Discography

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Introduction

Approximately 80% of the U.S. population suffers at least one episode of back pain at some time in their lives, while 5–10% of patients develop chronic back pain [1]. In 2011, the Center for Disease Control and Prevention's (CDC) National Center for Health Statistics reported that 28.4% of adults over age 18 experienced lower back pain during the previous 3 months [2].

As reported in the 2016 National Health Interview Survey, back pain significantly limits work and daily activity for 28.4% of Americans [3]. A commonly repeated figure suggests that, cumulatively, Americans lose 149 million workdays each year due to back-related disability [4, 5]. Despite the availability of multiple imaging modalities and clinical examination, ascertaining the source of any given patient's back pain can be challenging.

Discogenic pain is a mechanical pain that is usually experienced in the axial spine distribution. It is exacerbated by activity and relieved by rest. It accounts for 26–42% of chronic low back pain [6–8].

Discography is a diagnostic procedure used to assess discogenic pain by evaluating the intervertebral disc in the cervical, thoracic, and lumbar spine. Disc morphology, pressure, and volume along with the patient's response to injection are recorded and used to confirm or exclude the disc as the source of pain. This allows correlation of findings from spinal imaging studies with the patient's pain symptoms and pattern [9–11]. In theory, discography identifies a painful disc by stimulating nociceptors in the outer third of the annulus, stimulating annular tears extending into the nucleus that have developed neoinnervation or by stimulation of nociceptors within the vertebral endplate [12].

Discography is the only diagnostic technique that directly correlates a patient's symptoms with disc morphology [13]. In this way, discography is conceptually similar to manual palpation. Pain provocation on discography is analogous to tenderness elicited on palpation [14, 15]. Consistent and reproducible pain portends greater diagnostic certainty. Numerous formal investigations have demonstrated that discography performed by experienced interventionalists can improve both surgical and nonsurgical treatment outcomes [16–21].

Advances in MR imaging detect increasingly minute degenerative changes, which often require clinical correlation [14, 22–24]. Any of these findings are asymptomatic. Discography is unique in allowing a link between radiographic findings and clinical presentation. MRI findings including degenerative changes in disc morphology do not correlate with symptoms of lower back pain [25–27].

To better understand the role discography can play in the diagnosis of spinal pain, this chapter will review:

- Historical use of the procedure
- Procedure validation
- Disc anatomy and physiology
- Disc pathophysiology
- Indications and contraindications
- Patient selection criteria
- Pre-and peri-procedure considerations
- Discography procedure
- Post-procedure care
- Complications
- Results: interpretation, documentation, and follow-up
- Correlation of discography with other imaging studies
- Evidence supporting and controversies regarding the procedures
- Use of discography in treatment planning—regenerative/biologic treatment

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History of Discography

The identification of the intervertebral disc as a source of back pain and radiculopathy was advanced by the early work of Schmorl and Junghanns reported in 1932. Their imaging and dissection of 10,000 cadaveric spines demonstrated that the intervertebral disc could be a source of pain and introduced discography as an anatomic study of the internal structure of the cadaveric disc [11]. In 1934, Mixter and Barr further confirmed the intervertebral disc as a pain generator by surgically removing a prolapsed posterior disc, leading to pain relief [28]. Prior to discography, clinicians relied on Myelography with iophendylate (Pantopaque) to visualize spinal pathology; however, the disc and the epidural space remained opaque to this form of imaging inspection. Multiple authors published clinical reports throughout the 1940s [29] and 1950s [30] that advanced understanding of disc physiology, pathophysiology, the use of injected dyes to illuminate disc innervation and degeneration, and the evolving use of discography to diagnose disc pathology [11, 28, 31].

Lindblom has been credited with identifying discogenic pain as a primary source of back pain in 1941. He injected contrast into a cadaveric disc and concluded that injection of an opaque medium into the disc reveals disc ruptures and protrusions and identifies whether the patient's pain emanates from the punctured disc [31, 32]. Wise and Weiford performed the first discography in the USA in 1951 [33].

In 1964, Holt published a study of 50 patients with no history of neck or arm pain that challenged the validity of cervical discography as a diagnostic tool. In an examination of 148 discs, only 10 could be characterized as retaining injectate within the central confines of the annulus typically described as normal by other authors. He concluded that cervical discography is without diagnostic value [34]. Schellhas et al. compared MRI and cervical discography in 10 subjects without painful neck symptoms and 10 subjects with neck pain. The authors found that normal discs were not painful in either symptomatic or nonsymptomatic subjects. When pressurized, painful discs corresponded to the pain reported by the patient [35]. Holt in 1968 published a study questioning the credibility of lumbar discography. Discography was carried out on 30 volunteers from a penitentiary inmate population. He reported a 37% false-positive rate [36]. Simmons and Aprill reassessed Holt's paper finding four major issues. First, Hypaque contrast is irritating and likely irritated surrounding structures. Secondly, needle placement was likely improper as neither CT nor fluoroscopy was utilized. Thirdly, the study population and motivation for participation in this penitentiary study population are problematic, and lastly, errors in accounting of data are noted [37].

Walsh and Aprill replicated Holt's study in 1990 in 10 asymptomatic volunteers and 7 patients with lower back pain. Six of seven low back pain patients had positive discograms, while none of the ten asymptomatic volunteers had positive studies. The false-positive rate was 0%, and specificity was 100% [38].

Validation

There exists a gold standard dilemma. There is no histopathologic correlate of a painful disc against which to measure an imaging or diagnostic test such as discography. This lack of a criterion standard for lumbar discogenic pain—other than discography itself—implies that the validity of discography cannot be directly determined. The false-positive rate can be determined by studying the prevalence of positive responses in a group of asymptomatic volunteers [12].

Methodological variability in study design, clinical techniques, definitions, and interpretations of discography, as well as little consensus about what constitutes a false-positive rate, has made the reliability of systematic review, and thus evidence-based guideline development, challenging [12, 39–46]. Techniques and safeguards to address concerns identified in the clinical literature have developed. Lumbar discography was routinely performed without manometry until Derby demonstrated the importance of pressure measurement and operational criteria [17, 47]. The use of strict criteria including injection pressure and response intensity can decrease false positives and protect against putative risk of damage to the disc [9, 39, 41].

The operational definition of a "positive" vs a "negative" response to disc provocation is important. Derby et al. were able to demonstrate that when discography was applied with appropriate pressure, volume, and response intensity criteria the procedure yielded 0–10% false-positive results [12, 42, 48].

Guidelines by the Spine Intervention Society and the American Society of Interventional Pain Physicians focus on criteria for the use and interpretation of provocative discography [49].

Positive Discography Criteria

In ideal situations, a gold standard or criterion is obtained by tissue confirmation of the presence or absence of a disease. Surgical inspection of a degenerated disc and advanced imaging cannot assess the presence of discogenic pain [1].

Guidelines for provocation discography have been developed by multiple professional medical societies. The technique of lumbar discography has been standardized by the International Association for the Study of Pain as well as the Spine Intervention Society. Comprehensive literature reviews have been provided in the American Society for Interventional Pain Medicine guidelines of 2009, 2013, and 2018 [8, 50, 51].

In 2013, the Spine Intervention Society established the following criteria for definitive diagnosis of discogenic pain using provocation discography: [49].

- Concordant pain response of ≥6/10
- Volume limit of 3 mL
- Pressurization of the disc to no greater than 50 psi above the opening pressure
- Adjacent disc(s) provide controls
  - For one control disc: Painless response or nonconcordant pain that occurs at a pressure greater than 15 psi over opening pressure
  - For two adjacent control discs: Painless response at both levels or one painless disc and one disc with nonconcordant pain that occurs at a pressure greater than 15 psi over opening pressure

Similar criteria have been developed by the American Society of Interventional Pain Physicians (ASIPP) [1]. A discogram can be interpreted as positive only if the target disc:

Produces concordant pain with an intensity of ≥7 on a 10-point numerical pain rating scale or 70% of the highest reported pain (i.e. worst spontaneous pain of 7 = 7 × 70% = 5).

Two adjacent discs do not produce any pain at all with provocation discography or only one disc in the case of L5/S1 with low-volume and low-pressure injection.

"Concordant pain" will be defined here as pain during provocation that closely approximates the patient's usual pain pattern, whereas "nonconcordant pain" is a pain response upon pressurization that does not mirror usual pain pattern.

Disc Anatomy and Physiology

Intervertebral discs function primarily to transmit loads and facilitate movement between vertebral bodies. They are complex structures comprised of a thick fibrous outer ring of cartilage and an annulus fibrosus that surrounds an inner gelatinous centre called the nucleus pulposus. The disc is positioned between the inferior and superior cartilage endplates [31].

The annulus fibrosus is comprised of concentric lamellae of fibrocartilage. Each lamella consists primarily of collagen type I fibres that pass obliquely between vertebral bodies, with the orientation of the fibres reversed in alternating lamellae [52]. Annular fibres provide resistance to vertical, forward, backward, and lateral sliding movements in response to outward expansion of the nucleus pulposa. The annulus fibrosus acts like a ligament to restrain movement and stabilize the vertebral joint [31].

The nucleus pulposus, which is the central core of the disc, is located posteriorly within the disc [28]. It absorbs shock during axial loading by expanding radially and resists spinal compression by spreading axial load evenly across the vertebral body, even when the spine is flexed or extended [31, 52]. The nucleus pulposus consists of a proteoglycan and water gel held together loosely by an irregular network of fine collagen type II and elastin fibres. Aggrecan, the major proteoglycan of the disc, has a high anionic glycosaminoglycan content of chondroitin sulphate and keratan sulphate, which provides the osmotic properties needed to preserve hydration and resist compression [31, 52]. Because the nucleus pulposus does not have its own blood supply, it receives its nourishment via diffusion from the vasculature along the periphery of the annulus fibrosa and vertebral body [28].

The vertebral endplate is a thin (less than 1 mm), horizontal layer of hyaline cartilage that is weakly bonded to the perforated cortical bone of the vertebral body and the collagen fibres of the annulus and nucleus [31, 52]. Only the cartilaginous endplates have blood supply. Biochemically, the important constituents of the disc are collagen fibres, elastin fibres, and aggrecan [53].

Two interconnected nerve plexes innervate the cervical, thoracic, and lumbar discs. Both plexes innervate the annulus fibrosus to a depth of 3.5 mm, with most nerve endings concentrated dorsally and posterior laterally. Branches of two sympathetic trunks, the proximal ends of the lumbar ventral rami and the grey rami communicans, form the plexuses that innervate the anterior part of the disc. The sinovertebral nerve provides the main nerve supply to the posterior intervertebral disc and to every other structure of the spinal canal [31]. The density of receptors within the lumbar endplates and the annulus is similar. Endplate innervation is densest centrally, near the nucleus [53] (Fig. 16.1).

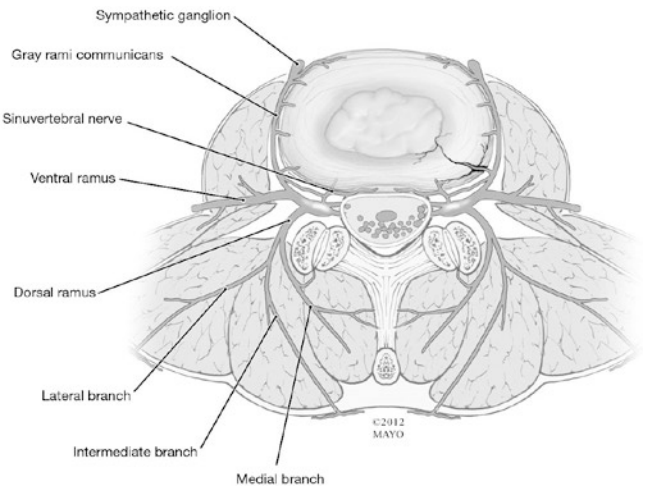

Fig. 16.1 Innervation of the intervertebral disc. (From: Maus and Aprill [106]. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved)

The intervertebral disc changes degeneratively, morphologically, and biochemically over the course of the human life cycle. With advancing age, proteoglycans and water decrease within the nucleus pulposus, resulting in insufficient hydrodynamic transfer of axial stress to the outer annulus fibrosus [52]. This decreased hydration results in loss of mechanical tension in the annulus fibrosus collagen fibres and results in abnormal spinal axial loading forces and segmental instability. Minor changes in stress forces on the spine can result in the development of neck or back pain and narrowing of the spinal canal over time. In early stage degeneration, the disc undergoes an imbalance of anabolic and catabolic factors that leads to extracellular matrix degradation [54, 55] (Fig. 16.2).

Abnormal distribution of axial stress results in the tearing of the annulus fibrosus, which reduces the structural integrity of the disc [56]. Excessive mechanical loading, whether through trauma, sustained physical activity such as sports, or activities of daily living, disrupts the disc's structure, precipitating cell-mediated responses that lead to further disrup-

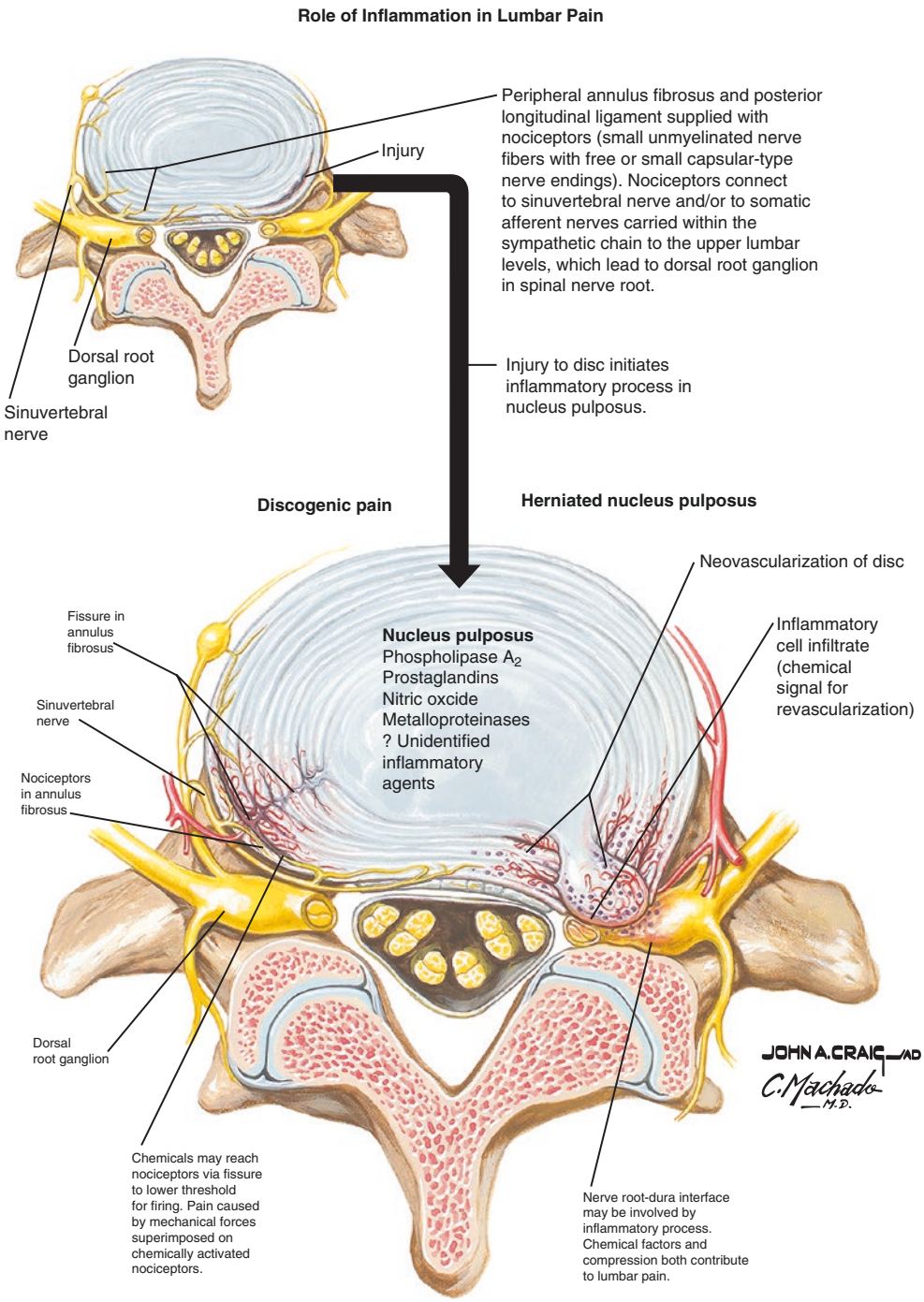

Fig. 16.2 Anatomic relationship of the lumbar disc, endplate, and nerve root. Pathologic changes secondary to neovascularization of the disc. (Source: Netterimages. Role of Inflammation In Lumbar Pain. Image# 7408. Netter illustration used with permission of Elsevier Inc. All rights reserved. www.netterimages.com)

tion. Genetic inheritance likely contributes to degenerative susceptibility [52]. Pathological changes within the disc are distinct from other types of disc degenerative disease such as herniation [6, 57].

Pathophysiology

The pathophysiology of the intervertebral disc is complex, and only a brief summary will be considered here. Degenerated discs exhibit abnormally widespread innervation with sensory nerve fibres penetrating deep into the nucleus pulposus [58, 59]. Most discs with positive pain provocation on discography show radial fissures within the annulus [60].

The process of disc degeneration produces an inflammatory response, generated by cells within the nucleus pulposus, where multiple inflammatory factors are released. Histologic studies reveal ingrowth of vascularized granulation tissue along the annular fissures [59]. Immunohistochemical analyses have demonstrated cytokine-sensitized nociceptors, phagocytic cells, and perivascular neoinnervation (axonogenesis). Small, free nerve fibres may be found in the outer annulus and extend to the inner annulus and nucleus pulposus [59, 61–63].

Patients with discogenic back pain have significantly higher levels of released interleukin-1, interleukin-6, and interleukin-8, compared to patients with disc herniation [61]. Nerve fibres in the disc may contain nociceptive neurotransmitters, such as substance P, calcitonin gene-related peptide, and vasoactive intestinal peptide. These inflammatory factors migrate through fissures into the outer third of the annulus or into the endplate, where stimulation of free nerve endings results in pain [62]. The degenerating discs thus exhibit free nerve endings (pain receptors) and inflammation, which are two of the factors responsible for the pain response [64].

Patient Selection

There is little discussion in the literature about how to identify which patients are suitable candidates for discographic procedures. In general, a high level of suspicion for discogenic pain, where the persistent level of pain is severe enough to consider surgical intervention, is required [31]. Because most patients with low back pain experience improvement and resolution within 3 months, discography is typically reserved for adults who report back pain for an extended period. Earlier discography should be considered rarely and only for specific extraordinary cases, and it should not be used as a routine procedure for patients with nonspecific back pain [31, 64–66]. Prior to discography, the patient should try multiple more conservative treatment modalities, (e.g. lifestyle and activity modification, medication, physical therapy, fluoroscopically guided injections, and other conservative methods) with insufficient therapeutic success [11, 28, 31]. The patient must also be able to understand the purpose of the procedure, comply with instructions, and provide meaningful feedback during the stimulation [11]. For example, the patient must be able to clearly describe any pain produced during disc stimulation and compare it to their usual pain [10]. The procedure is often performed using conscious sedation. This method supports patient comfort and allows the patient to be responsive during the pressurization phase of procedure.

Indications

Various authors describe the conditions for which discography is a suitable procedure [10, 11, 28, 64, 66]. These recommendations are not entirely uniform and, to some extent, vary based on the clinician's specialty (e.g. anaesthesiologist/interventional pain specialist, pain medicine and rehabilitation specialist, or radiologist).

Updated guidelines by the North American Spine Society enumerate a core set of criteria for which there is widespread agreement and which have withstood the test of time [65]. According to these criteria, indications for discography include, but are not limited to:

- Assessment of demonstrably abnormal discs to help evaluate the extent of abnormality or correlate the abnormality with the clinical symptoms. Such symptoms may include recurrent pain from a previously operated disc and lateral disc herniation.
- Assessment of patients with persistent, severe symptoms in whom other diagnostic tests have failed to reveal clear confirmation of a suspected disc as the source of pain.
- Assessment of patients who have failed to respond to surgical intervention, to determine if there is painful pseudarthrosis or a symptomatic disc in a posteriorly fused segment and to help evaluate possible recurrent disc herniation.
- Assessment of discs before fusion, to determine if the discs within the proposed fusion segment are symptomatic and to determine if discs adjacent to the segment are normal.
- Assessment of candidates for minimally invasive surgical intervention to confirm a contained disc herniation or to investigate dye distribution pattern before chemonucleolysis or percutaneous procedures.

A report by Walker et al. concurs with these criteria and adds that potential candidates for discography should have

no contraindications, particularly evidence of psychogenic pain [31].

Contraindications

The main contraindications to discography are similar to those of other interventional procedures:

- Known bleeding disorder and use of anticoagulation/antithrombotic therapy that cannot be with temporary medication discontinuation
- Pregnancy
- Systemic infection or skin infection over the puncture site
- Allergy to radiologic contrast that precludes testing with contrast media, local anaesthetic, or antibiotics (pretreatment with antihistamine and corticosteroids or use of gadolinium may ameliorate these problems in some patients)
- Psychiatric conditions, such as psychogenic pain, posttraumatic stress disorder, or psychotic diagnoses
- Inability or unwillingness to provide informed consent to the procedure
- Inability to assess the patient's response to the procedure, for example, due to sedation or significant analgesic use
- Anatomic features that would preclude a safe and effective procedure, for example, severe spinal stenosis resulting in intraspinal obstruction
- Solid bone fusion that prevents access to the disc
- Severe spinal canal compromise at the disc level to be investigated [11, 28, 31]

Some of the above contraindications, such as infection, can be temporary, and others, such as allergy and anticoagulation/antithrombotic therapy, can be addressed in the pre- and perioperative period.

Preoperative Considerations

Patient preexisting conditions, such as allergies to contrast, latex, iodine, and antibiotics must be addressed. Prophylactic medications, such as diphenhydramine and a steroid agent for allergy management, can be prescribed for those patients whose allergy is not severe. Patient compliance must be ensured [10].

Familiarity with all medications a patient is taking is essential, including herbs and supplements. Instructions regarding the use of approved medications prior to the procedure vary. The potential benefit to the patient receiving discography must outweigh the risk of withholding essential medications. Recommendations for patients receiving antiplatelet/anticoagulant/antithrombotic medications vary and have changed over time. Communication with the clinician managing the patient's medication is essential. Pain, antiinflammatory, sedative, and any other medications or substances that alter the patient's perception of pain should not be used the day of the procedure to ensure test results are not comprised [10].

Perioperative Considerations

Clinicians concur that the usual perioperative protocols and precautions common to other spine interventions also apply to discography. A complete history and physical examination should be performed. The patient's CT and MR imaging should be reviewed to determine the levels to be studied. The patient needs to be informed of the risks and benefits of discography, and it should be made clear to the patient that his/her response to disc stimulation is the basis for the test results. The procedure should be explained to the patient in sufficient detail to convey what to expect, including the likelihood of discomfort or pain during the provocation portion of procedure and soreness for a few days afterwards, so that the patient can provide informed consent. Further, it is critically important for patients to fully understand that they will be required to actively participate in the provocation portion of the procedure by comparing the pain evoked by the procedure with their usual pain. They should also be made aware of the potential for complications, including pneumothorax if thoracic or lower cervical segments are to be tested [10, 11, 28, 31, 64]. Options for patients with severe iodine contrast allergy include gadolinium contrast and saline.

On the day of the discography, the patient can drink fluids, but should not eat for 2 hours before the procedure. Instructions regarding approved medications prior to the procedure vary [10].

Prior to the procedure, the patient is typically positioned in a prone position, prepped, and draped in a sterile manner. To avoid any confusion between needle-induced annular pain and a provocative pain response, the disc can be approached from the asymptomatic side, if the typical pain is predominantly on one side. Patients can also be positioned in a modified lateral decubitus position with the symptomatic side down. This position also facilitates optimal fluoroscopic imaging and keeps the image intensifier out of the way during initial needle placement.

Intravenous sedation can be given to relax the patient, providing that it does not compromise the patient's ability to participate during the procedure. Short-acting analgesics that can be readily reversed are generally preferred. Analgesia should be individually titrated to avoid oversedation. Heart rate, pulse oximetry, blood pressure, and respiration should be monitored throughout the procedure.

Standard infection prophylaxis practice is to administer intravenous and intradiscal antibiotics prior to the procedure, which have been reported to reduce the risk of infection and discitis [28, 49, 67–69]. The skin is also typically prepped with a povidone-iodine solution to further mitigate infection risk as S. aureus/epidermidis are typical constituents of normal skin flora [70–74]. In patients with a known iodine allergy, there are noniodine or alcohol-based solutions that can be used instead. The proceduralist must maintain sterile technique throughout the procedure. At no time should the needle tip be touched with the gloved hand; sterile gauze can be used to manipulate the needle tip. Intradiscal and/or oral antibiotics can be given at the discretion of the physician [40]. The consequences of discitis are so significant that many practitioners consider the use of prophylactic antibiotics to be the standard of care, especially for high-risk patients [28]. In a survey of its members, the Spine Intervention Society reported that 83.81% use preoperative antibiotics and 84.97% use intradiscal antibiotics [75].

The Procedure

Lumbar Discography

The most likely level of the pain generator and the two adjoining levels should be investigated. It is uncommon to study more than four segments. When stimulating the discs, the patient is blinded regarding the onset and level stimulated. If the patient's usual pain is localized to one side, the disc space can be approached from the contralateral, asymptomatic, side. Approaching the asymptomatic side can potentially reduce confusion regarding the source of any provoked pain. The American Society of Interventional Pain Physicians, [28] and the Spine Intervention Society guidelines detail recommendations for this procedure [49].

Patients are typically positioned prone. Foam pillows or pads can be utilized to reduce lumbar lordosis. Both single-needle and two-needle techniques have been described. A two-needle system uses a longer, small-gauge procedure needle passed through a shorter, larger gauge needle into the disc. A single-needle technique uses a single styletted needle passed through the skin and directly into the disc. A retrospective study of 100 thoracic discographies used a single-needle technique, a 24-gauge, 3.5-inch needle inserted directly through the skin into the thoracic disc, using intermittent fluoroscopic guidance and bevel rotation. No patient experienced any serious complications [76]. Both single- and double-needle techniques must utilize styletted needles. The stylet prevents tissue from accumulating in the needle and entering the disc [77]. The fluoroscope is used to obtain an anterior–posterior (AP) image of the target level. The fluoroscope is then angled cephalad or caudad until the image beam is parallel to the planes of the inferior and superior endplates that surround the target disc. (Fig. 16.3).

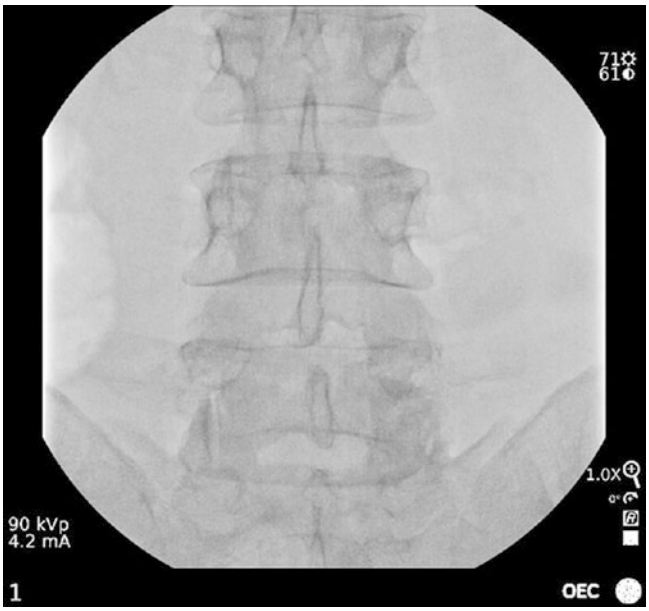

Fig. 16.3 AP View with the L4–5 endplates parallel to fluoroscopy beam

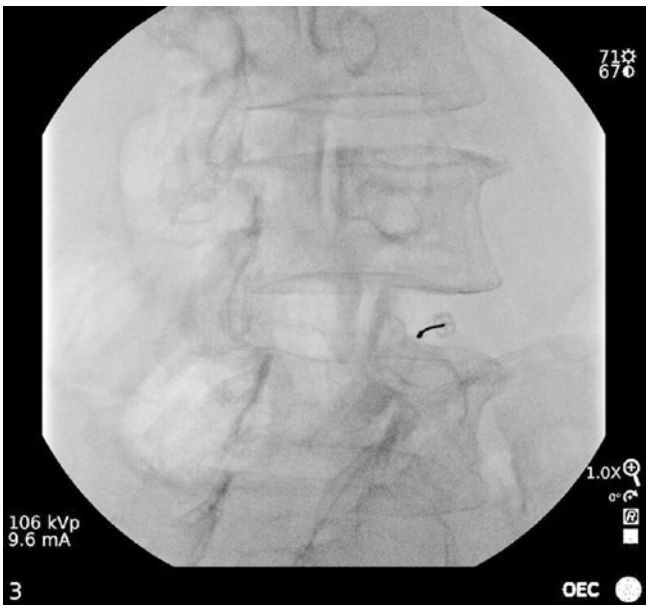

Fig. 16.4 L4–5 Oblique view. The SAP is in the midline of the disc space. The needle is slightly lateral to the SAP

The fluoroscope is next rotated obliquely towards the side of needle entry until the facet joint line is in the midline of the target disc. The needle is to be passed just lateral to the lateral aspect of the superior articular process (SAP) at the level of the target disc. (Fig. 16.4) (ring apophysis) [78] of L5 superiorly. (Fig. 16.5) A curved tipped needle can be used to avoid the iliac crest while obtaining disc access. (Fig. 16.6).

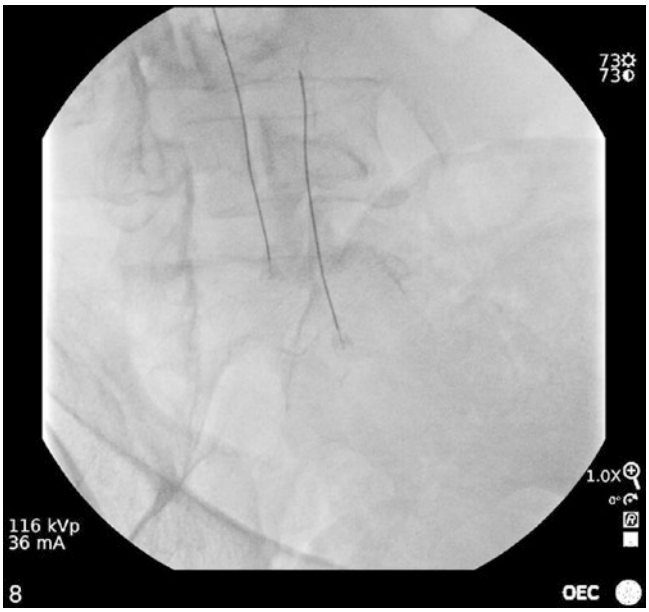

Fig. 16.5 L5-S1 Oblique view. The fluoroscopy beam has been angled cephalad to displace the iliac crest inferior. The existing needles are placed in the L3–4 and L4–5 disc spaces

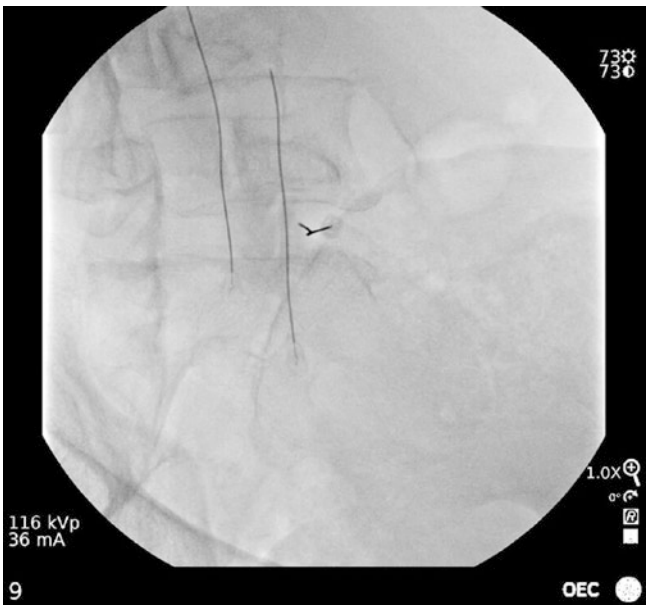

Fig. 16.6 L5-S1 Oblique view with needle inserted. Iliac crest is inferior, SAP medial to the needle. The curved tip needle can be used to avoid the iliac crest

The authors' standard needle length is 7 inches, although shorter needles can be used in slender patients. A longer needle, up to 10 inches, may be needed to access the L5-S1 disc in a large patient. A 22- or 25-gauge needle can be used to obtain disc access; however, 25-gauge needles can be difficult to manipulate due to their compliance but are less traumatic to the annular tissue. The needle is inserted through the skin parallel to the fluoroscopic beam and advanced just lateral to the SAP. If bone obstructs needle placement, the discographer must determine if the SAP or an endplate has been contacted and make the proper needle correction. Once the needle has been advanced distal to the SAP, the fluoroscopy beam is rotated to obtain a lateral image. (Fig. 16.7)

Care must be taken when crossing the level of the intervertebral foramen not to strike the ventral ramus. If the patient complains of paraesthesia during this portion of the procedure, the needle must be slightly withdrawn and redirected. The needle is then advanced, and, if no paraesthesia is elicited, the next structure that the needle will encounter is the disc annulus. A firm resistance will be felt by the discographer at this point. It is common for the patient to experience a dull ache in the lower back or buttock as the needle passes through the annulus. The needle is then advanced into the centre of the disc, and final needle position is confirmed with both lateral and AP imaging. (Fig. 16.8).

After proper placement of the needle into the target disc, the stylet is removed from the needle. The needle is connected to a syringe that will inject contrast mixed with antibiotic. If the patient has a known allergy to contrast, either saline or gadolinium [79] mixed with antibiotic can be injected. At least one painless disc must be identified as a control level during provocation discography in order to validate the procedure. If all discs studied are painful, the discogram can be considered invalid, and an adjacent level should be tested in order to identify a control. The diagnosis is stronger if the concordant disc displays a grade 3 fissure or greater on a post-discography CT scan. The diagnosis is

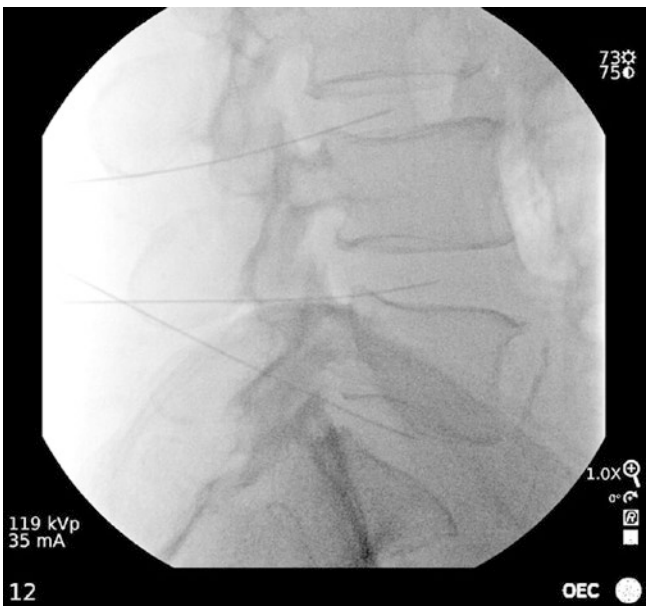

Fig. 16.7 Lateral view with needles inserted in the L3–4, L4–5 and L5-S1 discs. The needle is advanced into the centre of the disc as viewed laterally

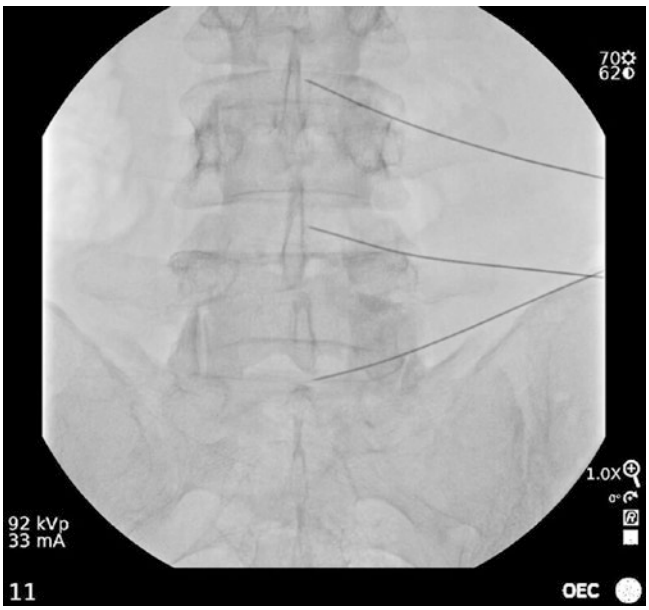

Fig. 16.8 AP view with needle in L3–4, L4–5, and L5-S1 discs. Needle placement should be midline in the AP and the lateral views. Note larger gauge needle used as introducer for FAD catheter

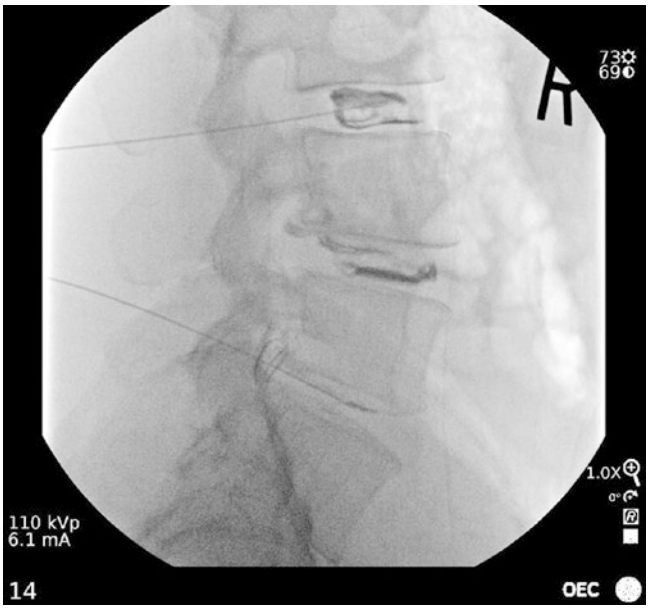

Fig. 16.9 Lateral view of a normal L3–4 disc. The L4–5 disc demonstrates a posterior tear. The L5-S1 disc space is narrowed and shows a posterior tear and posterior disc protrusion

most robust if a single disc demonstrates concordant pain production and the two adjacent discs are nonpainful [12].

Regardless of the technique employed, after the needles are positioned in the disc(s), each disc is evaluated by injecting contrast. Depending on the patient's size, a normal lumbar disc accepts from 0.5 mL to 3 mL with a firm endpoint or high discometric pressure [80]. Lumbar intradiscal pressure can be directly measured with a pressure gauge in psi at the onset of pain or with a firm endpoint. The volume and pressures are recorded while contrast is injected. The patient's response to the injection is noted [81]. In a normal disc, contrast remains in the nucleus and appears as a "cotton ball" (Figs. 16.9 and 16.10).

If the patient experiences pain with injection, the location, severity, and quality are documented. Transient pain can be provoked when fissures are opened. To be truly positive, the pain must be sustained during injection [17]. "Concordant pain" is pain during provocation that replicates the patient's usual pain pattern. "Nonconcordant pain" is pain during provocation that does not replicate the usual pain pattern. Disc morphology, including disc height, tears, and leaks, are also recorded. A confirmatory repressurization of a concordant disc or indeterminant disc is routinely performed to reconfirm the discographer's findings. Another method used to verify the consistency of the patient's response to disc pressurization is the use of a sham injection. The patient is told that the disc is being injected, while the syringe is held in the operator's hands. Any pain response is noted. Patients are expected to survive sham injection without response and to respond consistently to repressurization. A robust result would be one in which the patient

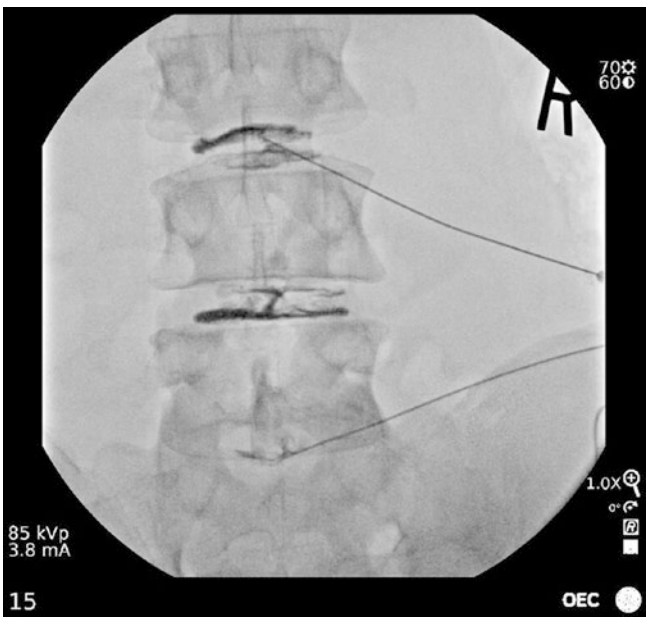

Fig. 16.10 AP view with normal L3–4 disc morphology and degenerative L4–5 and L5-S1 discs

survives sham injection without a painful response but responds consistently with a pain response to pressurization and repressurization to the disc.

Injection is continued until:

1. Pain is reproduced at a level of 6/10 or greater
2. Intradiscal pressure > 50 psi above opening pressure in a disc with a grade 3 annular tear

3. 4.0 ml of volume is reached
4. 80–100 psi is reached in a normal appearing disc [42, 82]

The opening pressure, pressure at onset of pain, and peak pressure are also recorded [79]. The use of manometry to measure intradiscal pressure during lumbar discography generates quantifiable, objective data which improve procedural consistency [17]. Intradiscal pressure monitoring also reduces the incidence of false-positive results by decreasing the likelihood of over-pressurization [83]. Pressures greater than 50 psi over opening pressure have been associated with a very high false-positive rate based on a retrospective study of pressure and pain response by O'Neill and Kurgansky [84].

Upon completion of the injections, x-rays of the lumbar spine are obtained in the posteroanterior and lateral views. A nucleogram of a normal lumbar disc appears as a rounded or bilobular-contained component of the lumbar disc. Annular disruption shows contrast spread beyond the nuclear border, typically in a radial fashion. Nucleogram patterns can range from normal (cotton ball and lobular) to abnormal (irregular, fissured, ruptured, and degenerative).

Post-Lumbar Discography Imaging

Post-lumbar discography CT imaging provides further detailed information about the presence and degree of annular pathology, as well as disc degeneration. The extent of annular pathology on CT-discography correlates with the likelihood of a concordantly painful disc [44]. The modified Dallas discogram classification system assists in assessing patients with lumbar spine pain for annular pathology. Grade 3–5 annular tears demonstrate a high correlation with concordant low back pain.

Graded morphology of internal disc structure:

- Grade 0: Normal disc morphology
- Grade 1: Contrast spreads radially along a fissure to the inner 1/3 of the annulus
- Grade 2: Contrast spreads into middle 1/3 of the annulus
- Grade 3: Contrast spreads to the outer 1/3 of the annulus, involving <30(degrees) of the disc circumference
- Grade 4: Contrast spreads to the outer 1/3 of the annulus, involving >30(degrees) of the disc circumference
- Grade 5: Full-thickness tear with extra-annular leakage into epidural space

Vanharanta and colleagues [60] were able to demonstrate from post-discography CT imaging that increasing disc degeneration was associated with increased likelihood of pain provocation. Discs with severe (grade 3 and above) annular disruption were associated with pain provocation 77% of the time.

Colhoun et al. [20] compared post-discography morphology with improved surgical outcomes. Patients with abnormal disc morphology and consistent response to pain provocation had successful surgical outcomes 89% of the time. Comparatively, they found successful surgical outcomes only 52% of the time in patients with abnormal disc morphology without pain provocation. (Table 16.1).

Cervical Discography

With some alterations, the pre- and peri-operative considerations discussed above also apply to cervical discography. Meticulous sterile technique and wide prep are important. Cervical discography may be performed using the original anterior approach or a modified anterolateral approach. The latter has been associated with less risk and has become the most commonly used approach. (Fig. 16.11).

The original **anterior paratracheal** technique places the patient in the supine position. The C-arm fluoroscope is employed to visualize the cervical spine. The patient's head and neck are placed in extension to widen the anterior disc space for easier access into the disc. Through patient or fluoroscope positioning, the spinous processes are aligned midline with visualization of the vertebral endplates and uncinate processes. (Fig. 16.12).

The oesophagus is typically located left of midline, so using a right-sided approach when performing cervical discography can lessen the risk of puncturing the oesophagus. With the nondominant hand, palpate anterior cervical structures with index and/or middle finger. Move the trachea and oesophagus medially and the carotid artery and internal jugular vein laterally. Direct the needle towards the anterolateral border of the endplate just below the target disc. This safety step is used to prevent overpenetration of the needle, which can travel through disc and directly into the spinal canal. Upon bony contact, the needle is held firmly, and the C-arm rotated into a lateral projection to confirm positioning. The needle is then walked off of the endplate superiorly into the disc annulus. The operator should be able to appreciate the clear tactile difference between hard bone and the more compliant disc. PA and lateral fluoroscopic views are used to

Table 16.1 Discography predicted success of subsequent surgical intervention.

Therapeutic utility			
		Response to treatment	
		Success	Failure
Disc stimulation	Positive	121	16
	Negative	16	15

Colhoun's data [20] showed sensitivity of 0.88 and specificity 0.48 in patients with positive discograms who underwent cervical spine surgery. Note that very few patients with negative discograms underwent surgery which may contribute to a selection bias

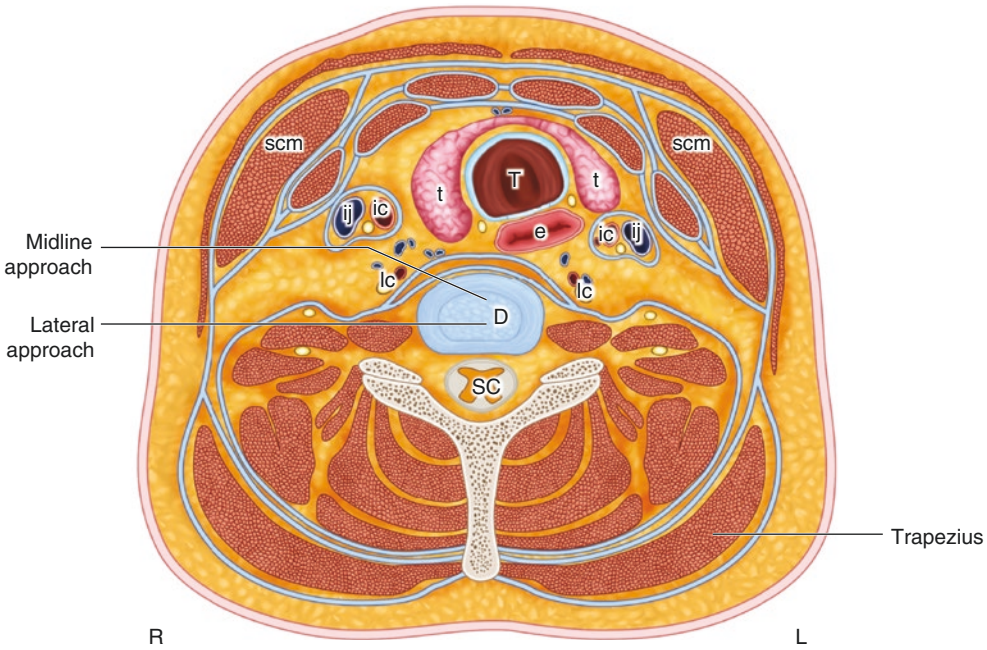

Fig. 16.11 Lateral and midline line approach trajectories. Cervical discography is typically done from the right side due to the left-sided location of the oesophagus. (From: Melnik et al. [126]; with permission of Springer Nature)

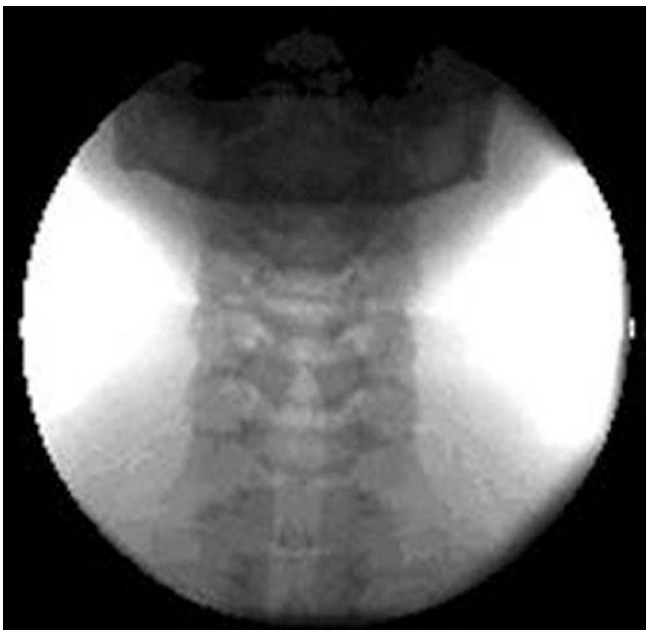

Fig. 16.12 AP C-spine with caudal tilt to square vertebral endplates. (From: Calodney and Griffin [127]; used with permission of Springer Nature)

advance tip into the centre of the disc space. A lateral view should be assessed as soon as the firm annulus fibrosis is felt.

Alternatively, the **oblique approach** has the advantage of keeping the operator's hand out of the fluoroscopic beam and is often the only way to enter lower cervical discs in larger patients. The disadvantage is that it puts the carotid artery at greater risk, as the course of the carotid can be anatomically variable. The patient is again positioned supine, and the C-arm is first positioned for a PA view of the cervical spine and then tilted caudally until the beam is parallel to the target disc space. The C-arm is then rotated towards the side of entry (generally the right side) to obtain open neural foraminal view. Using the focus of the beam as a guide directs the needle towards the medial edge of the uncinate process lateral and inferior to the disc space. Walk the needle off medially and superiorly into the disc annulus. (Figs. 16.13 and 16.14).

Again, once contact with annulus is felt, PA and lateral fluoroscopic views are utilized to advance the needle into the centre and confirm proper positioning. (Figs. 16.15 and 16.16).

After successful placement within the centre of the disc, the stylet is removed and the needle hub is filled with a few drops of contrast. Normal cervical discs can have volumes as small as 0.1 ml. In lieu of these small cervical volumes, even the dead space of the needle hub becomes important to consider. A 3 cc syringe and low volume extension tubing filled with contrast (containing the antibiotic) are attached to the needle. Often significant pressures are needed to reach dye point (the pressure at which contrast is first seen entering the disc) in the cervical spine, particularly in younger, normal discs. Additionally, dye point can be sudden and produce what we term an "opening snap", which can startle the patient and may be uncomfortable. It is important to distinguish this sensation from a positive painful discogenic response. Confirmatory techniques including sham injection and repressurization can help make this distinction and improve validity of patient response. (Fig. 16.17).

Contrast volume used for cervical discography ranges from approximately 0.1–0.5 ml. Occasionally, volumes over

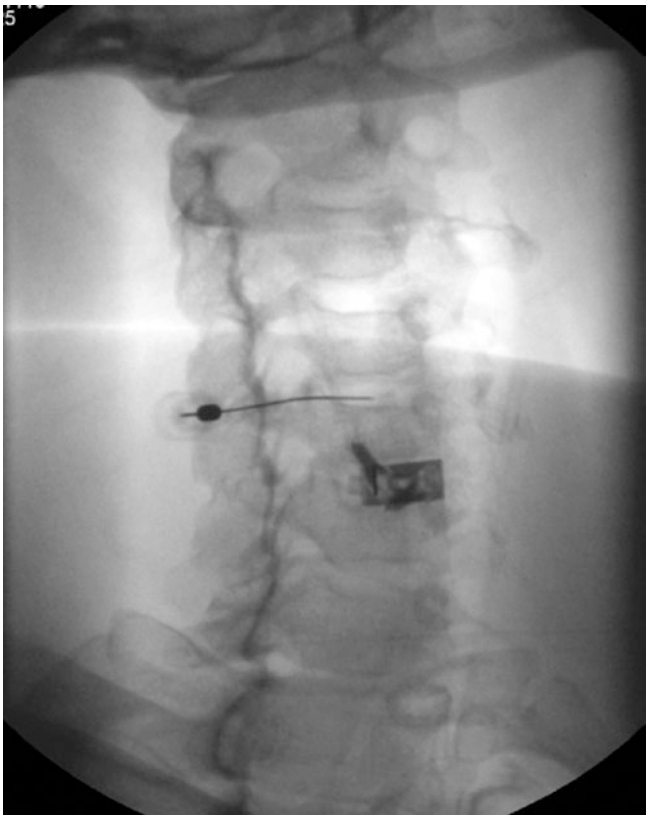

Fig. 16.13 Oblique view with needle tapping the medial edge of the uncinate process

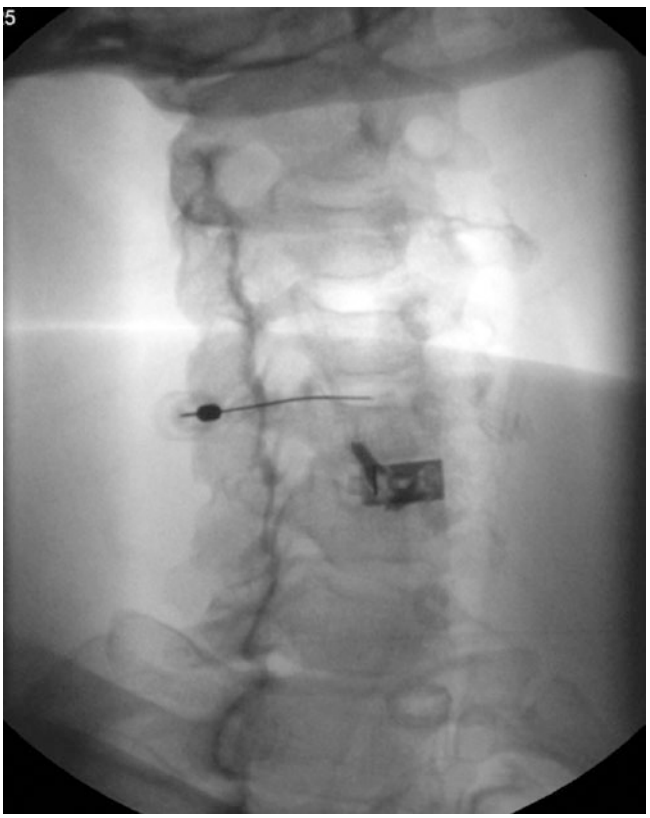

Fig. 16.14 Oblique view, needle walked off uncinate process medially and superiorly into the centre of the disc

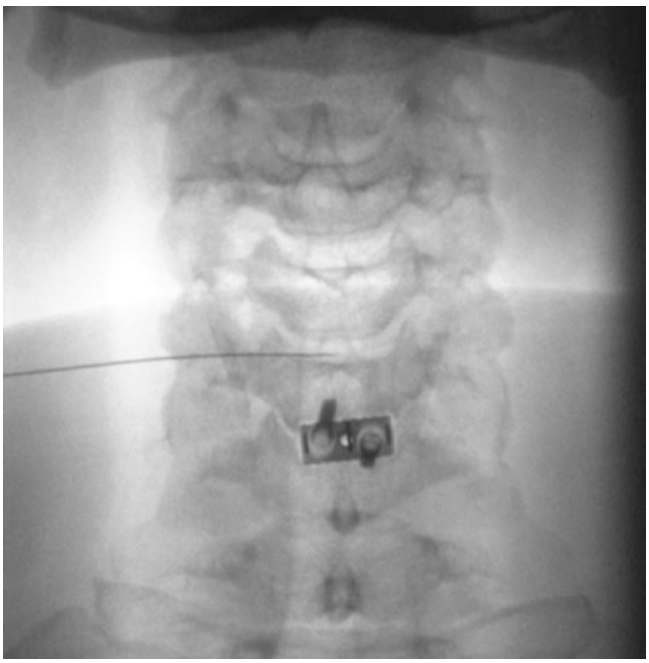

Fig. 16.15 AP view of the needle placed in the centre of the C6–7 disc space

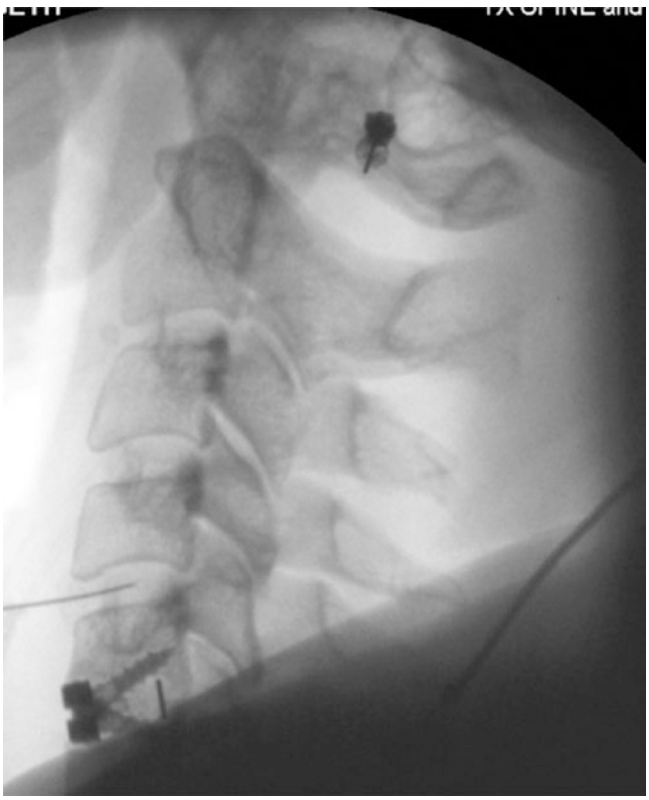

Fig. 16.16 Lateral view with needle in the centre of the disc space

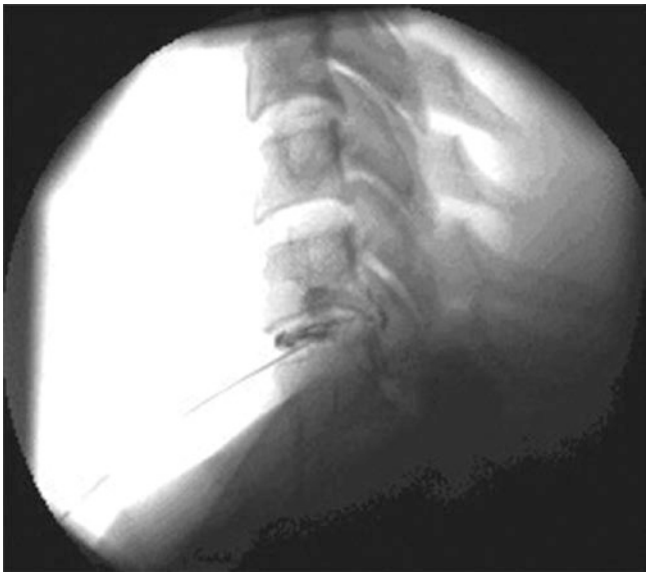

Fig. 16.17 Lateral view with contrast demonstrating small posterior tear and bulge

0.5 ml up to 1 ml may be required to pressurize the disc. These larger volumes can be an indication of incompetent or severely degenerated cervical discs. The average cervical disc volume noted by Ohnmeiss and colleagues [85] and corroborated by the authors' years of clinical experience is about 0.23 ml. Indeed, care should be taken if volumes exceed 0.5 cc. The injection of contrast should be terminated if a large leak is noted, firm resistance develops, or significant pain is experienced by the patient.

When investigating multiple cervical discs, the first needle is typically inserted into the most cephalad disc, followed by needle insertion into the remaining discs in a sequential and caudad direction. A single 25-gauge spinal needle is used to enter each disc level for the study. The needle entry should be more laterally at the C2/3 and C3/4 disc levels to avoid the hypopharynx and more medially at the C7/T1 level to avoid the apex of the lung.

Post-Cervical Discography Imaging

Post-cervical discography CT imaging is more challenging secondary to smaller injected contrast volumes. Generally, the CT should be done within 30–60 minutes of the contrast injection lest the contrast be largely redistributed before obtaining the CT images. Annular tears and protrusions involving the cervical disc that are detected by CT-discography are not always visualized by MRI, because the typical 3–5 mm MRI slice does not provide the necessary detailed information. CT-discography is optimal with 1 mm slices with gantry angles appropriately parallel to each cervical disc.

Thoracic Discography

Thoracic discography is less common and thus less studied than either lumbar or cervical discography. The general pre- and peri-procedural recommendations discussed in the corresponding cervical and lumbar sections also apply here. The technique used is similar to lumbar discography with some alterations to ensure the safety of the spinal cord in the thoracic spine. Another important pre-procedural consideration is that upper thoracic levels may be difficult to enter. Shorter disc heights and the close approximation of the ribs and costovertebral joints make this anatomy difficult to investigate. Additionally, degenerative changes tend to complicate matters further. Lower and midthoracic discs are generally easier and safer to study in most patients.

The patient should be placed in a prone position on the table. Adjust the C-arm to provide a posterior oblique position with the superior articular process one-third to one halfway across the disc space with squared endplates. The endplates at each level are squared off to ensure the parallel orientation of the beam with the sub- and supra-adjacent vertebral body margins. This view creates a "box" configuration formed by the endplates, the superior articular process\lamina, and the rib head. (Fig. 16.18).

The box defines a safe pathway into the annulus while avoiding the spinal cord medially and the lung laterally. Advance the needle within the confines of the box to the outer annulus. The needle must stay medial to the rib head and costovertebral joint in order to avoid the pleura. The needle must stay lateral to the lamina and interpedicular line to avoid entering the spinal canal. (Figs. 16.19, 16.20, 16.21, 16.22, and 16.23).

After encountering, the outer annulus continues into the central third of the disc using fluoroscopic guidance. Subsequent procedural steps are similar to those discussed in detail earlier in the text in regard to cervical contrast injection, as manometry is not generally used in with the thoracic or cervical regions.

Post-Thoracic Discography Imaging

CT imaging provides further detailed post-thoracic discography information on the degree of annular pathology and disc degeneration. The modified Dallas discogram classification system for annular pathology can be used to define the degree of abnormal findings.

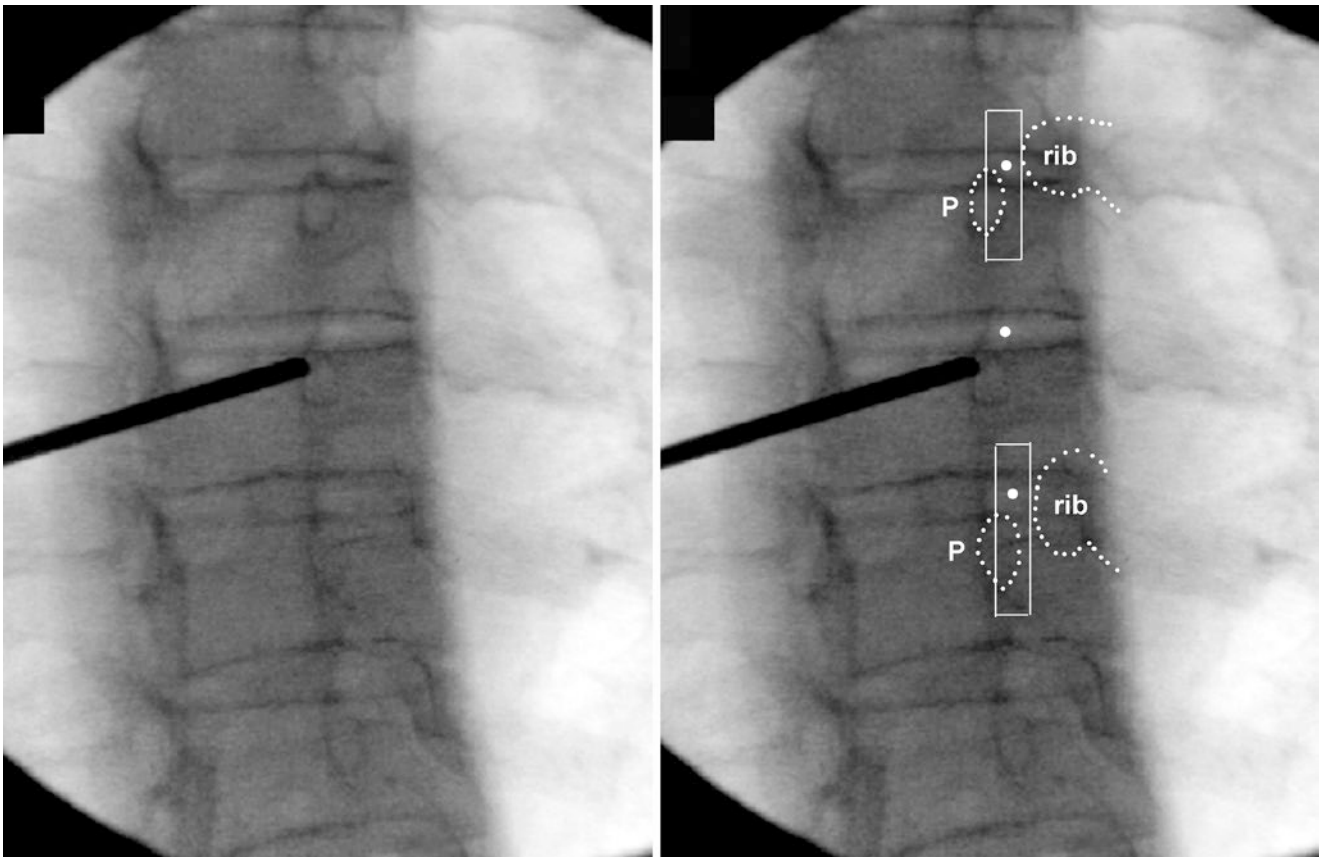

Fig. 16.18 The needle passes through a "box" bounded laterally by rib head, medially by lamina, and superiorly and inferiorly by endplates. (Reproduced with permission from Bogduk [128])

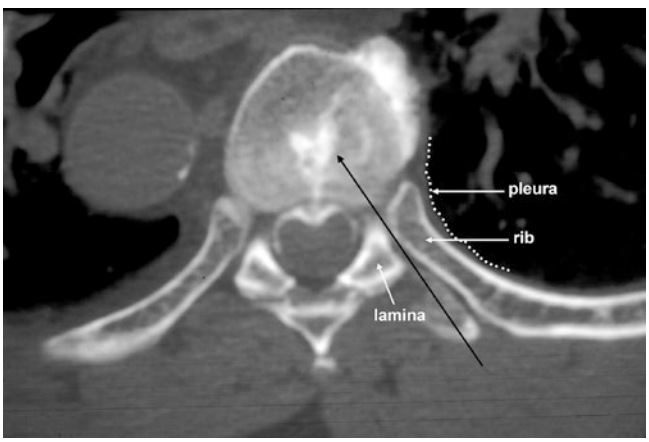

Fig. 16.19 Needle trajectory remains medial to the rib head and lateral to lamina to avoid pleura and spinal canal. (Reproduced with permission from Bogduk [128])

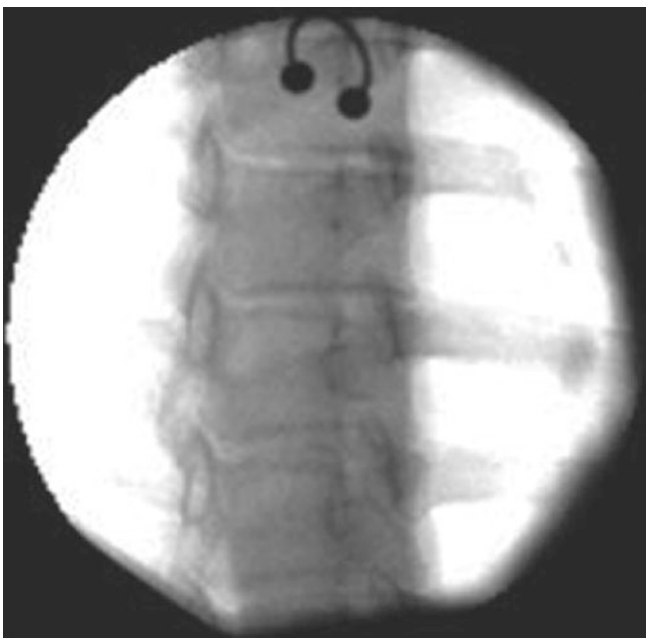

Fig. 16.20 Note that the endplates are squared and the C-arm is rotated towards the side of entry until the "box" is approximately 25% across the disc space

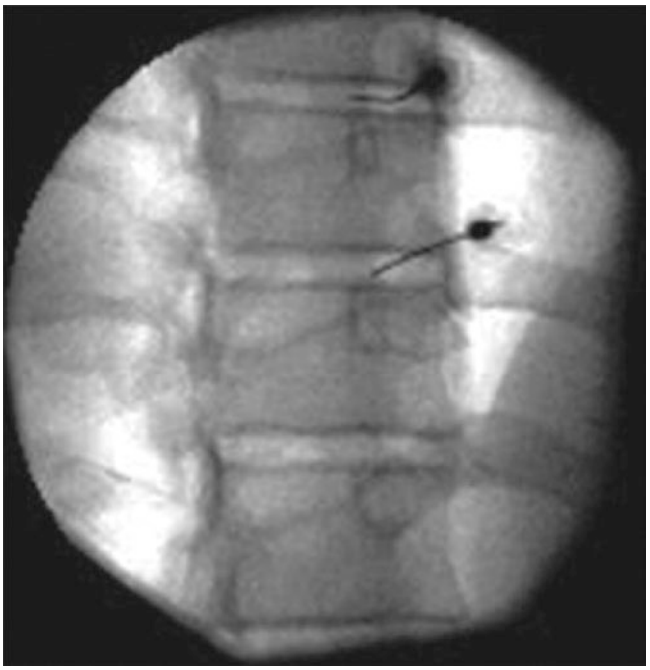

Fig. 16.21 Endplates must be parallel at the level of entry. The needles can be seen passing medial to the rib heads into the thoracic disc

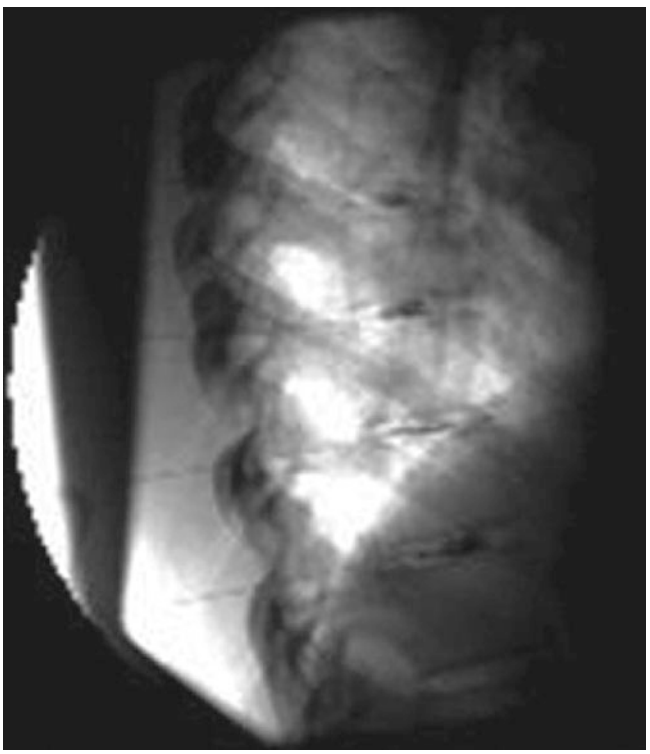

Fig. 16.22 Lateral view with needle in the middle of the disc space. The upper two discs appear normal. The Lower two levels demonstrated posterior annular abnormalities and recreated familiar pain on injection of contrast

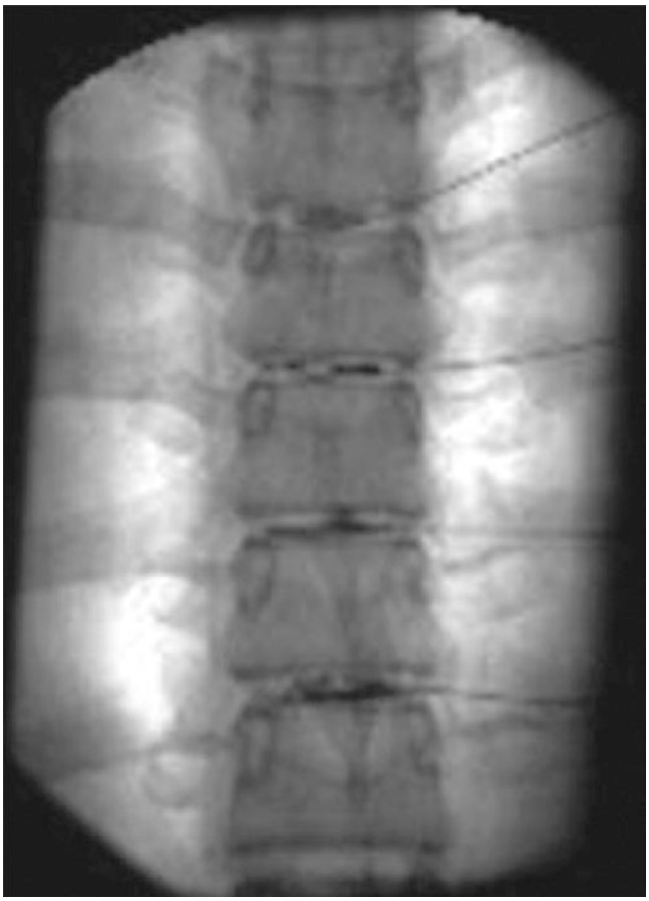

Fig. 16.23 AP view with contrast in the thoracic discs

Post-Procedure Care

Patients should be observed for at least 30–60 minutes following the procedure and instructed not to drive until the next day following the procedure. If needed, patients should be provided with post-procedure analgesia. Advise patients to call if they experience symptoms such as worsening pain, fever, chills, malaise, and night sweats within 1 week of the procedure, which could indicate a disc infection. Shortness of breath could indicate pneumothorax. Note: Discitis symptoms, which are typically severe back pain, may not appear for weeks to months after discography [10, 28, 76].

Interpretation and Documentation

The disc pressure (discometry or manometry) at the onset of pain during lumbar discography can be measured and recorded with a pressure gauge in pounds per square inch (psi). As mentioned above, manometry provides additional objective measure and its use in lumbar discography is gen-

erally considered standard of care. Manometry is infrequently used in cervical and thoracic discography.

Painful lumbar discs can be categorized into one of four categories with the aid of manometry [28]:

1. Normal discs: no pain
2. Chemically sensitive disc: pain <15 psi above opening pressure
3. Mechanically sensitive disc: pain >15 psi and < 50 psi above opening pressure
4. Indeterminate disc: pain >50 psi above opening pressure

Derby and colleagues [17] found that patients with chemically sensitive discs had better outcomes with interbody fusion when compared with intertransverse fusion or nonoperative treatment.

The pain level reaction reflects the pain intensity experienced by the patient during the injection regardless of whether the pain is concordant or discordant. The intensity is graded verbally on a numeric pain rating scale, often using 10 as the greatest degree of pain and 0 as no pain at all.

The pain quality is crucial because it establishes whether pain provoked during the procedure mirrors the pain experienced by the patient. The pain can be vague and discordant, partly concordant, (i.e. merely a component of their typical pain), or an exact reproduction of the patient's concordant pain.

Strict diagnostic criteria are crucial for discography as it is a provocational study; as such, it is inherently prone to the challenges of objectivity. Subjective patient input, the previous lack of standardization, and questionable specificity have fuelled debate among proceduralists [12, 17, 38, 42, 86–88]. The resultant discussions among peers have helped to advance the standards and ultimately the objective measure of discography.

The specificity of discography has historically been a source of controversy. However, data from a recent meta-analysis were able to demonstrate that lumbar discography adhering to updated practice guidelines is associated with a low false-positive rate [51]. A recent Wolfer et al. [42] meta-analysis of all completed data sets involving subjects asymptomatic for lower back pain using ISIS/IASP guidelines found a false-positive rate of 9.3% per patients and 6.0% per disc.

Others have been able to demonstrate a similarly low false-positive rate with cervical and thoracic discography. Schellhas et al., [35] in a study of 40 cervical discs in asymptomatic patients, there were no pain responses. Wood and colleagues [89] found that of asymptomatic volunteers 3 of 40 (7.5%) injections were painful. However, all three of these discs demonstrated prominent Schmorl's nodes, and the provoked response was unfamiliar and nonconcordant.

Strict diagnostic guidelines and procedural modifications have clearly increased the diagnostic accuracy of discography. However, controversy remains. Carragee has published multiple papers questioning the validity of discography. His works have suggested that discography may result in misdiagnosis, unnecessary surgery, and potentially accelerate disc degeneration [42].

Carragee demonstrated high false-positive rates of 40% in a sample of 20 post-discectomy or post-laminectomy patients who were asymptomatic at the time of discography [87]. These results are considered by many to be heavily influenced by the study's patient population and Carragee's use of higher-pressure cut-offs [82]. Greater than 75% of his patient sampling had somatization disorder. Discography is ultimately a subjective test as patient participation is a required component. Therefore, caution is needed when interpreting discography response in patients with low pain tolerances or in those with abnormal psychometric profiles. Secondly, this particular observational study was taken from a population who had previously undergone lumbar spine surgery in the form of discectomy or laminectomy. The results demonstrate a high likelihood of having a positive discogram at a previously operated level for both symptomatic and asymptomatic groups alike. False-positive rates may indeed be disproportionately higher in post-discectomy patients. This does not invalidate its efficacy but rather it implies that extra care should be taken when interpreting discography outcomes in these patient populations.

In 2009, prospective longitudinal cohort data were published to investigate the long-term impact of discography by comparing MRI indices in individuals who had undergone discography with matched controls [41]. A cohort of 75 subjects were followed for 7–10 years after baseline workup. The research group showed that individuals who received discography were subsequently found to have higher rates of lumbar disc degeneration, lumbar disc herniation, spine surgery, significant lower back pain episodes, and more medical follow-up compared to the control group [41].

Deeper review found that for the sample sizes used in this study the confidence intervals between study and control groups overlap with regard to higher levels of disc degeneration and Modic changes and are therefore not likely to be statistically significant [40]. Foraminal disc herniations were found to be 2–5 times more common in the post-discography group. However, the rates of foraminal herniation in the general population are nearly equivalent with those found in his treatment group, while his control group was curiously less affected [40]. A similar trend was observed with regard to the prevalence of Modic changes. The control cohort had significantly lower rates of Modic changes (11%) compared to those found in the general population (36%) [9]. Other questions arose with regard to this study's substantial loss to follow-up, lack of adherence to current SIS/IASP procedural guidelines, and the exclusion of appropriate discography candidates [9]. The loss to follow-up rate was substantial.

While a high attrition rate is generally expected in long-term clinical studies, the loss to follow-up was reported as high as 30% in the 2009 data [9]. The magnitude of this attrition rate significantly impairs the ability to comment on true patient outcomes [9]. With regard to procedural technique, inappropriately high disc pressures were produced in a majority of subjects. In fact, 96% of subjects were subjected to pressures of 80 psi or greater. This is an important procedural error, as high disc pressures have been demonstrated to cause annular disruption [90].

Other long-term cohort studies have not demonstrated higher rates of disc degeneration associated with discography. In a small prospective study ($N = 36$), Pfirrmann scores in subjects with symptomatic low back pain who had undergone provocation discography with or without confirmation by intradiscal bupivacaine injection were compared with matched controls [91]. Ohtori et al. found that no significant difference in disc degeneration was observed on MRI between both groups at 3–5-year follow-up intervals. Similarly, a cross-sectional cohort study found no evidence of degenerative disc changes 10–20 years after discography [92]. However, radiography (not MRI) was used to assess degree of change. Without MRI to detect minute changes, it is hard to draw definitive conclusions from this longitudinal study. Data from a 7-year matched cohort study using MRI, likewise, found no relationship between progression of degenerative disc disease and provocative discography. In this study by McCormick et al., 66 discs exposed to provocative discography following SIS/ASIP guidelines were matched to a control cohort of patients with low back pain. There was no difference in proportion of punctured discs that advanced in Pfirrmann scores compared to matched cohort, nor was there a difference between puncture and nonpunctured discs within the provocative discography group. The same study also found no differences in T2-signal-intensity-to-CSF ratio, disc height, new disc herniations, new HIZs, or new Type 1 Modic changes in the group exposed to provocative discography [93].

Published animal data seem to suggest that disc puncture with small-gauge needles does not cause a progressive increase in disc degeneration, [9] These data seem even more relevant when considering needle size to disc height ratio in these smaller animal models [94].

In conclusion, Carragees' studies demonstrate that discography has false positives like any other diagnostic test. Abnormal psychometric testing and patients with previously operated discs have disproportionately higher false rates, and therefore, their results should be interpreted with caution. Likewise, strict adherence to SIS/IASP guidelines is important both to limit number of false positives and to limit risk of over-pressurization injury. The risk of progression of disc degeneration following provocative discography has not been reproduced in similar matched cohort studies. The findings of Carragee may have been influenced with methodologic flaws in study design, lack of adherence to current guidelines, and substantial loss to follow-up.

Complications

The overall complication rate for discography is quite low (i.e. estimated to be less than 1 per cent) [95]. Improved injection techniques, advanced imaging, and better contrast materials have all contributed to a decreased incidence of complications over time. Infection is a potential and well-recognized complication of any interventional procedure. The two most grave complications of discography are discitis and neural injury. Incidence of discitis has significantly declined after widespread use of prophylactic intradiscal and intravenous antibiotics. Likewise, the use of proper technique can avoid neural injury. A paraesthesia is a clear indication to the discographer to withdraw and redirect the needle. Overall reported complications associated with lumbar discography range between 0% and 2.7% of patients.

A retrospective analysis of 4400 cervical disc injections in 1357 patients, to assess the morbidity and mortality of cervical discography, was reported by Zaidman et al. in 1995. The authors found that less than 0.6% of the patients experienced a significant adverse event, and 0.16% of cervical discograms resulted in patient injury [96]. In a systematic review of cervical discography, Kapoor et al. found a discitis rate of 22 in 14,133 disc injections (0.15%) in 21 of 4804 patients (0.44%) [97].

Willems et al. reported on a case series of 200 lumbar discography patients (435 discograms) and also conducted a systematic review of the literature to identify discitis risk and assess the need for prophylactic antibiotics. In nine studies reviewed, the authors found an incidence of 12 cases of discitis in 4891 patients (0.25%) and 12,770 discs (0.094%) where clinicians had not used prophylactic antibiotics. In one study examined, where clinicians used prophylactic antibiotics in 127 patients, no cases of discitis were reported [98].

Thoracic discography is rare, and no recent analysis of complications for thoracic discography was identified. Pobiel et al. conducted a retrospective review of 12,634 discographies performed at all levels in 10,663 patients over a 12-year period. Of these, thoracic discographies were done on 1141 patients and 3083 discs. While 17 cases could not be completed, no instances of thoracic discitis occurred. At all spinal levels and procedures, only two patients experienced discitis, for an overall incidence of 0.016% [69].

Potential, although very rare, complications include:

- allergic contrast allergy
- bleeding

- bowel perforation
- bruising
- discitis
- epidural abscess
- increased pain
- meningitis
- myelopathy
- nerve root injury
- pneumothorax
- retroperitoneal structures, including the kidney and spleen
- subarachnoid puncture
- trauma to the spinal cord
- vagal response [10, 28, 31, 49]

Correlating Imaging with Discography

Disc degeneration is a ubiquitous term often meaning different things to different experts. The process by which a disc becomes painful has not be directly established [40]. The microenvironment within the disc shifts as ageing chondrocytes become less able to maintain the homeostasis of the matrix [99]. Cyclic loading, genetic, epigenetic, and metabolic environment all seem to play a role in disc degeneration [99]. However, age is the strongest correlate of degenerative changes [99]. The epidemiologic evidence demonstrates that these changes are not painful, and the moniker may in itself be a source of distress to patients [99].

Internal disc disruption is not an age-related phenomenon and is associated with axial pain [99]. The aetiology of internal disc disruption is fatigue failure occurring with cyclic loading with the subsequent recruitment of inflammatory cytokines and activation of metalloproteases [99]. Vertebral endplates are susceptible to fatigue failure when subjected to repeated compression loads as small as 50% to 60% of the ultimate tensile strength of the endplate [100]. The endplate can fracture after as few as 100 reps [40]. Stress profilometry can be used to detect and quantify endplate disruption. A pressure transducer is inserted across the diameter of the disc and slowly withdrawn, while intradiscal pressures are monitored. (Fig. 16.24).

Internal disc disruption generally demonstrates a characteristic profilometry profile with posterior endplate fractures [99]. Internal disc disruption is characterized by isolated radial fissures through the annulus fibrosis of lumbar intervertebral discs. These findings can be seen on post-discography CT imaging.

Rapidly advancing imaging technology provides the clinician with vast amounts of digital data; however, in the absence of clear clinical correlates, these data can quickly become a barrier to selecting patient appropriate therapy. Provocation discography remains the reference standard for the diagnosis of discogenic pain; however, it is reasonable to consider if the diagnosis can be established based on imaging alone.

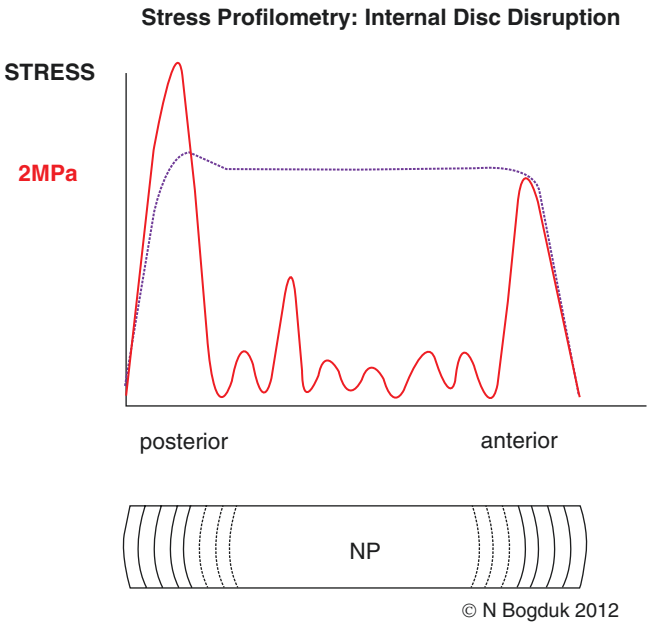

Fig. 16.24 Features of a normal disc and one affected by internal disc disruption (IDD) under stress profilometry. Graph showing the magnitude of stresses within the disc across a diameter as probe passes from the anterior annulus to the posterior annulus. In normal disc, the stresses are uniform. In a disc with IDD, the stresses in the nucleus pulposus are irregular, decreased, and may be zero, but the stress in the posterior annulus is increased substantially more than normal. (From: Bogduk [129]. By permission of Oxford University Press)

Many studies have been able to demonstrate that as disc degeneration advances so too does the potential for discogenic pain [101, 102]. In a population of symptomatic patients with axial pain considered discogenic in nature, severe loss of disc height has a specificity of at least 97% and a PPV of 90%. (Fig. 16.25).

O'Neill and colleagues were able to demonstrate that changes in disc contour, specifically disc bulge, were associated with a + LR of 5.3 [103]. Analysis of available data performed by Maus & Aprill in 2012 found that uniformly dark T2 signal with or without loss of disc height is a likewise a finding of high specificity (88–96%). Discs with severe T2 signal loss are rarely nonpainful. Endplate marrow changes were originally classified by Modic in 1988 [104]:

- Type 1 change represents ingrowth of vascularized granulation tissue into sub-endplate marrow. Type I Modic change exhibits hypointense T1 and hyperintense T2 signals on MR imaging.
- Type II change exhibits elevated T1 and T2 signals and reflects fatty infiltration of the sub-endplate marrow.
- Type III changes are hypointense on T1 and T2 and are likely representative of an area of bony sclerosis. Type III Modic changes are typically not associated with pain (B1).

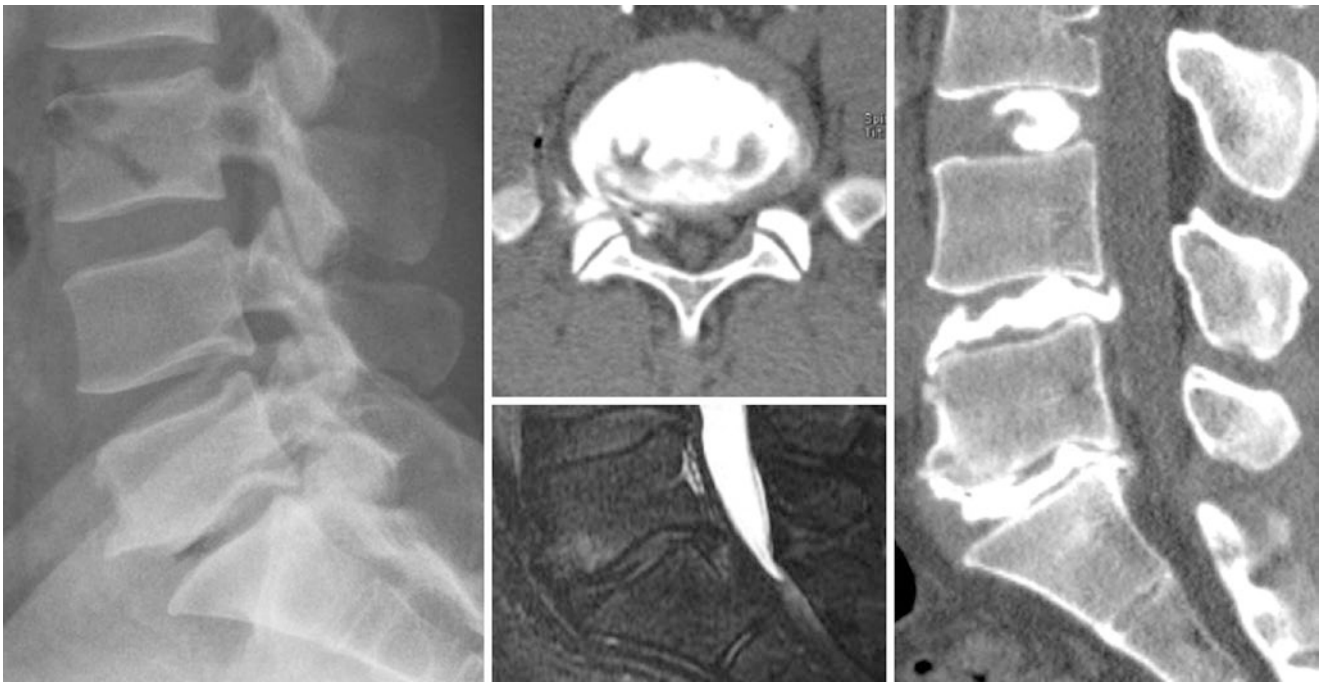

Fig. 16.25 Symptomatic patients who have severe loss of disc height and signal loss on MRI strongly correlate with a positive result on discography. L5 disc space narrowing, L4 nuclear signal loss in a patient with concordant pain at L4 and L5 on discography. (From: Maus and Aprill [106]; with permission from Elsevier)

Type I changes are felt to represent an active inflammatory state compared to type II or type III changes. Toyone and colleagues found that type I or type II Modic changes involving greater than 25% of the vertebral body strongly correlate with a positive result on provocation discography [105]. These findings were associated with high specificity, PPV, and LRs. (Fig. 16.26).

A high-intensity zone (HIZ) is believed to represent a complex grade 4 circumferential tear where nuclear material has been trapped within the annulus fibrosis [106]. The presence of an HIZ was found to have a sensitivity of 82% and a specificity of 89%. Additionally, an HIZ represents a LR of 7.3 [106] (Fig. 16.27).

These five structural changes correlate strongly with a positive result on discography. However, the presence of these features in the symptomatic patient population are rare and are generally felt to represent the advanced stages of internal disc disruption. The absence of these features does not preclude the disc as a potential source of pain. Additionally, some of these features may be seen in asymptomatic patients usually of advanced age [99]. On the opposite end of the spectrum, a normal disc on MRI is associated with high negative likelihood ratios [40, 106]. The normal discs on MRI are rarely painful. Although, a recent publication by Zucherman et al. demonstrated that a normal MRI can still surprise with a positive discography [107]. In synthesizing these data, it is reasonable to conclude that MRI is most helpful when characterizing the extremes of internal disc disruption. Intermediate MRI changes do not provide the clinician with definitive evidence for or against the possibility of discogenic sources of pain. Provocative discography continues to be the reference standard for the diagnosis of discogenic pain [106].

Uses of Discography in Regenerative Medicine

Our understanding of the cellular biology of the disc has advanced greatly over the last decade paralleled nicely by the development of new potential regenerative interventions. Despite these advancements, there are still gaps in our understanding of the pathogenesis of disc degeneration. The presumed aetiology of the degenerative process appears to be driven by changes in the behaviour of resident cells, which culminates in the loss of disc hydration, changes in the extracellular matrix, and ultimately changes in gross architecture and load-bearing potential [108]. The majority of this information has largely been extrapolated by examining discs taken at autopsy, removed during surgery, or from large animal studies [108, 109]. Here is a brief summary of the histopathologic changes that have been observed in the degenerative disc [108, 109]:

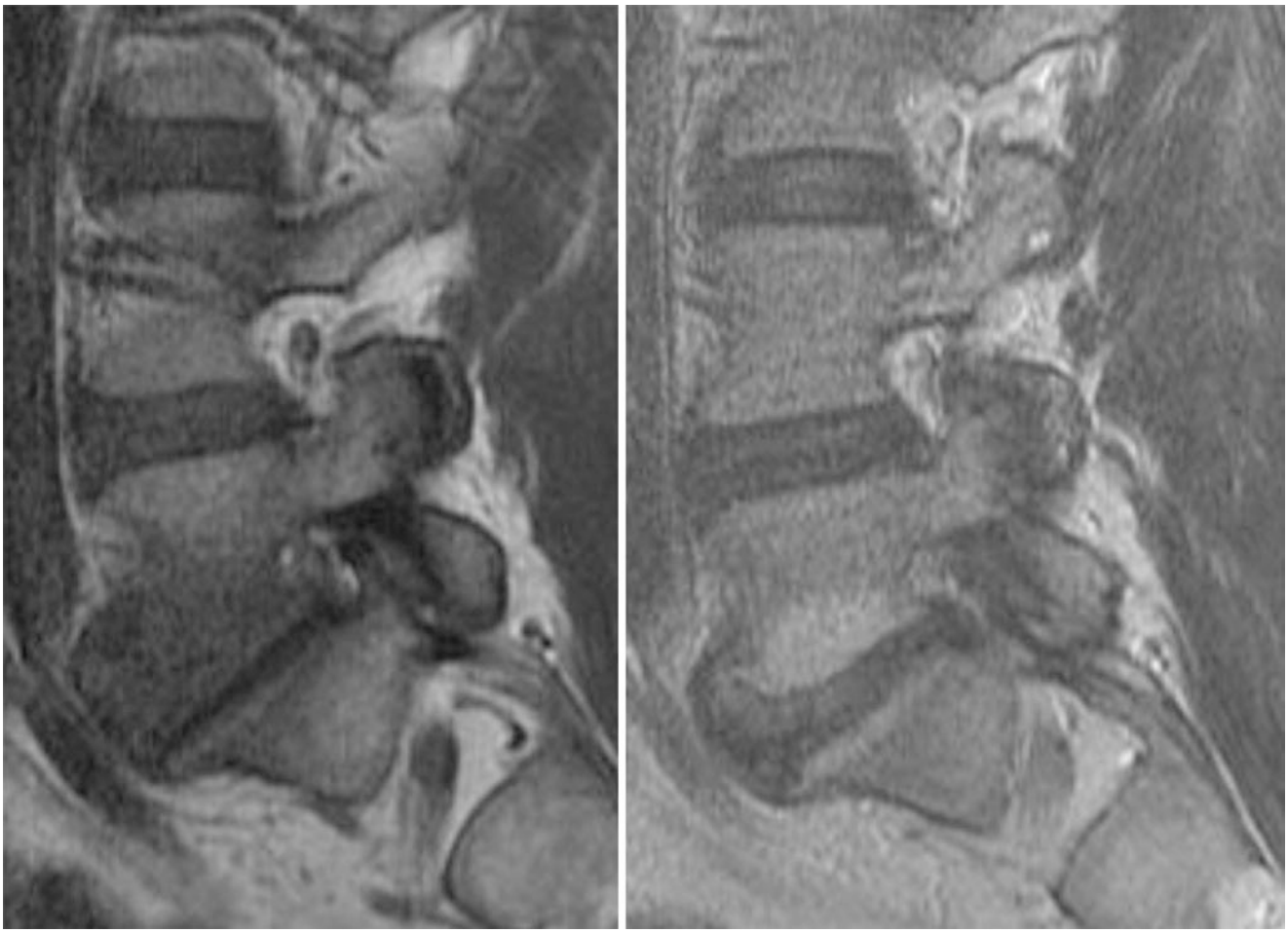

Fig. 16.26 L5 level demonstrating Type I Modic change involving >25% of vertical height of a vertebral body. (From: Maus [130]. Copyright International Spine Intervention Society 2015; used with permission)

- Markedly higher concentrations of proteases (i.e. aggrecanase and metalloprotease)—Macromolecular degradation outpaces the macromolecular synthesis [108]
- Decreased aggrecan (a large polyanionic proteoglycan with a high osmotic pressure [110])—with less of this proteoglycan, there is less osmotic potential. Disc desiccation ensues.
- Lamellar disorganization—the discs lose structural integrity and load-bearing potential [108]
- Cartilaginous endplates calcify—decreasing nutrient transport to cells [111]
- Angiogenesis and neurogenesis occur in response to cellular damage/stress—healthy discs are generally avascular aneural structures [108]
- Recruitment of inflammatory cells (i.e. macrophages) is amplified by angiogenesis—healthy discs are generally avascular and therefore are relatively nutrient poor. Higher concentrations of more metabolically active macrophages deplete native nutrient pools quickly. Glucose and pH decrease [108]
- Inflammatory cytokines at higher concentrations due to larger populations of inflammatory cells in the degenerated disc—this upregulates matrix degradation and exacerbates nutritional stresses [108]
- Decrease in viable and functional cell numbers, with large populations of senescent cells—calcified cartilaginous endplates greatly limit the recruitment of new cells. Specific chemokines, CCL5, and CXCL6 are upregulated and play a role in cellular recruitment [108] (Fig. 16.28)

Cell therapy in the form of mesenchymal stem cells (MSCs), bone marrow aspirate concentrate (BMAC), and platelet-rich plasma (PRP) have shown great potential to slow or even potentially reverse the degenerative process before major structural changes occur [112]. Svanvik et al. found that MSCs co-cultured with native IVD cells have the potential to differentiate towards chondrocyte-like cells that are phenotypically similar to those found within the NP of the disc [113]. These cells are capable of mobilizing endogenous populations of stem/progenitor cells, stimulating ana-

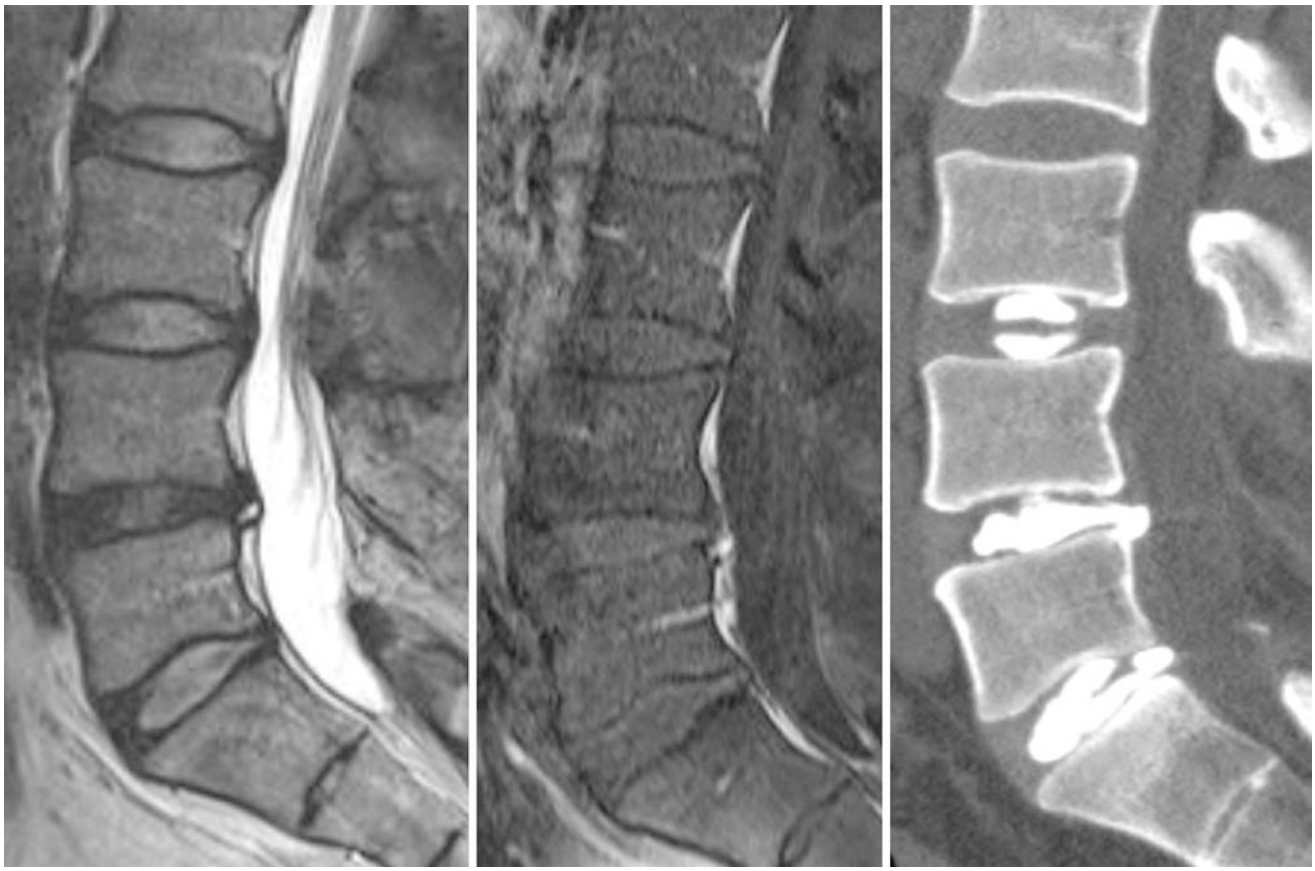

Fig. 16.27 L4 level demonstrating presence of a high-intensity zone (HIZ) and subsequent positive discogram at that level. (From: Maus and Aprill [106]; with permission from Elsevier)

bolic processes, and dampening inflammatory activity [114]. These observations highlight the potential therapeutic benefits of intradiscal MSCs in preventing and possibly even reversing the early steps of the degenerative cascade. Early data for cellular regenerative therapy using various animal models have been promising [115] (Fig. 16.29).

Likewise, positive outcomes have been achieved with human disc cells or mesenchymal stem cell transplantations into porcine models [113]. Mesenchymal stem cells seem to demonstrate some ability to interact with resident cell populations, regulate local homeostasis, and attract additional cells. Stem cells have demonstrated in vitro chondrogenic differentiation potential and may, therefore be, capable of stimulating new ECM; however, the regenerative potential seems to be limited to reversing or slowing earlier degenerative changes before structural remodelling can occur [113]. More research is needed to determine the precise point at which biologic therapy is likely to be of little use. Additional concerns regarding safety and efficacy remain, and much more data are required before definitive statements can be made.

Conclusion

Discography has become an indispensable tool in the evaluation of spinal pain [38, 116–118]. The differential diagnosis when evaluating patients with back pain is broad, and the disc is a common potential culprit. The clinical picture is further complicated by ubiquitous age-related degenerative changes [99]. These changes accumulate and do not necessarily implicate a specific source of pain. There are a handful of radiologic findings which strongly implicate discogenic pain; however, these are rare and may potentially be present in asymptomatic patients. Discography continues to be the reference standard for diagnosing discogenic pain. There are both historical and current controversies surrounding its use [17, 38, 42, 87, 88, 119]. This has generated healthy discussion and advanced the standards of this diagnostic procedure. The use of manometry, sham injection, and strict criteria for identifying positive discs are all intended to limit the likelihood of a false-positive result. It is acknowledged that discography has been interpreted with caution in patients with certain behavioural pathology.

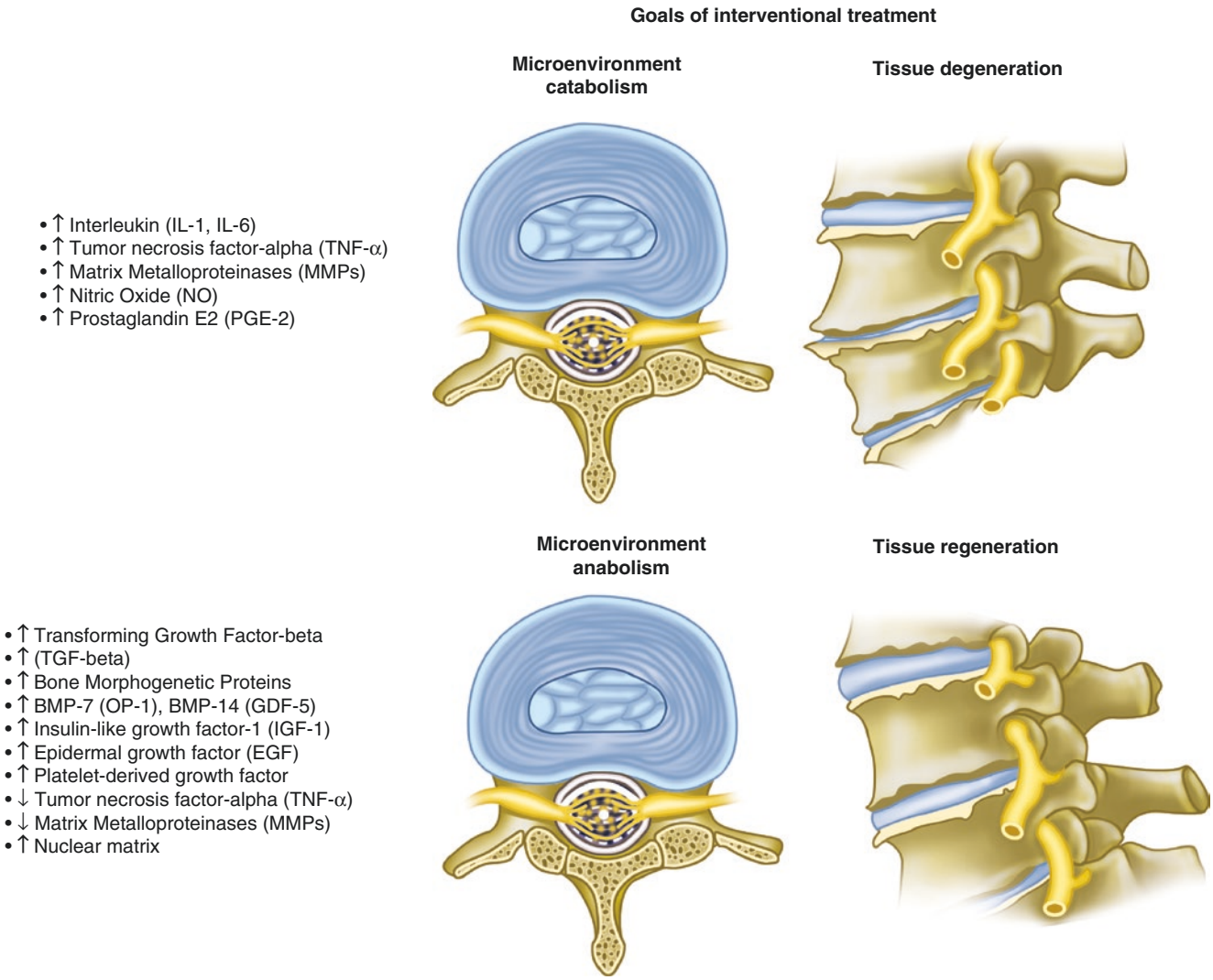

Fig. 16.28 Figure 19.28 Goals of interventional treatment are to improve the microenvironment of the disc to allow for tissue regeneration. (**a**) Increasing inflammatory cytokine favours the development of a catabolic microenvironment. Goals of biologic therapy are to down regulate the production of inflammatory cytokines in order to decrease catabolic activity and (**b**) up regulate extracellular matrix proteins that increase anabolic activity

There is an expanding role for new, minimally invasive spinal interventions for the treatment of painful discogenic back pain. Emerging biologic therapies in the form of cellular replacement or cell-rich scaffolding offer potentially therapeutic options where previously there were none. These potential treatments demand a sensitive diagnostic test to select appropriate potential candidates. Discography is the current standard. However, new noninvasive diagnostic modalities are currently being developed. Magnetic resonance spectroscopy (MRS) is a noninvasive study being used to characterize in vivo metabolic features within tissues in several clinical [120]. Keshari and colleagues were able to demonstrate that certain disc chemicals specifically lactate and proteoglycan can provide spectroscopically quantifiable biomarkers for discogenic pain [120]. These biomarkers have well-documented features of the degenerative disc microenvironment. Early data suggest that MRS may be a highly specific screening modality for patients with discogenic sources of pain. MRS as it is used to work up discogenic pain is in the early stages of development, and it may yet be many years before this technology experiences widespread clinical use.

It is the authors' contention that discography when used in conjunction with radiographic imaging is the preferred method to evaluate the lumbar disc as a potential source of axial back pain. Discography can help clarify the clinical picture, identify which patients may benefit from novel regenerative techniques, and guide surgical intervention.

When using a diagnostic test to select patients for treatment, the accuracy of the test is important [121–124]. A rela-

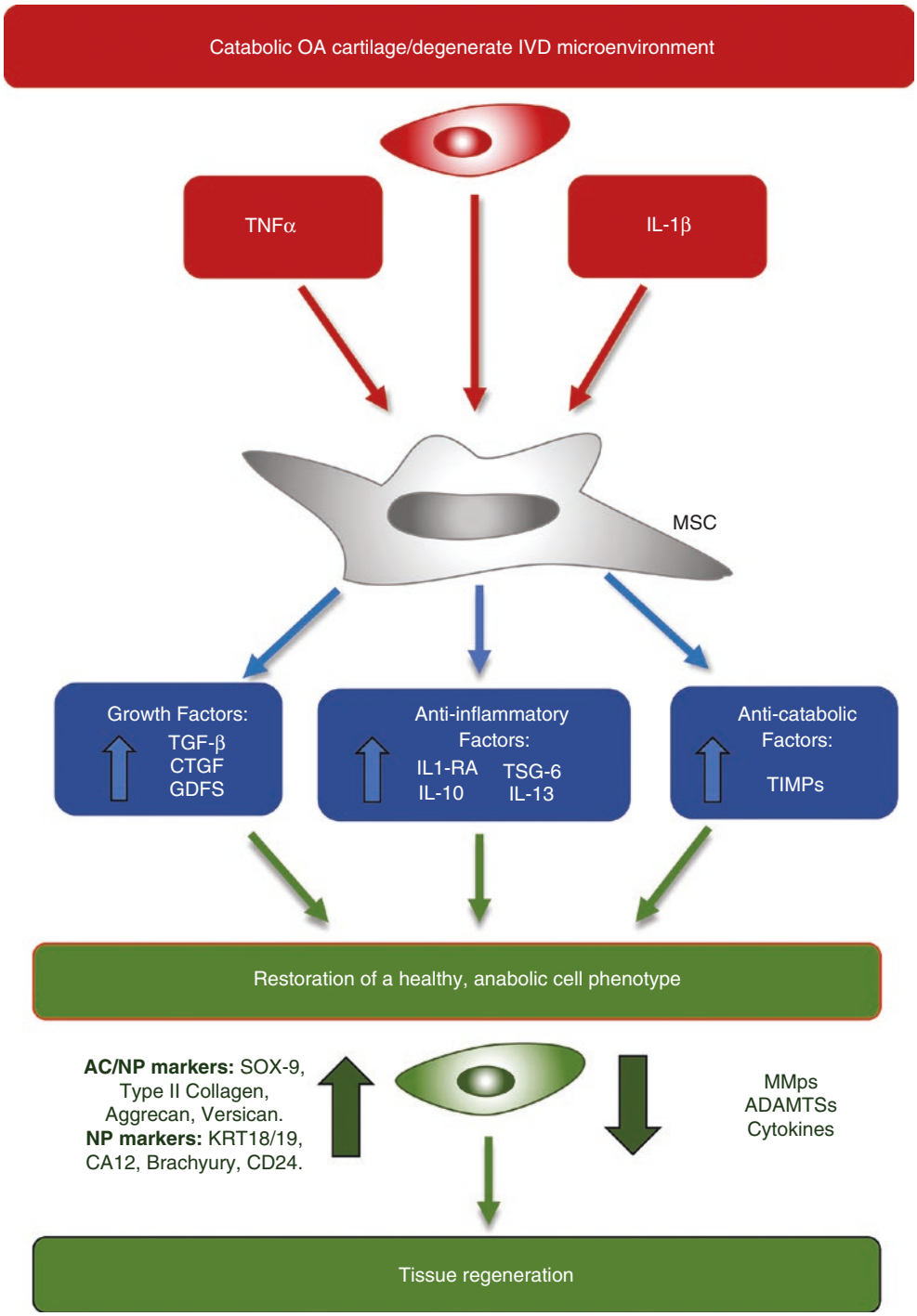

Fig. 16.29 Catabolic environment of the painful degenerative disc is associated with increased levels of pro-inflammatory mediators. Regenerative biologics may help restore a healthy, anabolic phenotype. (From: Richardson et al. [131]; with permission of Elsevier)

tively inexpensive and low-risk procedure such as an intradiscal biologic favours the use of a highly sensitive screening test. If the diagnosis is missed, the patient may be subject to more costly and invasive treatments such as surgery. A test with high specificity and positive predictive value is preferred for more costly and risky intervention including spine fusion. This would reduce unnecessary exposure to risk for the patient.

There are potential limitations associated with any interventional procedure, discography notwithstanding. A positive level on discography does not rule out the presence of other sources of pain; it does not prove the clinical significance of the pain, nor guarantee interventional or surgical outcome. A negative discogram effectively rules the disc out as a pain generator. It has diagnostic utility and negative predictive value. It acts as a barrier to excessive surgery and disc-related intervention and provides closure.

The lumbar intervertebral disc is a common cause of chronic lower back pain. Discography can accurately iden-

tify appropriate candidates for current and future intradiscal or subchondral therapies [125]. The skill set for performing discography includes disc access, which is needed for any intradiscal injection procedure.

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