroiliac joint receives its innervation from the ventral rami of L4 and L5, the superior gluteal nerve, and the dorsal rami of L5, S1, and S2. Abnormalities with joint function and mobility – hypo- or hypermobility – are the primary cause of the irritation. Inflammatory systemic disease, e.g., ankylosing spondylitis, is of course another reason for pain generation.

As with other diarthrodial joints, the cartilage of facet joints may also be sex-hormone sensitive. Estrogen has been associated with chondrodestruction, although controversy exists as to its actual role in the development of osteoarthritis. However, Ha and Petscavage-Thomas (2014) have found a statistically significant association between the increased expression of estrogen receptors on the articular cartilage of facet joints and the severity of facet arthritis (Binder and Nampiaparampil 2009).

Invasive Interventions

Myelography – an invasive procedure with contrast media (iodinated) being injected into the subarachnoid space, penetrating the thecal sac, to analyze the spinal canal, including the cord, nerve roots, and foramina. With the introduction of MRI, myelography has diminished in importance as a diagnostic tool. Yet it still can play an important role in diagnosis for those for whom MRI is contraindicated, e.g., those with a pacemaker in situ.

Discography – an invasive provocative procedure to determine whether or not the disc is the cause of the pain. One or a number of needles are placed in the nucleus pulposus (i) of the disc(s) at varying levels and then contrast media injected to attempt to reproduce the patients symptoms. Positive discography is defined as follows: (1) abnormal morphology of the examined disc; (2) consistency of pain by provocation; (3) no pain experienced by provocation of the nearest disc; and (4) less than 3 mL of injected contrast agent.

Discography has been the subject of vigorous debate and controversy with strong advocates for and against this functional test. Many studies have shown it to be valid with high correlation to the person's pain (Walsh et al. 1990; Peng et al.

2006). Other studies have questioned the usefulness of the technique. One of the main points of concern was that pain provocation is a subjective measure dependent on the patient, which despite quantification by the VAS, inevitably yields a high rate of false positives in patients with a psychological fear of pain or hyperesthesia from chronic pain or personality trait scores. Also it can be operator dependent with pressure and flow rates of injection leading to reduced stimulation of pain receptors (Derby et al. 2005; Ohnmeiss et al. 1995).

If used it must be critically examined in association with the patients profile, pain diagnosis, and other image-guided treatments performed, e.g., facet joint injections or nerve root blocks.

The Dallas discogram description grade is the mainstay of reporting (Saboeiro 2009) and is a combination of the interventional procedure followed by a diagnostic CT scan.

The Dallas discogram protocol for performance and reporting (or now more appropriately the modified Dallas classification system) is a widely used and accepted method for describing the CT findings of the test in association with the patient's intra-procedural symptoms (Sachs et al. 1987; Resnick et al. 2005; Carragee and Alamin 2001; Cohen and Hurley 2007; Cohen et al. 2005; Madan et al. 2002). When properly performed, low false-positive rates in the order of 6–10% can be anticipated (Bogduk et al. 2013).

There are six possible categories that describe the severity of the radial annular tear.

The grade 0 is a normal disc, where no contract material leaks from the nucleus.

The grade 1 tear will leak contrast material only into the inner 1/3 of the annulus.

The grade 2 tear will leak contrast through the inner 1/3 and into the middle 1/3 of the disc.

The grade 3 tear will leak contrast through the inner and middle annulus. The contrast spills into the outer 1/3 of the annulus.

The grade 4 tear further describes a grade 3 tear. Not only does the contrast extend into the outer 1/3 of the annulus, but it is seen spreading concentrically around the disc. To qualify as a grade 4 tear, the concentric spread must be greater than 30°. Pathologically, this represents the merging of a full-thickness radial tear with a concentric annular tear.

The grade 5 tear describes either a grade 3 or grade 4 radial tear that has completely ruptured that outer layers of the disc and is leaking contract material out of the disc. This type of tear, which one is most likely to suffer from, can cause a chemical radiculopathy in one or both of the extremities and result in persistent leg pain (Fig. 9).

Irrespective of the controversy, it is currently the only test which can directly link symptoms felt to be significant to the patient to the presumed pathology, and studies have shown that patients selected for intervention in this way have improved outcomes compared to those without precision diagnosis (Colhoun et al. 1988; Margetic et al. 2013; Xi et al. 2016).

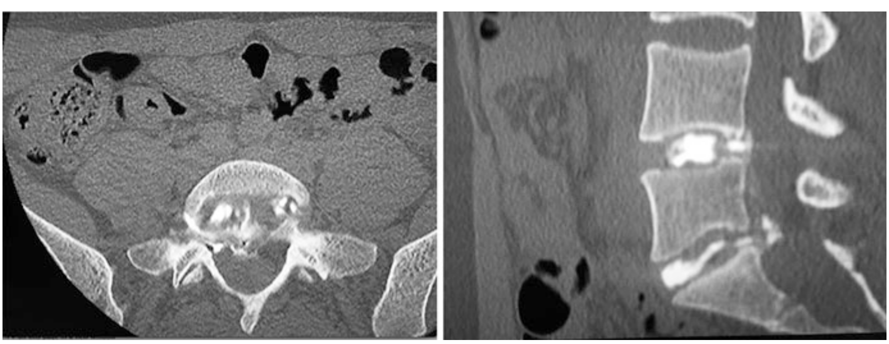

Fig. 9 Note the contrast passing from the nucleus through the outer annulus into the epidural space

Corticosteroid Injections

Which corticosteroid?

- There is great variability in the use of the injected corticosteroid.

Commonly used steroids are:

- Dexamethasone sodium phosphate
- Betamethasone acetate
- Methylprednisolone acetate
- Triamcinolone acetonide

The amount used may also vary considerably and below are examples:

- Dexamethasone sodium phosphate 4–8 mg
- Betamethasone acetate 0.25–1.0 ml
- Methylprednisolone acetate 4–10 mg
- Triamcinolone acetonide 2.5–5 mg

Commonly used local anasthetics and doses:

- Lidocaine hydrochloride (0.25–2 mls)
- Bupivacaine hydrochloride (0.25–2 mls)
- Procaine hydrochloride

Safety

A comprehensive review of the use of injected corticosteroids was undertaken by MacMahon et al. (2009), and this had particular relevance to spinal pain therapy. A number of factors were revealed which previously were not taken into account in terms of safety and protocol. In particular, this related to the particulate composition of steroids. Most corticosteroid preparations contain corticosteroid esters (apart from dexamethasone), which are highly insoluble in water and thus form microcrystalline suspensions. This property cannot only cause adhesions (problematic at subsequent open decompression procedures) but also cause particulate steroid emboli; thus they are likely the primary cause of the reported CNS complications, e.g., paraplegia or stroke. Non-particulate steroid is not known to cause this complication (MacMahon et al. 2009).

Other general complications range from common but minor risks of skin changes or transient hyperglycemia to rare but more significant complications including durotomy causing CSF meningocele and/or arachnoiditis and infection causing osteomyelitis or epidural abscess. Such material risks may be mentioned in discourse if relevant as part of informed consent prior to the injection being performed (Zotti et al. 2012). Cervical injections, particularly, carry the unique risk of vascular injury – particularly radicular artery injury – which can impair spinal cord and brain stem perfusion.

Specific contraindications should be sought and include bleeding diatheses or active use of anticoagulant (for epidural or perineural injections), infection at targeted site (unless for purpose of obtaining a biopsy), immunosuppression, poorly controlled diabetes, and noted contrast or injectable allergy.

Given the above, the alternatives and expected benefits need to be considered for any intervention. In common neurointerventional and spinal surgical practice, corticosteroids when combined with appropriate education and rehabilitation strategies can cure and assist patients with conditions of favorable natural history and who are either unsuitable for or do not wish to undergo formal surgical intervention or, alternatively, palliate patients' conditions.

Mechanism of Action

Corticosteroids predominantly affect the action of cytokines and inflammatory mediators (e.g., substance P, PLA2, arachidonic acid, IL-1, and prostaglandin E2) involved in inflammation. They lead to increased blood flow and downregulation of immune function, inhibiting cell-mediated immunity, reducing cellular accumulation at inflammatory sites, and decreasing vascular responses. Corticosteroids cause these effects through a mechanism that ultimately involves its active moiety entering cells and combining with receptors to alter messenger RNA production, mainly altering the protein annexin-1 (previously called lipocortin-1) (Barnes 1998; Eymontt et al. 1982; Buckingham et al. 2006; D'Acquisto et al. 2008).

Types of Corticosteroid Injection

Facet joint injection (intra-articular) – the spinal needle is placed into the facet joint cavity and steroid injected along with local anesthetic. Indications include presumed facetogenic lumbar and thoracic or cervical pain. This may include facet-related pain resulting from posterior load-bearing transfer from patients with degenerative disc disease and anterior column pathology where treatment of anterior spinal structures (e.g., intervertebral disc) is thought to be high risk or undesirable. It is important that these patients are counselled that only a portion of their pain will be treated (appropriated to pain relief that may have been experienced from the medial branch block).

There is dispute over the efficacy of these injections, and some of it likely stems from only a limited proportion, perhaps 10–20% of patients having "pure" facetogenic pain. For some, common practice/convention may prevail over scientific evidence as to their efficacy and validity. For greatest accuracy the injection needs to be image controlled. An alternative, which also covers nociceptors from the facet joint but does not violate it, is the medial branch block of the dorsal ramus (Boswell et al. 2007; Sehgal et al. 2007a; Manchikanti et al. 2010; Cohen and Raja 2007; Jackson et al. 1988; Schwarzer et al. 1994, 1997; Sehgal et al. 2007b) (Fig. 10).

Medial branch block – a minimally invasive procedure whereby local anesthetic is injected along the pathway of the medial branch of the dorsal ramus of the spinal nerve, which supplies the facet joints, to determine if the origin of the pain is from the facet joints. It is important to note the innervation of the joint, recognizing that it is not single. The facet joint receives branches from the level above and below. The innervating branch lies with the depression/junction of the transverse process with the body of the vertebra.

Blockade of the medial branch of the posterior ramus nerve is generally preferred over intra-articular facet blocks as it is easy, less traumatic, and less risky than intra-articular injections (including no risk of joint infection) (Dreyfuss et al. 1997). Generally, when facet joint denervation is being considered, it is preferable to assess the patient's response to medial branch blocks given that it allows assessment of analgesic response due to blockade of the anatomic structure to be ablated. A response of 50% or more reduction of pain is an indication for RFD. However, in the presence of inflammation, intra-articular injections may be superior to medial nerve blocks.

Lumbar facet injections and medial branch blocks are both valuable in terms of diagnosis of the patient's pain generator and suitability for other interventions, e.g., radio-frequency neurotomy. However, in themselves there is limited relief of "facetogenic" low back pain. Marks, Houston, and Thulbourne reported limited relief after 3 months with relief of pain diminishing between 1 and 3 months (Marks et al. 1992). Manchikanti and colleagues reported the

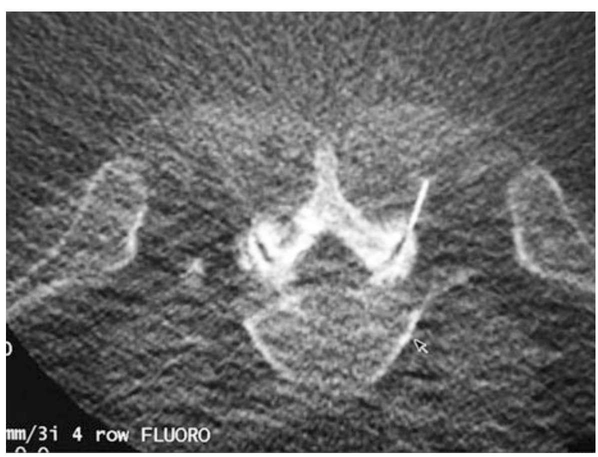

Fig. 10 The needle within the facet joint during an intra-articular injection of L5/S1

majority of patients having improvement in their facet pain at 1 year, however, irrespective of whether treated with local anesthetic alone or with steroid (Manchikanti 2001, 2010).

Most studies report that cervical medial branch facet blocks tend to have longer duration compared to lumbar facets with effect lasting between 3 and 5 months for each injection (Manchikanti 2008). The mean duration of effect for cervical facet block can be up to 8–12 months (Kim 2005), and repeated injections can provide sustained relief at a year and beyond (Manchikanti et al. 2015a). Thoracic facet interventions have not been well studied, and, as such, fair evidence is only available for medial branch blocks in the thoracic spine.

In the lumbar spine, for long-term effectiveness, there is Level II evidence for radio-frequency neurotomy and lumbar facet joint nerve blocks, whereas the evidence is Level III for lumbosacral intra-articular injections. In the cervical spine, for long-term improvement, there is Level II evidence for cervical radio-frequency neurotomy and cervical facet joint nerve blocks and Level IV evidence for cervical intra-articular injections. In the thoracic spine, there is Level II evidence for thoracic facet joint nerve blocks and Level IV evidence for radio-frequency neurotomy for long-term improvement (Manchikanti et al. 2015a). Evidence for diagnosis of cervical facet joint pain with controlled comparative local anesthetic blocks is Level I or II-1. The indicated evidence for therapeutic facet joint interventions is Level II-1 for medial branch blocks and Level II-1 or Level II-2 for radio-frequency neurotomy (Manchikanti et al. 2015a).

Facet joint denervation – this is the "follow on" from a positive medial branch block, which has confirmed that the pain generator is the facet joint. The next step is to denervate the facet joint via radio-frequency ablation or with 90% alcohol. Radio-frequency denervation, involving heating of the targeted nerve typically at 90 °C for 90 s, can provide longer-term relief than the standard facet joint corticosteroid injection. Alcohol denervation also provides significant relief, and some studies show a longer benefit than radio-frequency ablation (Joo et al. 2013).

As a day procedure usually under light sedation and performed with specialized radio-frequency equipment (an addition to standard radiology machine), the medial branches of the dorsal rami are ablated. The technique is very important, and good understanding of anatomy and physical properties of the equipment is paramount. Risks are minimal, but there have been case reports of transient radiculopathy, neural injury, and thermal burns which relate to inappropriate technique and preparation (Barr et al. 2000).

In the cervical spine, the main indication for injections or radio-frequency neurotomy remains facetogenic pain, but facet-pain targeted injections have also been used with varying success for facet pain resulting from herniated nucleus pulposus (load transfer to posterior elements from disc compromise), whiplash, and myofascial pain (Kim et al. 2005).

Like with all forms of thoracolumbar spinal treatment, radio-frequency denervation has been shown in some studies to provide significant pain reduction in patients with chronic low back pain selected with a positive medial branch block for between 6 and 18 months. In addition, this low-morbidity procedure is found to be efficacious on case series when repeated in patients who had a successful prior procedure (Zotti and Osti 2010; Schofferman and Kine 2004; Son et al. 2010) effective in around ~70% of patients for 8–9 months (Zotti and Osti 2010).

Patient selection (i.e., use and quantitative response to intra-articular compared to medial branch blocks) and mode and location of lesioning have been cited for potential inconsistencies in the results of these studies. The majority of patients, in the order of 60–80%, obtain at least 90% relief of pain when selected correctly with a mean effect typically lasting 9–12 months for both cervical and lumbar facet denervation. The evidence for radio-frequency neurotomy for sacroiliac pain is mixed in terms of quality, but sham surgery placebo-controlled trials overall were supportive of this technique (Rupert et al. 2009). However, other studies have shown little benefit to this procedure (Evans et al. 2003; Blasco et al. 2012; Zotti and Osti 2010; Bogduk et al. 2011).

A recent study by Van Tilburg and associates (2016) which was a randomized sham-controlled double-blinded study design was unable to reject the null hypothesis of efficacy for this intervention. However, several studies support the efficacy for this procedure compared to comparative controls (Gallagher et al. 1994; Van Kleef et al. 1999, 2005; Tekin et al. 2007; Kroll 2008).

Synovial cyst puncture and aspiration – a symptomatic synovial cyst from a degenerate facet joint can cause compression upon a descending nerve root and inflammation. The aim of the radiologist to achieve therapeutic relief is to puncture and if possible aspirate the cyst or rupture it, followed by an injection of steroid and local anesthetic. There are two mechanisms for the above:

(i) A direct puncture (which is not always possible due to its position in the canal as access may not be not possible due to the lamina or facet joint covering the anticipated needle pathway).
(ii) An indirect rupture via the facet joint – filling the latter with injectate – steroid and local anesthetic and saline until the cyst ruptures. This technique can be very painful.

Percutaneous treatment for facet cysts has been reported to only fair long-term success, approximately 50–80% of patients in literature reviews, and relief for up to 1 year has been reported (Vad et al. 2002; Carmel et al. 2007). Many of the cysts targeted are gelatinous and not amenable to aspiration, leaving the large residual cyst capsules to continue compressing the neural/dural structures, and cause ongoing neurological dysfunction. Along with the 37.5–50% risk of recurrence is a 45–50% chance of success with repeated cyst rupture attempts (Imai et al. 1998; Rauchwerger et al. 2011; Sabers et al. 2005; Schulz et al. 2011; Shah and Lutz 2003). A further trial can be attempted in refractory cases or recurrence, but a high proportion of these patients (50–60%) will require open spinal surgery. The uncertain efficacy of this intervention has led some authors to advocate for surgical intervention rather than repeated attempts (Epstein and Baisden 2012).

Selective nerve root injections/perineural injections and epidural injections – the spinal needle is placed next to the suspected pain-generating nerve, and a mixture of local anesthetic and steroid (e.g., dexamethasone and bupivacaine being injected) is injected. Again the steroid used varies as does the utilization of the radiology modality and the amount. The technique is most commonly done with fluoroscopy or under CT guidance. There are a number of different techniques/approaches which include transforaminal, interlaminar, and caudal. The most widely used and accepted is the transforaminal approach. The consensus from the literature (and certainly anecdotally) is that epidural steroid injections are effective and of value particularly for limb and girdle pain. However, the degree of efficacy is much and varied. In saying this, the degree of efficacy of the injection is based upon many factors which include the spinal pathology, the severity of the pathology, the expertise and skill of the operator, the exact position of the needle, the patient's mental state, and other systemic or local pathologies. As aforementioned, the mechanism by which the steroid works is manyfold including reducing inflammation/swelling via neutralizing inflammatory mediators, e.g., substance P, PLA2, arachidonic acid, IL-1, and prostaglandin E2. The steroid also increases blood flow and reduces the activity of the immune system (Akuthota et al. 2013; De Smet et al. 2005; Salahadin et al. 2007; Vad et al. 2002; Carmel et al. 2007; Lutz et al. 1998) (Fig. 11).

Many studies report the effectiveness of this intervention, including randomized trials, but large level 1 double-blinded studies with a placebo comparator are lacking. This is particularly so for contained herniated pulposus lesions (MacVicar et al. 2013) with mild neural compression, whereas injections into segments affected by extruded or sequestered disc fragments are thought to be less effective. While the addition of CSI is generally favorable, some studies have suggested that they alter the natural history of the patient and reduce the number of patients who undergo surgery of continued symptoms.

Interestingly, some trials have reported benefit of injection but no additional benefit to

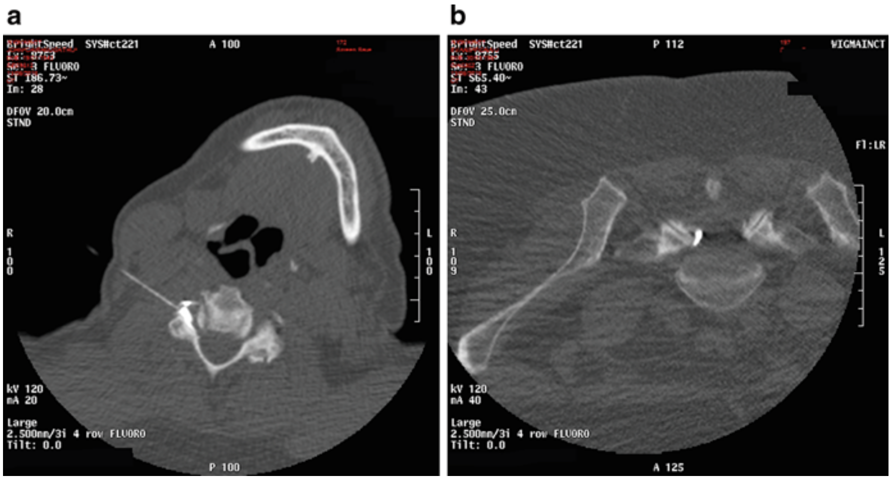

Fig. 11 (**a**) and (**b**) Note the transforaminal approach with contrast (prior to steroid injection) to confirm position around the exiting nerve root and also passing into the epidural space. Note in the next picture the paramedian interlaminar approach noting contrast between the ligamentum flavum and thecal sac in the epidural space

corticosteroids added to local anesthetic (Ng 2005). The majority of patients, in the order of 70–75%, will have significant reduction of their symptoms when they have been presented for less than 3 months. However, patients with symptoms longer than 3 months tend to have more variable success. Furthermore, patients with shorter duration of symptoms can be expected to experience more sustained relief than those with chronic symptoms. When effective, a reduction of at least 50% for 1–2 months can be expected in around 70% of patients and complete resolution in around 30% of patients (Ackerman and Ahmad 2007).

Cervical transforaminal epidural injections are effective for around 70–80% of patients with radiculopathy and have been shown to prevent the need for surgery in around 70% of patients (Costandi 2015; Vallee 2001). While at 3 and 6 months, around 30% of patients have complete resolution of symptoms, this reduces to around 20% at 1 year (Vallee 2001). To achieve sustained and effective relief, repeated injections may be required. For example, Slipman et al. (2000) reported pain reduction, return to full-time work status, reduction or elimination in analgesic use, and satisfaction with treatment in 60% of patients at 12–45 months' follow-up, but treatment on average consisted of 2.2 injections.

Interlaminar injections have good evidence for usage in the setting of herniated discs and radiculitis and fair evidence for axial/discogenic pain without facet joint pain and are technically simpler in the hands of experienced operators. They have been shown to have superior effect for chronic lumbar disc herniation at 2 years compared to caudal and transforaminal injections (Manchikanti 2015b). They have also been shown to be superior to caudal injections for lumbar central spinal stenosis (Manchikanti et al. 2014). In addition, there is Level II and Level II/III evidence for long-term management of cervical disc herniations or stenosis and thoracic disc herniations, respectively. Caudal injections, on the other hand, have good evidence for herniated disc and radiculitis with only fair evidence for axial/discogenic back pain, spinal stenosis, and post-surgery syndrome.

Both interlaminar and caudal injections for axial or discogenic pain are shown to be effective, but interlaminar injections have marginal superiority over caudal injections for this indication (Manchikanti 2015b). Interlaminar and caudal techniques have been reported to be effective for lumbar disc herniation or radiculitis (Kaye et al. 2015); however, some studies have reported them to be less effective than transforaminal injections for radiculopathy due to herniated nucleus pulposus (Kamble et al. 2016; Ackerman and Ahmad 2007; Lee et al. 2009; Thomas et al. 2003).

Sacroiliac Injections

Sacroiliac joint pain – the great mimicker. One of the greatest challenges in diagnosing the pain from this joint is that the symptoms can imitate other pain-generating conditions, e.g., facet joint arthropathy and discogenic or radicular pain from herniated discs with the malady being both around the sacroiliac joint but also radiating down the lower limb or into the groin. As always, imaging can provide both diagnosis and treatment. The issue the clinician faces is that in many cases, the imaging does not directly confirm the provisional diagnosis. Arthropathy may be present; however the joint may show no signs of pathology on plain X-ray, CT, and MRI. The physical examination is therefore paramount to test the suspicion of SI pain with the location of the patient's symptoms and any worsening with provocative tests. Like with other joint-related conditions, steroid and local anesthetic blocks can aid in both diagnosis and treatment.

Patients are prone and the needle advanced before a sensation of entering the joint which is confirmed on multiple planes to be in the joint. It is performed by imaging guidance due to the highly variable morphometry of pelvises between patients for diagnostic and therapeutic purposes. Smaller doses of LA/steroid focusing on the posterior-inferior hyaline portion of the joint tend to be diagnostic, while larger doses that aim to bathe the entire joint are therapeutic. Some clinicians favor the addition of separating more superior injection into the fibrous component of the joint. The controlled diagnostic blocks utilizing the International Association for the Study of Pain (IASP) criteria demonstrated the prevalence of pain of sacroiliac joint origin in 19–30% of the patients suspected to have sacroiliac joint pain (Forst et al. 2006).

Evidence from meta-analyses (Hansen et al. 2007; McKenzie-Brown et al. 2005), albeit based on low quality data, supports the role of SI injections in treating painful sacroiliac dysfunction and spondyloarthropathy. Maugars et al. (1996) performed a double-blinded placebo assessment of CSI versus placebo and found a statistically and clinically important difference. Eighty-six percent had positive effect at 1 month, while the majority continued to have efficacy of the injection with 58% reporting relief at 6 months (Fig. 12).

Coccyx Injections

Diagnostic and therapeutic injections into the coccygeal region are performed for coccydynia. Ideally, the local infiltration blocks the ganglion

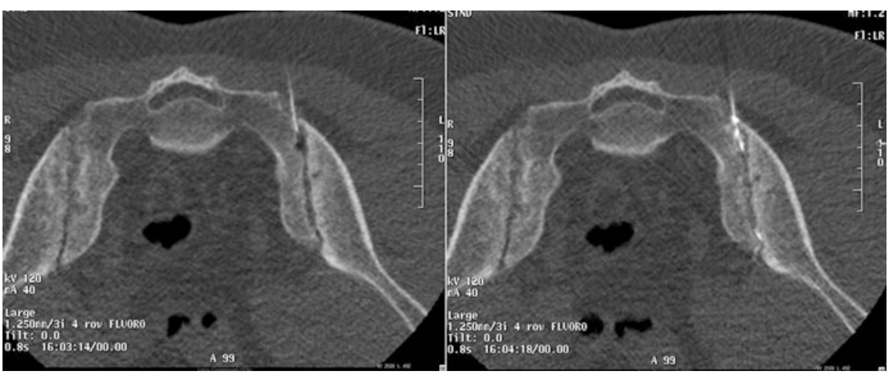

Fig. 12 CT-guided left sacroiliac joint injection. Note the needle confirmed to be within the sacroiliac joint

impar, which is a relay station for nociceptive pain emanating from the sacrococcygeal joint. Indications include coccydynia due to post-traumatic pain/hypermobility or pain from the sacrococcygeal disc. Unique complications to this procedure include rectal laceration and bowel content contamination of the injected field.

The patient is generally prone with sterile preparation and draping and sometimes sedation. Direct percutaneous placement of needle through and proceeding just anterior to the margin of the sacrococcygeal disc with confirmation on lateral and anteroposterior views with dye (if the procedure is done under Xray control rather than CT) followed by injection of LA and CSI to ganglion impar. Occasionally combined with per rectal manipulation in the setting of hyperflexed posture due to trauma or laxity.

Literature for effectiveness is generally limited to smaller cohort studies and case series making it hard to recommend treatments (Howard et al. 2013). Injection alone is effective in around 60–85% of patients with long-term success in around 45–50% with median relief at 6 months (Maigne 2011; Gunduz et al. 2015). Repeated injections were effective in the majority of those presenting with recurrent symptoms (Hodges 2004). Injection combined with manipulation results in around 85% successful outcomes with long-term success in around 60% with the theory for additional manipulation being that abnormally flexed posture of the coccyx leads to increased dural tension.

Other Invasive Forms of Image-Guided Treatment

Vertebroplasty and Kyphoplasty

These are procedures done under image guidance for the treatment of pain due to vertebral compression fractures, usually from osteoporosis. The combination of orthopedic bone cement and direct image guidance of a needle into the vertebra has allowed the past treatments for compression fractures – typically weeks to months of bed rest, analgesia, and sometimes bracing to be replaced or at least supplemented. Kyphoplasty involves partial reduction of fractures by use of an image-guided transpedicular balloon implant prior to cement insertion into the void. These techniques can also be applied to fractures from primary or secondary neoplasia affecting the vertebral body. Success rates vary, but overall significant pain reduction and improvement in the ability to perform ADL have been shown to be statistically significant (Barr et al. 2000; Evans et al. 2003; Blasco et al. 2012). Although felt to be a successful intervention, vertebroplasty for osteoporotic fractures (as distinct from metastases) has been removed from payer coverage in several countries because of equivocal results in sham-controlled procedures.

Spinal Stimulators

Spinal dorsal column stimulators can be inserted either under image guidance or by open techniques in theater with a formal approach and laminectomy. The principle is neuromodulation via electrodes placed onto the spinal cord through interference of emitted frequencies upon pain transmission in the spinal cord. It is believed to take effect through either blockage of pain transmission pathways or upregulation of inhibitory pathways. The patient generally has to meet strict criteria and has a trial period before definitive implantation occurs. The apparatus includes a battery, wires, and an electrode paddle that is applied to the targeted area (depending on pathology).

While the indications are evolving, they are generally indicated for refractory neuropathic pain despite other treatments in patients not amenable to or suitable for any further surgical intervention (low prospect of surgery being able to correct any neuroanatomic abnormality). A classic indication would be arachnoiditis after multiple posterior surgeries but may also include true “failed back surgery syndrome” and complex regional pain syndrome.

Measuring Success of Injections/ Radiology Treatments

There are numerous indicators for pain analysis and benchmarking the premorbid severity and therapeutic impact of interventions and thus providing a means of objectively measuring outcomes and success of treatments. Both statistical and clinical significance of outcomes are both important and measured. More so than other forms of medicine, interventional treatments involving needle injections into joints have undergone extensive analysis against placebo (sham) controls in multiple studies.

Below are listed some of the many available unidimensional assessments relating to pain in such trials but also commonly used in clinical practice (e.g., post-discography or diagnostic injection):

(a) VAS (visual analogue scale)
(b) NRS (numerical rating scale)
Multidimensional scales (looking at both dimensions of pain and effects on life quality):
(c) Brief Pain Inventory Short form
(d) McGill Pain Questionnaire
(e) West Haven Multidimensional Pain Inventory
(f) SF-36 and Oswestry Disability Questionnaire

All of the above have been combined into the Treatment Outcomes of Pain Survey which is a comprehensive and detailed instrument for measuring pain and outcomes (Younger et al. 2009). Future analytic tools should elaborate upon existing ones by assessing indirect and direct effects upon the patient and the economy including changes in need for aids, opioid usage, employment capability, use of healthcare resources (visits/hospitalizations), and need for care in daily living.

Conclusions

Radiology provides a harmonious and encompassing trinity of diagnosis, quantification, and therapy in relation to spinal pathology. Technology has allowed radiology to become an integral part of diagnosis and treatment, both preand postoperatively in those with spinal pain. Radiology provides the clinician with numerous adjuncts to the clinical history and examination by allowing direct analysis of the suspected spinal pain generator and the additional means of providing accurate treatment via targeted imaging. Although the success of image-guided therapeutic techniques is open to some contention, two points should always be kept in mind. First, the skill and subspecialization of the operator are paramount, with them having an interest and formal training and education in the field of spinal pathology. This allows safety for the patient and provides the best chance of obtaining a positive result. Secondly, the majority of patients with back and neck pain will be amenable to several minimally invasive therapeutic technique to obtain relief and return to more "normal" lives, hence, the importance of the first point. With all of the above considered, the usefulness of radiology is self-evident in its ability to provide benefits and alter the natural history of painful conditions with a limited risk profile in selected patients.

References

Ackerman WE 3rd, Ahmad M (2007) The efficacy of lumbar epidural steroid injections in patients with lumbar disc herniations. Anesth Analg 104(5):1217–1222. tables of contents

Akuthota V, Bogduk N, Patel A, Prather H, et al (2013) Lumbar transforaminal epidural steroid injection review & recommendation statement. Review and Recommendation Statement Work Group. North American Spine Society, Burr Ridge, IL

American society of Radiologic Technologists (2018) History of the American Society of Radiologic Technologists. Retrieved https://www.asrt.org/main/about-asrt/asrt-history. Accessed 7 June 2018

Amzallag-Bellenger E, Uyttenhove F, Nectoux E et al (2014) Idiopathic scoliosis in children and adolescents: assessment with a biplanar X-ray device. Insights Imaging 5(5):571–583. https://doi.org/10.1007/s13244-014-0354-0

Barnes PJ (1998) Anti-inflammatory actions of glucocorticoids: molecular mechanisms. Clin Sci (Lond) 94:557–572

Barr J, Lemley T, McCann R (2000) Percutaneous vertebroplasty for pain relief and spinal stabilization. Spine 25(8):923–928

Binder D, Nampiaparampil D (2009) The provocative lumbar facet joint. Spaulding rehabilitation hospital,

Harvard Medical School, Boston, MA USA. Curr Rev Musculoskelet Med 2(1):15–24. Published online 2009 Mar 31
Blasco J, Martinez-Ferrer A, Macho J et al (2012) Effect of vertebroplasty on pain relief, quality of life, and the incidence of new vertebral fractures: a 12-month randomized follow-up, controlled trial. J Bone Miner Res 27(5):1159–1166
Bogduk N, Macintosh J, Marsland A (2011) Technical limitations to the efficacy of radiofrequency neurotomy for spinal pain. Neurosurgery 20(12):2160–2165
Bogduk N, Aprill C, Derby R (2013) Lumbar discogenic pain: state-of-the-art review. Pain Med 14:813–836
Boswell MV, Colson JD, Sehgal N et al (2007) A Systematic review of therapeutic facet joint interventions in chronic spinal pain. Pain Physician 10:229–253
Boszczyk BM, Boszczyk AA, Korge A et al (2003) Immunohistochemical analysis of the extracellular matrix in the posterior capsule of the zygapophysial joints in patients with degenerative L4-5 motion segment instability. J Neurosurg 99(1 Suppl):27–33
Buckingham JC, John CD, Solito E et al (2006) Annexin 1, glucocorticoids, and the neuroendocrine-immune interface. Ann N Y Acad Sci 1088:396–409
Carmel A, Charles E, Samuels J, Backonja M (2007) Assessment: use of epidural steroid injections to treat radicular lumbosacral pain: report of the therapeutics and technology assessment subcommittee of the American Academy of Neurology. Neurology 68(10):723–729
Carragee EJ, Alamin TF (2001) Discography a review. Spine J 5:364–372
Cohen SP, Hurley RW (2007) The ability of diagnostic spinal injections to predict surgical outcomes. Anesth Analg 105:1756–1775
Cohen SP, Raja SN (2007) Pathogenesis, diagnosis and treatment of lumbar zygapophysial (facet) joint pain. Anesthesiology 106:591–614
Cohen SP, Barna SA, Larkin TM et al (2005) Lumbar discography: a comprehensive review of outcome studies, diagnostic accuracy and principles. Reg Anesth Pain Med 30:163–183
Colhoun E, McCall IW, Williams L, Cassar Pullicino VN (1988) Provocation discography as a guide to planning operations on the spine. J Bone Joint Surg 70-B(2):267–271
Costandi SJ, Azer G et al (2015) Cervical transforaminal epidural steroid injections: diagnostic and therapeutic value. Reg Anesth Pain Med 40(6):674–680
D'Acquisto F, Paschalidis N, Raza K, Buckley CD, Flower RJ, Perretti M (2008) Glucocorticoid treatment inhibits annexin-1 expression in rheumatoid arthritis CD4+ T cells. Rheumatology (Oxford) 47:636–639
De Smet A, Jeffrey D, Stanczak J, Fine J et al (2005) Lumbar radiculopathy: treatment with selective lumbar nerve blocks – comparison of effectiveness of triamcinolone and betamethasone injectable suspensions. Radiology 237(2):738
Derby R, Kim BJ, Chen Y, Seo KS, Lee SH (2005) The relation between annular disruption on computed tomography scan and pressure-controlled diskography. Arch Phys Med Rehabil 86:1534–1538
Deschenes S, Charron G, Beaudoin G et al (2010) Diagnostic imaging of spinal deformities. Spine 35(9):989–994
Dreyfuss P, Schwarzer A, Lau P et al (1997) Specificity of lumbar medial branch and L5 dorsal ramus blocks: a computed tomography study. Spine 22(8):p895–p902
Epstein NE, Baisden J (2012) The diagnosis and management of synovial cysts: efficacy of surgery versus cyst aspiration. Surg Neurol Int. https://doi.org/10.4103/2152-7806.98576
Evans AJ, Jensen ME, Kip KE, DeNardo AJ et al (2003) Vertebral compression fractures: pain reduction and improvement in functional mobility after percutaneous polymethylmethacrylate vertebroplasty retrospective report of 245 cases. Radiology 226(2):366–372
Eymontt MJ, Gordon GV, Schumacher HR, Hansell JR (1982) The effects on synovial permeability and synovial fluid leukocyte counts in symptomatic osteoarthritis after intraarticular corticosteroid administration. Medline 9:198–203
Forst S, Wheeler MT, Fortin JD, Vilensky JA (2006) The sacroiliac joint: anatomy, physiology and clinical significance. Pain Physician 9(1):61–67
Furunes H, Hellum C, Brox JI et al (2018) Lumbar total disc replacement: predictors for long-term outcome. Eur Spine J 27(3):709–718. https://doi.org/10.1007/s00586-017-5375-1
Gallagher J, Petriccione di Vadi PL, Wedley JR et al (1994) Radiofrequency facet joint denervation in the treatment of low back pain: a prospective controlled double-blind study to assess its efficacy. Pain Clin 7:193–199
Gates GF (1988) SPECT imaging of the lumbosacral spine and pelvis. Clin Nucl Med 13(12):907–914
Gates GF (1998) SPECT bone scanning of the spine. Semin Nucl Med 28(1):78–94
Goodbody C, Kedem P, Thompson M et al (2017) Reliability and reproducibility of subject positioning with EOS low-dose biplanar X-ray. HSS J 13(3):263–266. https://doi.org/10.1007/s11420-017-9548-6
Gunduz OH, Sencan S, Kenis-Coskun O (2015) Pain relief due to transsacrococcygeal ganglion impar block in chronic coccygodynia: a pilot study. Pain Med 16(7):1278–1281. https://doi.org/10.1111/pme.12752
Ha AS, Petscavage-Thomas JM (2014) Imaging of current spinal hardware: lumbar spine. Am J Roentgenol 203 (3):573–581. https://doi.org/10.2214/AJR.13.12217
Hansen HC, McKenzie-Brown AM, Cohen SP et al (2007) Sacroiliac joint interventions: a systematic review. Pain Physician 10(1):165–184
Hendee WR, O'Connor MK (2012) Radiation risks of medical imaging: separating fact from fantasy radiology. Radiology 264(2). https://doi.org/10.1148/radiol.12112678
Hodges SD, Eck JC, Humphreys SC (2004) A treatment and outcomes analysis of patients with coccydynia. Spine J 4(2):138–140
Howard P, Behrns W, Di Martino M et al (2013) Manual examination in the diagnosis of cervicogenic headache:

a systematic literature review. J Man Manip Ther 23(4):210–218
Imai K, Nakamura K, Inokuchi K, Oda H (1998) Aspiration of intraspinal synovial cyst: recurrence after temporal improvement. Arch Orthop Trauma Surg 118:103–105
Jackson RP, Jacobs RR, Montesano PX (1988) Facet joint injection in low-back pain. A prospective statistical study. Spine 13:966–971
Joo YC et al (2013) Comparison of alcohol ablation with repeated thermal radiofrequency ablation in medial branch neurotomy for the treatment of recurrent thoracolumbar facet joint pain. J Anesth 3:390–395. https://doi.org/10.1007/s00540-012-1525-0
Kamble PC, Sharma A, Singh V et al (2016) Outcome of single level disc prolapse treated with transforaminal steroid versus epidural steroid versus caudal steroids. Eur Spine J 25(1):217–221
Kaye AD, Manchikanti L, Abdi S et al (2015) Efficacy of epidural injections in managing chronic spinal pain: a best evidence synthesis. Pain Physician 18(6): E939–E1004
Kim T, Kim K, Kim C, Shin S et al (2005) Percutaneous vertebroplasty and facet joint block. J Korean Med Sci 20(6):1023–1028
Kitchen D, Rao PJ, Zotti M et al (2018) Fusion assessment by MRI in comparison with CT in anterior lumbar interbody fusion: a prospective study. Glob Spine J 8:586
Kroll H, Duszak R, Nsiah E et al (2008) Trends in lumbar puncture over 2 decades: a dramatic shift to radiology. Am J Roentgenol 204(1):15–19
Laredo J, Wybier M, Bellaiche L et al (2010) Know-how in osteoarticular radiology. Sauramps Med 12:1–9
Le Huec JC, Mathews H, Basso Y et al (2005) Clinical results of Maverick lumbar total disc replacement: two-year prospective follow-up. Orthop Clin North Am 36(3):315–322
Lee JH, Moon J, Lee SH (2009) Comparison of effectiveness according to different approaches of epidural steroid injection in lumbosacral herniated disk and spinal stenosis. J Musculoskelet Rehab 22(2):83–89
Lutz G et al (1998) Fluoroscopic transforaminal lumbar epidural steroids: an outcome study. Arch Phys Med Rehabil 79(11):1362–1366
MacMahon P, Eustace S, Kavanagh E (2009) Injectable corticosteroid and local anesthetic preparations: a review for radiologists. Radiology 252(3):647–661. https://doi.org/10.1148/radiol.2523081929
MacVicar J, King W, Landers MH, Bogduk N (2013) The effectiveness of lumbar transforaminal injection of steroids: a comprehensive review with systematic analysis of the published sata. Pain Med 14(1):14–28. https://doi.org/10.1111/j.1526-4637.2012.01508.x
Madan S, Gundanna M, Harley JM et al (2002) Does provocative discography screening of discogenic back pain improve surgical outcomes? J Spinal Disord Tech 15:245–251
Maigne JY, Pigeau I, Aguer N et al (2011) Chronic coccydynia in adolescents. A series of 53 patients. Eur J Phys Rehabil Med 47(2):245–251
Malham G (2018) Modic 2 changes and smoking predict vascular adherence during anterior lumbar exposure. Presented Sunday 28th April at Spine Society of Australia annual scientific meeting, Adelaide
Manchikanti L (2008) Evidence-based medicine, systematic reviews, and guidelines in interventional pain management, part I: introduction and general considerations. Pain Physician 11(2):161–186
Manchikanti L, Pampati V, Bakhit CE et al (2001) Effectiveness of lumbar facet joint nerve blocks in chronic low back pain: a randomized clinical trial. Pain Physician 4(1):101–117
Manchikanti L, Singh V, Falco FJE, Cash KA, Pampati V (2010) Evaluation of lumbar facet joint nerve blocks in managing chronic low back pain: a randomized, double-blind, controlled trial with a 2-year follow-up. Int J Med Sci 7(3):124–135
Manchikanti L, Cash KA, Pampati V, Falco FJ (2014) Transforaminal epidural injections in chronic lumbar disc herniation: a randomized, double-blind, active-control trial. Pain Physician 17(4):E489–E501
Manchikanti L, Kaye AD, Boswell MV et al (2015a) A systematic review and best evidence synthesis of the effectiveness of therapeutic facet joint interventions in managing chronic spinal pain. Pain Physician 18(4): E535–E582
Manchikanti L, Pampati V, Benjamin RM, Boswell MV (2015b) Analysis of efficacy differences between caudal and lumbar interlaminar epidural injections in chronic lumbar axial discogenic pain: local anesthetic alone vs. local combined with steroids. Int J Med Sci 12(3):214–222. https://doi.org/10.7150/ijms.10870
Margetic P, Pavic R, Stancic MF (2013) Provocative discography screening improves surgical outcome. Wien Klin Wochenschr 125(19–20):600–610
Marks RC, Houston T, Thulbourne T (1992) Facet joint injection and facet nerve block: a randomised comparison in 86 patients with chronic low back pain. Pain 49(3):325–328
Maugars Y, Mathis C, Berthelot JM et al (1996) Assessment of the efficacy of sacroiliac corticosteroid injections in spondylarthropathies: a double-blind study. Br J Rheumatol 35(8):767–770
McKenzie-Brown AM, Shah RV, Sehgal N, Everett CR (2005) A systematic review of sacroiliac joint interventions. Pain Physician 8(1):115–125
Modic MT, Steinberg PM, Ross JS, Masaryk TJ, Carter JR (1988) Degenerative disk disease: assessment of changes in vertebral body marrow with MR imaging. Radiology 166:193–199
Ng L, Chaudhary N, Sell P (2005) The efficacy of corticosteroids in periradicular infiltration for chronic radicular pain: a randomized, double-blind, controlled trial. Spine (Phila Pa 1976) 30(8):857–862
Ohnmeiss DD, Vanharanta H, Guyer RD (1995) The association between pain drawings and computed

tomographic/discographic pain responses. Spine (Phila Pa 1976) 20:729–733
Peng B, Hou S, Wu W, Zhang C, Yang Y (2006) The pathogenesis and clinical significance of a high-intensity zone (HIZ) of lumbar intervertebral disc on MR imaging in the patient with discogenic low back pain. Eur Spine J 15:583–587
Rahme R and Moussa R (2008) The Modic Vertebral Endplate and Marrow Changes: Pathologic Significance and Relation to Low Back Pain and Segmental Instability of the Lumbar Spine Am J Neuroradiol 29 (5):838–842. https://doi.org/10.3174/ajnr.A0925
Rauchwerger JJ, Candido KD, Zoarski GH (2011) Technical and imaging report: fluoroscopic guidance for diagnosis and treatment of lumbar synovial cyst. Pain Pract 11:180–184
Resnick D, Choudhri TF et al (2005) Guidelines for the performance fusion procedures for degenerative disease of the lumbar spine. Spine 2:662–669
Rupert MP, Lee M, Manchikanti L et al (2009) Evaluation of sacroiliac joint interventions: a systematic appraisal of the literature. Pain Physician 12(2):399–418
Sabers SR, Ross SR, Grogg BE, Lauder TD (2005) Procedure-based nonsurgical management of lumbar zygapophyseal joint cyst-induced radicular pain. Arch Phys Med Rehabil 86:1767–1771
Saboeiro GR (2009) Lumbar discography. Radiol Clin N Am 47(3):421–433
Sachs BL, Vanharanta H et al (1987) Dallas discogram description. A new classification of CT/discography in low-back disorders. Spine 12:288–294. (Table 2, page 288)
Salahadin A, Sukdeb D, Schultz D, Rajive A et al (2007) Epidural steroids in the management of chronic spinal pain: a systematic review. Pain Physician 10:185–212
Schofferman J, Kine G (2004) Effectiveness of repeated radiofrequency neurotomy for lumbar facet pain. Spine (Phila Pa 1976) 29(21):2471–2473
Schulz C, Danz B, Waldeck S et al (2011) Percutaneous CT-guided destruction versus microsurgical resection of lumbar juxtafacet cysts. Orthopade 40:600–606
Schwarzer AC, Aprill CN, Derby R et al (1994) Clinical features of patients with pain stemming from the lumbar zygapophysial joints. Is the lumbar facet syndrome a clinical entity? Spine 19:1132–1137
Schwarzer AC, Aprill CN, Derby R et al (1997) International Spinal Injection Society guidelines for the performance of spinal injection procedures: I. Zygapophysial joint blocks. Clin J Pain 13:285–302
Sehgal N, Dunbar EE, Shah RV, Colson J (2007a) Systematic review of the diagnostic utility of facet (zygoapophysial) joint injections in chronic spinal pain: an update. Pain Physician 10:213–228
Sehgal N, Rinoo V, Colson J. (2007b) Chronic pain treatment with opioid analgesics: benefits versus harms of long-term therapy. Expert Rev Neurother 13(11): 213–228
Shah RV, Lutz GE (2003) Lumbar intraspinal synovial cysts: conservative management and review of the world's literature. Spine J 3:479–488
Slipman CW, Lipetz JS, Jackson HB et al (2000) Therapeutic selective nerve root block in the non-surgical treatment of atraumatic cervical spondylotic radicular pain: a retrospective analysis with independent clinical review. Arch Phys Med Rehabil 81:741–746
Son JH, Kim SD, Kim SH, Lim DJ, Park JY (2010) The efficacy of repeated radiofrequency medial branch neurotomy for lumbar facet syndrome. J Korean Neurosurg Soc 48(3):240–243
Storheim K, Berg L, Hellum C et al (2017) Fat in the lumbar multifidus muscles – predictive value and change following disc prosthesis surgery and multidisciplinary rehabilitation in patients with chronic low back pain and degenerative disc: 2-year follow-up of a randomized trial. BMC Musculoskelet Disord 18:145
Tekin I, Mirzai H, Ok G et al (2007) A comparison of conventional and pulsed radiofrequency denervation in the treatment of chronic facet joint pain. Clin J Pain 23(6):524–529
Thomas E, Cyteval C, Abiad L et al (2003) Efficacy of transforaminal versus interspinous corticosteroid injection discal radiculalgia – a prospective, randomised, double-blind study. Clin Rheumatol 22(4–5):299–304
Vad VB, Bhat AL, Lutz GE, Cammisa F (2002) Transforaminal epidural steroid injections in lumbosacral radiculopathy a prospective randomized study. Spine 27(1):11–16
Vallee JN, Feydy A, Carlier RY et al (2001) Chronic cervical radiculopathy: lateral approach periradicular corticosteroid injection. Radiology 218:886–892
van Kleef M, Barendse GA, Kessels A et al (1999) Randomized trial of radiofrequency lumbar facet denervation for chronic low back pain. Spine (Phila Pa 1976) 24(18):1937–1942
van Kleef M, Barendse GA, Kessels A et al (2005) Radiofrequency denervation of lumbar facet joints in the treatment of chronic low back pain: a randomized, double-blind, sham lesion-controlled trial. Clin J Pain 21:335–344
Van Tilburg CWJ, Stronks DL, Groeneweg JG et al (2016) Randomised sham-controlled double-blind multicentre clinical trial to ascertain the effect of percutaneous radiofrequency treatment for lumbar facet joint pain. Bone Joint J 98-B(11):1526–1533
Walsh TR, Weinstein JN, Spratt KF et al (1990) Lumbar discography in normal subjects. A controlled, prospective study. J Bone Joint Surg Am 72:1081–1088
Xi MA, Tong HC, Fahim DK, Perez-Cruet M (2016) Using provocative discography and computed tomography to select patients with refractory discogenic low back pain for lumbar fusion surgery. Cureus 8(2):e514
Younger J, McCue R, Mackey S (2009) Pain outcomes: a brief review of instruments and techniques. Curr Pain Headache Rep 13(1):39–43

Zotti MGT, Osti OL (2010) Repeat percutaneous radiofrequency facet joint denervation for chronic back pain: a prospective study. J Musculoskelet Pain 18(2):153–158

Zotti VA, Zotti MGT, Worswick D (2012) Obtaining informed medical consent: a legal perspective. Bulletin (Law Soc South Australia) 34(1):22–24

Zotti MGT, Boas FV, Clifton T et al (2017) Does pre-operative magnetic resonance imaging of the lumbar multifidus muscle predict clinical outcomes following lumbar spinal decompression for symptomatic spinal stenosis? Eur Spine J 26 (1):2589–2597

Zuo J, Joseph GB, Li X et al (2012) In-vivo intervertebral disc characterization using magnetic resonance spectroscopy and $T_{1\rho}$ imaging: association with discography and Oswestry disability index and SF–36. Spine 37(3):214–221