Current Concepts Review

Current Concepts Review - The Use of Radiographic Imaging Studies in the Evaluation of Patients Who Have Degenerative Disorders of the Lumbar Spine*

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The previous two decades have resulted in substantial technological advancements in neuroradiological imaging. New non-invasive imaging modalities have been developed and existing modalities have been refined, rendering exploratory operations on the spine obsolete. The ubiquitous availability of modalities for improved anatomical visualization of the spine, however, may lead to overutilization and inappropriate application in an area such as lumbar degenerative disorders, which may affect 60 to 80 per cent of the population.

Errors in clinical decision-making after radiographic investigation of the lumbar spine may arise in one of three general areas: (1) the timing of the application of the study during the patient's clinical course, (2) the matching of the clinical indications to the choice of the optimum imaging study, and (3) the precise correlation of the abnormalities seen
on imaging with the clinical symptoms. The goals of this article are to review the general principles of imaging of the spine and to discuss each within the context of the most common clinical presentations of degenerative spinal disorders: low-back pain, pain in the lower limb, and pain after spinal procedures.

As with any diagnostic test, the ideal time to perform an imaging study of the lumbar spine is when the information that is obtained will affect the treatment plan. The appropriate timing may vary according to the diagnosis and patient-related factors. Because of the continuously changing anatomy (such as the shrinking of disc herniations and degenerative changes in the marrow), imaging studies should not be performed prematurely. Major resorption of a herniated lumbar disc can occur in just a few months, rendering the imaging study outdated as a guide for operative planning.16,34

I believe that diagnostic imaging studies should be used to confirm the information gathered from a thorough history and physical examination. As a rule, advanced neurodiagnostic imaging studies should not be used for general screening in the absence of a working clinical diagnosis nor should they be used in place of a careful physical examination. Most imaging modalities are highly sensitive and relatively unselective. "Let's get a magnetic resonance imaging scan to see if there is anything wrong with the spine" is the beginning of a dangerous thought process. This danger arises from the high prevalence of abnormal findings on images of asymptomatic individuals.12 (Fig. 1). Excessive reliance on diagnostic studies without precise clinical correlation can lead to erroneous or unindicated treatment of degenerative disorders of the lumbar spine.
To assess the clinical performance of any diagnostic study, the physician must know its sensitivity and specificity. Sensitivity is expressed as a percentage and is derived by dividing the number of true-positive results by the sum of the true-positive and false-negative results and multiplying by 100. Sensitivity is a reflection of the false-negative results, or the ability of the test to detect disease when it is present. More relevant to the avoidance of overtreatment is specificity, which is a reflection of the false-positive results, or the ability of the test to remain negative in the absence of disease. Specificity is expressed as a percentage and is derived by dividing the number of true-negative results by the sum of the false-positive and true-negative results and multiplying by 100. The false-positive rate of diagnostic imaging tests of the spine has most often been measured in a population of symptomatic patients who have had an operation to confirm the imaging findings. However, this can lead to an underestimation of the actual rate of false-positive results because it does not take into account the frequency of abnormal findings in asymptomatic individuals. It is helpful to understand the frequency and spectrum of abnormalities that can be seen on images without causing symptoms, in order to best interpret such findings in symptomatic patients who have a degenerative disorder of the spine (Table I).

Other measures of the performance of diagnostic studies include the over-all accuracy and the predictive values. Accuracy is expressed as a percentage and is derived by dividing the sum of the true-positive and true-negative results by the total number of tests and multiplying by 100. The positive predictive value is expressed as a percentage and is derived by dividing the number of true-positive results by the sum of the true-positive and false-positive results and multiplying by 100. The negative predictive value is expressed as a percentage and is derived by dividing the number of true-negative results by the sum of the true-negative and false-negative results and multiplying by 100.
Acute Low-Back Pain
The prognosis for patients who have acute low-back pain that is treated non-operatively is so favorable that imaging studies are rarely needed\textsuperscript{89}. Imaging is not necessary during the first six weeks if the patient does not have neurological findings, constitutional symptoms, a history of traumatic onset of the symptoms or of a malignant tumor, or an age of more than fifty or less than eighteen years. After six weeks, if no clinical improvement has occurred, plain anteroposterior and lateral radiographs may be made. The goal is to rule out tumor, infection, instability, spondyloarthropathy, occult osteoarthrosis of the hip, and defects of the pars interarticularis. If the latter is suspected, oblique radiographs may be helpful, and the findings may be confirmed with a computed tomography scan. Degenerative changes, such as narrowing of the disc space, traction osteophytes, vacuum-disc phenomenon (a radiolucent area within the intervertebral disc space), and end-plate sclerosis, are common in older individuals but have demonstrated a poor correlation with clinical symptoms\textsuperscript{104-107,111}.

In patients who have mechanical low-back pain (pain that is worsened by an erect posture and activity and that is relieved by recumbency), instability at a spinal motion segment may be seen on lateral flexion-extension radiographs\textsuperscript{84,99}. Radiographic instability is often difficult to measure accurately, and there is still some debate as to whether radiographs made while the patient is bearing weight or is recumbent are optimum for the observation of motion\textsuperscript{1}. The inaccuracy of measurements obtained from uniplanar radiographs often prevents the detection of motion. Another difficulty lies in the definition of the limits of instability. Attempts have been made, in both cadaveric and \textit{in vivo} studies, to resolve this issue, and the current consensus is that more than three millimeters of relative motion (sagittal translation) may be abnormal in the lumbar spine\textsuperscript{11,82}. Radiographic instability can also be observed as excessive angular rotation, but this has been less well studied.
In the absence of clinically relevant findings on plain radiographs, a normal radionuclide bone scan, made with technetium-99m-labeled polyphosphate, can be helpful in confirming the absence of occult tumor, infection, or fracture. As many as 40 per cent of patients who have metastatic disease and normal plain radiographs have abnormalities on bone scans. In patients who have low-back pain, bone-scanning with single photon emission computed tomography of the lumbar spine may allow the visualization of lesions not seen on planar images. In a study of thirty-four patients who had back pain, twenty-seven had a lesion that was seen on single photon emission computed tomography. Of these twenty-seven, twenty-four (89 per cent) had abnormalities on computed tomography and only eighteen (67 per cent) had abnormalities on plain radiographs. Single photon emission computed tomography allowed identification of fifty-four lesions, of which only twenty (37 per cent) were detected on planar bone scans. In a study of twenty-six patients who had had a previous osteoporotic compression fracture and had chronic back pain, degenerative facet disease at the level cephalad to the compression fracture was identified as the cause of the pain in twenty-one (81 per cent). While bone-scanning is extremely sensitive for locating areas of increased bone turnover, it usually does not yield a specific diagnosis and may serve only as a guide for determining the necessity of and the locations for additional diagnostic studies.

Only rarely is the early management of patients who have low-back pain changed because of the results of magnetic resonance imaging scans, provided that infection, tumor, and fracture have been ruled out. Furthermore, there is a high prevalence of age-related abnormal findings that are unrelated to the etiology of the pain; these findings may create a picture of spinal deterioration that needs repair and the perception of a damaged self (Table II). These perceptions are not helpful for the psychological state of a patient who has low-back pain. Finally, since invasive treatments for recalcitrant low-back pain are generally not
contemplated for at least six months after the initiation of non-operative treatment, a magnetic resonance imaging scan that is made early for a patient who has non-radiating low-back pain without neurological deficit is likely to be outdated by the time that additional invasive diagnostic tests or treatments are considered.

**Chronic Low-Back Pain**
Radiographic evaluation of patients who have low-back pain of more than six months' duration must first rule out the presence of a missed fracture (of the pars interarticularis, pedicle, or vertebral body), tumor, and instability. In such patients, magnetic resonance imaging is the most sensitive and least invasive test for providing this information. T1-weighted spin-echo images may show a hypointense signal in the pars interarticularis before an abnormality is detected on plain radiographs or computed tomographic scans. In addition, on magnetic resonance images, changes in the marrow signal intensity of the pedicle adjacent to the spondylolytic defect can be observed in a specific age-related pattern that resembles the changes in the marrow signal seen adjacent to a degenerated intervertebral disc. Although segmental instability is often detected at lumbar disc levels that appear normal on magnetic resonance imaging scans, a characteristic signal pattern for the adjacent bone marrow has been described in patients who have instability. In a study of magnetic resonance imaging scans of seventy-four patients who had degenerative lumbar-disc disease, Toyone et al. identified two patterns of marrow changes; hypermobility was observed in twenty-six (70 per cent) of thirty-seven patients who had decreased marrow signal intensity and in only six (16 per cent) of thirty-seven who had increased marrow signal intensity.

Magnetic resonance imaging is the best imaging modality for the assessment of degeneration of an intervertebral disc. Disc degeneration may be manifested as a decreased signal intensity within the nucleus.
pulposus on T2-weighted images, as annular bulging, or as an annular tear. The most commonly involved lumbar levels are between the fourth and fifth lumbar vertebrae and between the fifth lumbar and the first sacral vertebrae.

The intervertebral-disc nucleus signal appears bright (white) in a healthy young disc and may progress to a speckled or eventually dark appearance on T2-weighted magnetic resonance imaging sequences. These changes are thought to represent biochemical degeneration resulting from decreased proteoglycan and water content within the disc. There is some diurnal variation in the signal intensity of the disc, which may correlate with changes in hydration as it is unlikely that proteoglycan content could vary that rapidly. Muscle degeneration seen as focal fat deposits has also been noted to increase with age.

The prevalence of intervertebral disc degeneration has been estimated on the basis of magnetic resonance imaging scans of asymptomatic individuals. In a study of sixty-seven asymptomatic subjects, my colleagues and I found that twelve (34 per cent) of thirty-five subjects who were between twenty and thirty-nine years old and all but one of fourteen who were between sixty and eighty years old had degeneration at at least one disc level as seen on T2-weighted magnetic resonance imaging scans. In a similar study, fifty-one (52 per cent) of ninety-eight asymptomatic individuals had a bulging disc at at least one lumbar level. Magnetic resonance imaging scans can also demonstrate tears in the annulus fibrosus, but the clinical importance and natural history of such lesions are poorly understood.

Changes in the signal intensity of intervertebral discs on magnetic resonance imaging scans are often accompanied by a series of progressive changes in the signal intensity of the adjacent vertebral bone marrow on either side of the involved disc. Modic et al. identified three patterns: type-I changes, consisting of decreased signal intensity on T1-weighted spin-echo images and increased signal intensity on T2-
weighted images\textsuperscript{69}; type-II changes, consisting of increased signal intensity on T1-weighted images and isointense or slightly increased signal intensity on T2-weighted images\textsuperscript{69}; and type-III changes, indicated by a hypointense signal (often seen as end-plate sclerosis on plain radiographs) on both T1 and T2-weighted images\textsuperscript{68} (Table III).

After magnetic resonance imaging has been performed for a patient who has chronic low-back pain, it must be decided whether to proceed to a provocative imaging study such as discography, in an effort to isolate one or two intervertebral discs as the specific source of pain. Reproduction of concordant pain (the patient's typical back pain) on blinded injection of radiographic contrast medium, with a negative pain response at at least one control disc level, is considered to indicate a positive discogram\textsuperscript{90}. Coupling of the pain response with extravasation of contrast medium on plain radiographs or on computed tomographic scans made after discography is also an important component of this test\textsuperscript{65,103,112,113}. Ruptures of the outer portion of the annulus fibrosus may have the best correlation with reproduction of concordant low-back pain\textsuperscript{70}. Discography is superior to computed tomography alone or to myelography for the identification of disc degeneration and tears of the annulus fibrosus\textsuperscript{5,43,67}, and it also may be superior to magnetic resonance imaging for the identification of tears of the annulus fibrosus\textsuperscript{125}. An early study by Holt suggested that twelve (40 per cent) of thirty asymptomatic subjects (twenty-seven [38 per cent] of seventy-two discs) had an abnormal discogram\textsuperscript{49}. Re-analysis of these data highlighted the fact that only abnormal disc morphology, and not the important criterion of concordant pain reproduction, was tabulated\textsuperscript{94}. More recently, Walsh et al. performed discography in ten young asymptomatic subjects and found that, while five had radiographic evidence of abnormalities of the intervertebral disc, none had a major pain-provocation response\textsuperscript{116}. While the false-positive rate may be low, it is also possible to have a
false-negative discogram; this occurs most commonly when the abnormality is limited to the outer portion of the annulus fibrosus. With the advent of magnetic resonance imaging, it was originally thought that individuals who had a normal scan would not need discography. Unfortunately, there have been an increasing number of reports of abnormal discograms at levels that appeared normal on magnetic resonance imaging scans.

Horton and Daftari showed that certain patterns observed on magnetic resonance imaging scans are more or less likely to be associated with a negative pain-provocation response on discography; only one of eighteen white (bright) discs had a positive discogram, compared with seven of twelve dark discs with a torn or bulging annulus fibrosus. Despite the seemingly rational use of discography to provoke a pain response in a patient who has a damaged disc, the clinical results in patients who have had a spinal arthrodesis on the basis of a discogram have been unpredictable. Although the rate of complications with use of this test is low, its utility in determining which patients will benefit from an arthrodesis remains to be validated in a prospective trial.

Patients who have pain in the lower limb or sciatica, with or without low-back pain, need a different approach to diagnostic imaging than those who have predominantly low-back pain. Neurodiagnostic imaging is indicated only if there has been spinal trauma, if a tumor or infection is suspected, if there is a cauda equina syndrome with loss of bowel or bladder control, or if there is progressive neurological loss or a pattern inconsistent with a monoradiculopathy. Thus, the overwhelming majority of patients who have pain in the lower limb, including those who have intermittent neurogenic claudication, are managed non-operatively for at least six to eight weeks. The most common causes for pain in the lower limb are a herniated nucleus pulposus and lumbar spinal stenosis, and the optimum sequence of the imaging studies depends on which diagnosis is most likely as well as on the quality and availability of magnetic resonance imaging.
Plain radiographs are rarely useful in the initial assessment of patients who have pain in the lower limb. If there is no response to non-operative treatment, then identification of spondylolisthesis, hypertrophy of a facet joint, congenital stenosis, tumor, or infection may be possible, but these diagnoses are easily made with use of other tests that provide more definitive information about the presence, severity, and location of neural compression. Computed tomography essentially replaced myelography in the 1980's as the study of choice to confirm a herniated lumbar disc. In one study of 461 patients, myelography was compared with computed tomography with regard to sensitivity (82 and 73 per cent, respectively), specificity (67 and 77 per cent), and positive predictive value (93 and 94 per cent). Other studies have shown the accuracy of myelography (77 per cent) to be comparable with that of computed tomography (82 per cent). Computed tomography has improved the detection of far lateral disc herniations (disc herniations that are lateral to the neural foramen) and has eliminated the complications associated with myelography. However, in a study of fifty-two asymptomatic individuals, a herniated disc or spinal stenosis was found in twelve (23 per cent). While computed tomography alone used to be the study of choice to confirm the diagnosis of herniation of an intervertebral disc, I do not believe that this modality provides adequate information unless it is combined with myelography. This combination increases the diagnostic accuracy compared with that of either study alone.

For patients who have pain in the lower limb and a strong history of progressive neurogenic claudication, I prefer myelography followed by computed tomography. My rationale for choosing this combination rather than magnetic resonance imaging for patients who have spinal stenosis is the improved visualization of bone and hypertrophic spurs, as well as the ability to obtain information on the size and anatomy of the pedicles, which may be useful in the planning of an operative reconstruction. In addition, my impression is that there is a tendency for
magnetic resonance imaging, particularly T2-weighted sequences, to lead to an overestimation of neural compression. Finally, a myelogram provides the added benefit of demonstrating compression of the thecal sac that is severe enough to result in a functional block of contrast material (or cerebrospinal fluid) through the stenotic area. Newer magnetic resonance pulse sequences will make it easier to assess the dynamics of cerebrospinal fluid flow.

For patients who have a history of and physical findings consistent with a herniated intervertebral disc, magnetic resonance imaging has proved to be the most accurate study for demonstrating the anatomy of the cauda equina and the presence of a herniated disc. As with all imaging studies of the spine, magnetic resonance imaging scans should be used to confirm the clinical diagnosis only for patients who have not responded to non-operative management and immediately before the operative intervention. The justification for this is twofold: disc herniations tend to diminish in size over time so a scan that is made too early may no longer be accurate, and there is a 28 percent prevalence of herniated discs in asymptomatic individuals so a disc herniation that is visualized may or may not be the source of a patient's pain. This problem of abnormal scans in asymptomatic individuals highlights the limitations of the use of magnetic resonance imaging of the lumbar spine as a screening tool as well as the importance of precise correlation of the imaging findings with the clinical signs and symptoms before invasive treatment.

In an effort to distinguish symptomatic from asymptomatic disc herniations on magnetic resonance imaging scans, nerve-root enhancement after administration of gadolinium contrast medium has been studied. Several authors have reported a strong correlation between intrathecal nerve-root enhancement and radicular symptoms caused by herniated lumbar discs. An animal study suggested that nerve-root enhancement with use of this test is associated with inflammation and disruption of capillary endothelium. Of 115 patients who were
managed with a discectomy for a herniated disc, forty-five (39 per cent) had nerve-root enhancement preoperatively, compared with sixty-eight (59 per cent) postoperatively; there was no correlation with postoperative radicular pain\textsuperscript{100}. In a study of thirty asymptomatic subjects who had magnetic resonance imaging, eighteen had nerve-root enhancement that was thought to be related to prominent radicular veins\textsuperscript{61}. Thus, at present, nerve-root enhancement is a potentially interesting phenomenon with unknown clinical relevance.

With the development of minimally invasive treatments for herniated discs, such as intradiscal enzyme therapy, percutaneous nucleotomy, arthroscopic discectomy, and endoscopically assisted transforaminal excision of the disc, the need to distinguish sequestered disc herniations from contained or subligamentous disc herniations is critical. Magnetic resonance imaging is the only imaging modality that can make this distinction reliably. Its accuracy in distinguishing between these types of disc herniations has been estimated to be 85 per cent, although in one report the rate was as low as 52 per cent\textsuperscript{59,66,93}. After injection of a gadolinium contrast agent, a sequestered fragment will often display a peripheral ring of enhancement that is due to surrounding inflammatory and scar tissue\textsuperscript{117,123}.

In patients who have pain in the lower limb, magnetic resonance imaging may also demonstrate two less common abnormalities: cysts in the synovial membrane of a facet joint and isthmic spondylolisthesis. Cysts of the facet joints occur most commonly at the junction of the fourth and fifth lumbar vertebrae and appear as a dorsal epidural mass of variable signal intensity\textsuperscript{53,63,121}. In all of seventeen patients who had isthmic spondylolisthesis, the shape of the neural foramen on sagittal magnetic resonance images was abnormal\textsuperscript{4}. In the thirty-three foramina that were examined, the appearance of the exiting nerve correlated with the side of the symptoms: eight had a normal-appearing nerve root; sixteen had a compressed nerve; and nine had disappearance of the fat signal, precluding identification of the nerve. This observation supports the
clinical impression that sagittal magnetic resonance images provide superior visualization of foraminal stenosis as compared with axial computed tomography or myelography.

Finally, while the use of discography for patients who have pain predominantly in the lower limb is not routinely advocated, there is one potential application. In a patient who has pain in the lower limb but no major disc herniation causing impingement or displacement of the nerve root, it has been postulated that a chemical radiculitis may result from leakage of irritants from the nucleus pulposus through an annular tear. In such a situation, discography may demonstrate extravasation of contrast medium at the correct level and side of the affected nerve root. The results of operative treatment of this problem, however, are unpredictable.

It has been estimated that 300,000 first-time laminectomies are performed annually in the United States, and as many as 15 per cent of these patients may have continued or recurrent pain and disability. Because most degenerative disorders of the lumbar spine are progressive, recognition of the unique issues involved in the imaging of patients who have had a previous operation is important.

The interpretation of images of the lumbar spine in such patients is more complex because of the superimposition, on the images, of normal postoperative changes with normal age-related degenerative changes. The primary objective in these patients is to distinguish between mechanical and non-mechanical causes of pain. The most common mechanical lesions are recurrent or residual herniated disc material, spinal instability (including pseudarthrosis after unsuccessful arthrodesis), spinal stenosis, and intervertebral discitis. These entities can all produce symptoms by exerting direct pressure on neural elements or
indirect pressure caused by excessive motion, and they are amenable to operative intervention.

The non-mechanical entities include scar tissue (intrathecal [arachnoiditis] or extradural [epidural fibrosis]), psychosocial problems, and systemic medical disease; these entities will not be improved by any type of additional operation\textsuperscript{36}.

**Back Pain**

Non-union of the site of a spinal arthrodesis is difficult to diagnose with use of non-invasive imaging. The presence of an asymptomatic non-union further complicates this problem. Iatrogenic instability caused by overextensive decompression or a postoperative stress fracture of the pars interarticularis may be slightly easier to diagnose. Plain radiographs, including oblique and flexion-extension radiographs, are of limited accuracy in documenting spinal motion\textsuperscript{28}. Stereophotogrammetry, which is not available in most centers, may help to document small amounts of motion\textsuperscript{72}. If internal fixation is in place, evaluation may be further complicated by obstruction of the fusion mass by metal implants. Even a loosened or broken implant does not always signify a non-union. Plain tomography may be useful in the observation of the trabecular bone pattern and the continuity of the fusion mass, and computed tomography (axial or three-dimensional reconstructions) may afford increased visualization of a lumbar fusion mass\textsuperscript{62}. In summary, plain radiographs are unreliable, and ultimately a high index of clinical suspicion and operative exploration may be the only certain approach for the diagnosis of a pseudarthrosis\textsuperscript{10}.

For patients in whom a postoperative infection of the disc space is suspected, magnetic resonance imaging is the diagnostic modality of choice. The usual clinical signs of fever, leukocytosis, and wound infection are seen in only a few patients, so clinical suspicion must be
high if the diagnosis is to be made. The challenge with regard to imaging is to be able to distinguish normal postoperative changes after an uncomplicated discectomy from the changes of a postoperative infection of the disc space.

My colleagues and I performed a prospective study of fifteen patients who had had an uncomplicated, successful lumbar discectomy and seven patients who had confirmed discitis. The magnetic resonance imaging finding that was most predictive of postoperative discitis was gadolinium enhancement of the adjacent vertebral bone marrow on each side of the affected disc space. This observation was part of a triad that also included decreased marrow signal on unenhanced T1-weighted sequences and increased signal on T2-weighted sequences, and gadolinium enhancement of the disc space or the posterior portion of the annulus fibrosus, or both. These findings must be distinguished from those that were described earlier for degenerative disc disease (Table III).

**Pain in the Lower Limb**

The most important goal of postoperative imaging in a patient who has pain in the lower limb after a previous operation is to distinguish scar tissue from treatable entities, such as a residual or recurrent herniation of an intervertebral disc or spinal stenosis. With use of unenhanced computed tomography, scar tissue can be distinguished from disc material in 43 to 60 per cent of these patients. Use of computed tomography with intravenous injection of a contrast agent increases the likelihood of a correct diagnosis to 70 to 83 per cent. Unenhanced magnetic resonance imaging has been reported to have an accuracy of 76 to 89 per cent, comparable with that of enhanced computed tomography. The diagnostic accuracy of contrast-
medium-enhanced magnetic resonance imaging approaches 96 to 100 per cent\textsuperscript{22,51}. Digital subtraction may further increase the rate of diagnostic accuracy in more complex situations\textsuperscript{74}. Thus, for a patient who has had a previous operation on the lumbar spine, magnetic resonance imaging should always be performed with use of an intravenous injection of paramagnetic contrast medium. If magnetic resonance imaging is contraindicated (as in patients who have a ferromagnetic spinal implant or a pacemaker), myelography followed by computed tomography is the next-best choice of imaging modalities.

It is important to be able to distinguish normal postoperative changes on magnetic resonance imaging scans from findings that can cause symptoms. Postoperative studies in which computed tomography was used have shown that approximately 40 per cent of asymptomatic patients have persistent herniated discs or other findings that are indistinguishable from those of symptomatic patients postoperatively\textsuperscript{22,52,71}. A study of the results of unenhanced magnetic resonance imaging revealed that nine of thirteen patients who had had a discectomy had an area of dural compression that resembled the preoperative herniation of a disc\textsuperscript{85}. Several reports have now documented the timing and sequence of changes observed on magnetic resonance imaging scans after an uncomplicated discectomy\textsuperscript{32}. These reports demonstrated that a soft-tissue mass impinging on the thecal sac, as seen on magnetic resonance imaging scans made in the early postoperative period (the first three months), can be misleading because of the presence of an immature hematoma or scar that can mimic residual herniated disc material (Figs. 2-A and 2-B)\textsuperscript{7,14,108}. These early postoperative changes that are consistent with disc material are thought to be the result of avascular hematoma and scar, which become increasingly vascular and shrink during the first three to six months after discectomy\textsuperscript{3,76,86}. 
Nerve-root enhancement has been observed on magnetic resonance imaging scans of patients who have had a previous operation on the lumbar spine, but this finding is of unknown clinical importance. The involved nerve root demonstrates increased signal intensity on gadolinium T1-weighted sequences, tracking proximally to the conus medullaris. Although this finding has been noted in some patients who have radiculopathy preoperatively, and it may be present quite frequently after disectomy, it does not seem to be associated with residual symptoms postoperatively57,100. The prevalence of this finding decreases dramatically during the first six months after the operation14.

Arachnoiditis may be seen, on magnetic resonance imaging scans postoperatively, as one of three distinct patterns: central clumping of the nerve roots, the appearance of an empty sac because of peripheral clumping of the nerve roots, and a soft-tissue mass in the subarachnoid space29. Arachnoiditis occurs in less than 5 per cent of patients who have persistent symptoms postoperatively, a rate far lower than has been estimated in the past21,38. When arachnoiditis is present, the chances for a postoperative reduction in pain are diminished unless a clear mechanical lesion can be identified.

With the use of highly refined imaging capabilities, it is now possible to examine the anatomy of the lumbar spine non-invasively, with excellent resolution. This has led to a better understanding of the frequency and spectrum of findings that can be present as part of the normal aging process without causing clinical symptoms. It is also now possible to distinguish accurately between mechanical causes of nerve-root compression that may result in radicular symptoms and normal radiographic findings.

Despite progress in the diagnostic imaging of entities that result in pain in the lower limb or other radicular symptoms, we are still limited in our ability to identify the sources of axial low-back pain, dysfunction of the sacro-iliac joint, and other types of referred-pain syndromes. Clearly,
most of the dark discs seen on magnetic resonance imaging scans are not painful or in need of repair. However, as operative interventions become less invasive, less morbid, and more successful, we must develop more reliable methods to distinguish which degenerative disc problems can be improved by operative intervention and to determine the optimum timing of such intervention. The improved diagnostic imaging of lumbar ligaments, facet joints, and muscles is also worth attention. Finally, we must demonstrate, in well designed clinical studies, that the decisions and interventions that are based on these improved diagnostic imaging studies lead to improved clinical results for our patients.


Scott D. Boden, MD: Internationally known researcher focuses on conservative treatments for patients with spine problems

Throughout his career in research and patient care, Scott Boden, MD, professor of Orthopaedic Surgery and director of the Emory Orthopaedics & Spine Center, has focused on applying the most conservative treatments for back problems, first and only resorting to surgical solutions when absolutely necessary.

At Emory, he has assembled one of the largest and most highly qualified multi-specialty teams focused exclusively on patients with spine problems, ranging from neck and arm pain to back and radiating leg pain, offering patients relief with treatment. Dr. Boden’s early research is internationally known.

- In 1990, he demonstrated that MRI scans of the spine frequently show abnormal findings (herniated discs, pinched nerves, etc.) even in people who have no pain or symptoms.
- This realization has prevented unnecessary back surgeries around the world and is one of the most frequently quoted spine imaging articles.

Over the last decade, Dr. Boden has led a research team that has been instrumental in the development of a bone growth factor, Bone Morphogenetic Protein-2 (BMP-2).