Lumbar Discography: A Comprehensive Review of Outcome Studies, Diagnostic Accuracy, and Principles

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Background and Objectives: Since its advent more than 50 years ago, the use of discography has been mired in controversy. The purpose of this review is to provide a clinical overview of lumbar discography and discogenic back pain, with special emphasis on determining the accuracy of discography and whether or not the procedure improves outcomes for surgery.

Methods: Material for this review was obtained from a MEDLINE search conducted from 1951 thru September 2004, bibliographic references, book chapters, and conference proceedings.

Results: Based on a large number of comparative studies, plain discography is less accurate than magnetic resonance imaging in diagnosing lumbar herniated nucleus pulposus and comparable or slightly more sensitive in detecting degenerative disc disease. For disc degeneration, CT discography remains the gold standard for diagnosis. There are very few studies comparing surgical outcomes between patients who have undergone preoperative provocative discography and those who have not. What little evidence exists is conflicting. Before disc replacement surgery, approximately half the studies have used preoperative discography. A comparison of outcomes did not reveal any significant difference between the 2 groups but none of the studies was controlled, and they used different outcome measures, follow-up periods, and surgical techniques. Because all intradiscal electrothermal therapy (IDET) studies have used discography before surgery, no conclusions can be drawn regarding its effects on outcome.

Conclusions: Although discography, especially combined with CT scanning, may be more accurate than other radiologic studies in detecting degenerative disc disease, its ability to improve surgical outcomes has yet to be proven. In the United States and Europe, there are inconsistencies in the use of lumbar discography such that it is routinely used before IDET, yet only occasionally used before spinal fusion. *Reg Anesth Pain Med 2005;30:163-183.*

Key Words: Degenerative disc disease, Discogenic pain, Discography, Internal disc disruption, Intervertebral disc, Lumbar spine.

Discography was first described in 1948 as a diagnostic tool for herniated nucleus pulposus (HNP).[1] Since that time, the development of simpler, safer, and more accurate imaging modalities have largely supplanted discography as an investigative technique for nerve root compression. Yet, provocative lumbar discography continues to be a popular, if controversial, means for diagnosing axial low back pain (LBP) caused by internal disc disruption (IDD). This is because, unlike magnetic resonance imaging (MRI) or computed tomography (CT) scanning, discography is not just an imaging modality but a provocative test purported to correlate symptoms with pathology. Although some studies have shown a high degree of correlation between discography results and histologic findings[2,3] and discography and surgical outcomes,[4,5] others have failed to show such a relationship.[6,7]

Anatomy

The intervertebral disc is composed of 3 major components: the nucleus pulposus (NP), annulus fibrosus (AF), and vertebral endplates (VE). Above

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and below the disc lie the vertebral bodies. The disc is attached to the adjacent vertebral bodies by the VE centrally and the ligamentous attachments of the AF peripherally. These components form a joint-like structure that allows for movements in the sagittal, horizontal, and coronal planes.[8] Posteriorly, it is supported by the other components of the "3-joint structure," the 2 zygapophysial joints. Together, these joints function to support and stabilize the spine and prevent injury by limiting motion in all planes of movement.

The healthy adult disc is essentially avascular, with its nutrition being supplied through the VE and AF via diffusion. The nucleus itself has no blood supply. The annulus contains blood vessels only in its most superficial lamellae. Nutrients that pass through the endplates come from the arteries supplying the vertebral bodies. Anabolic functions of the healthy disc are maintained by chondrocytes and fibroblasts; catabolic functions are performed by the matrix metalloproteinase enzymes collagenase (which degrades collagen) and stromelysin (which degrades proteoglycans). This balance is pH dependent, requiring oxygen, glucose, and substrates. The pH of the NP is between 6.9 and 7.1, reflecting anaerobic metabolism secondary to its lack of oxygen.[9,10] Any number of factors can contribute to a breakdown in the functional capacity of the disc, including inflammatory mediators, changes in pH, and nutritional deficiencies.[8]

The nerve supply to the intervertebral disc is complex. The most significant source of innervation to the lumbar spine is derived from the L2 dorsal root ganglion.[11] This is the basis for the eradication of lumbar discogenic back pain after blockade of the L2 nerve roots.[12]

Functionally, the innervation to the lumbar intervertebral discs stems from 2 extensive nerve plexi that accompany the posterior and anterior longitudinal ligaments.[8] These are known as the posterior and anterior plexuses. The sinuvertebral nerve, formed from the confluence of a somatic root from the ventral ramus and an autonomic root from the gray ramus communicantes (which receives its autonomic input from the sympathetic trunk), is the largest branch in the posterior plexus. This plexus is a diffuse network of interconnecting fibers receiving somatic and autonomic branches from multiple spinal levels.[8,13] In addition to the discs, the posterior plexus innervates the ventral aspect of the dura mater, the posterior longitudinal ligament, and the posterior portion of the vertebral bodies.

The anterior plexus receives contributions from the anterior branches of the rami communicantes, small medioventral branches of the sympathetic trunk, and perivascular nerve plexi. The posterior and anterior plexi are connected via a less prominent conglomeration of nerves known as the lateral plexus, formed by branches of the grey rami communicantes.[8] Several different types of nonvascular nerve endings have been described including simple, cluster, partially, and fully encapsulated.[14] Although the exact role of each type of nerve ending is unknown, it is speculated that under nonpathological conditions they primarily function as mechanoreceptors (Fig 1).[15]

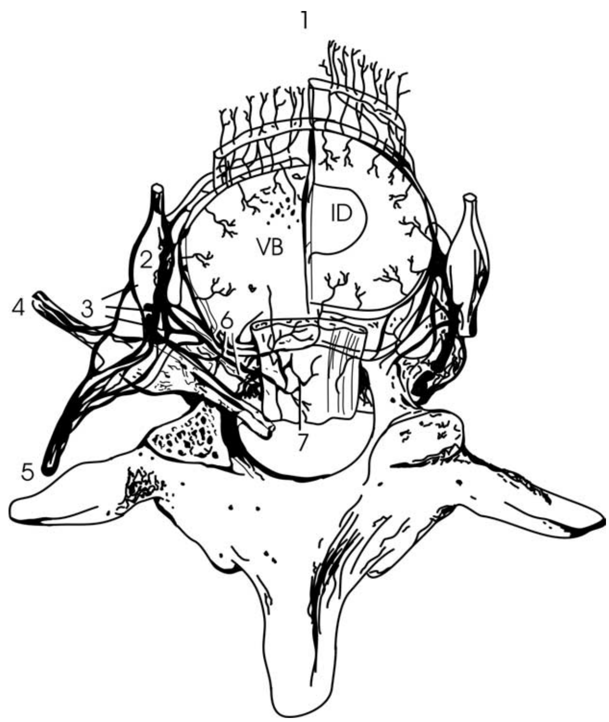

Fig 1. Schematic drawing of the nerve plexi surrounding the vertebral body (VB) and intervertebral disc (ID); 1 and 7 represent the anterior and posterior plexuses, respectively. The deep, extensive penetration of the nerves indicates degeneration has occurred. 2, sympathetic trunk; 3, rami communicantes; 4, ventral ramus of the spinal nerve; 5, dorsal ramus; 6, sinuvertebral nerves. (Modified from Groen et al.[13] Drawing courtesy of Specialist Jennifer Sempsroft, US Army.)

Emerging Theories on the Pathogenesis of Discogenic Pain

In the 1940s and 50s, the disc itself was thought to be devoid of any nerve supply and thus incapable of being a potential pain generator.[16,17] Subsequent studies have since refuted this assertion. In the normal human disc, sensory nerves extend into the outer third of the annulus. In the degenerated disc, the innervation is deeper and more extensive, with some nerve fibers penetrating into the nucleus pul-

Table 1. Modic Changes on MRI in Patients With Degenerative Disc Disease

Category of Signal Intensity Change*	T1-Weighted MR Image	T2-Weighted MR Image	Histopathologic Changes
Type I†	Decreased signal intensity	Increased signal intensity	Disruption and fissuring of the endplate and vascularized fibrous tissue within the adjacent marrow
Type II	Increased signal intensity	Iso- or slightly hyperintense signal	Endplate disruption with yellow marrow replacement in the adjacent vertebral body
Type III	Decreased signal intensity	Decreased signal intensity	Extensive bony sclerosis, indicative of dense woven bone within the vertebral body rather than the marrow

Adapted from Modic et al.[28]
*Refers to signal intensity changes in the vertebral body marrow adjacent to the end plates of degenerative intervertebral discs.
†Type I changes have been observed to progress to type II, whereas type II changes tend to remain stable.

posus.[15,18,19] It is now generally accepted that intervertebral discs can be and frequently are a significant source of back pain.[13,14,20-22]

Mechanical Changes. In the normal disc, weight bearing is uniformly distributed across the entire disc plane.[23,24] This is accomplished by mechanical interplay between the AF and NP. When a load is placed on the disc, the NP acts as a noncompressible mass, with its gelatinous contents bulging in the axial, sagittal, and coronal planes. The intact fibers of the annulus tend to resist this outward bulging, resulting in an even distribution of force throughout the entire surface of the disc.[8] In the healthy spine, the AF is not unduly stressed because its broad surface area translates into the nucleus carrying the bulk of the load.

Age-related changes can lead to a breakdown in the normal mechanical process of load bearing. As early as the second decade of life, the nutritional supply to the endplate diminishes because of a gradual reduction in blood flow.[25] This, combined with either an acute event such as a torsional load greater than the disc is capable of handling or repetitive low-level stress, can lead to 2 possible sources of injury. The first is a break in the continuity of the VE, also known as a microfracture.[26] The second is a tear in the lamellar structure of the annulus (i.e., annular tear) from torsional overload. Once this occurs, the ability of the nucleus to dissipate a compressive load changes. Unlike normal discs, a compressive load in degenerated discs is not uniformly distributed. Instead, the preponderance of the weight bearing burden is borne by the AF.[23,24] Although this can be maintained for short time periods, if the endplate fracture does not heal, the repetitive stress on the annulus eventually leads to the development of tears. These tears reduce the weight bearing capacity of the annulus because the lamellar fibers that are torn no longer function as support apparatus. This results in even more stress on the remaining fibers, which leads to further tearing and an eventual loss of annular integrity.[27] The disc is then predisposed to herniation of its contents and subsequent diminution in height. The loss of disc height may then degenerate into further shortening of the disc, replete with the pathologic changes commonly seen in degenerative disc disease (DDD) such as Modic changes, sclerosis of the endplates, and bridging osteophytes (Tables 1 and 2).[28,29] In severe cases, this manifests as autofusion and ankylosis of adjacent segments.[30]

Chemical Changes. The chemical changes that occur within the disc are 2-fold. First, the fracture of an endplate can lead to the introduction of inflammatory cytokines into the nucleus. This upsets the delicate nutritional balance of the disc, resulting in reduced oxygen diffusion, a rise in lactate levels, and a decrease in pH. These factors serve to slow metabolic and reparative processes and augment catabolic processes via an increase in metalloproteinase and chondrocyte activity, leading to further disc degradation.[10,31] Under certain circumstances, cytokines can be a direct source of pain. If the annulus is intact, the patient should not experience pain because inflammatory mediators cannot reach sensory nerve endings in the outer disc. However if an annular tear is present, these chemical pain mediators can now reach nociceptors, producing LBP.[32] The situation may be further compounded by perivascular or nonvascular nerve ingrowth penetrating as deep as the NP, which is well described in DDD.[15] Pain may also be produced by the sensitization and irritation of nerve endings in the endplate.[27] This model of chemical nociception

Table 2. Categorization of Degenerative Disc Disease Based on MRI

Category	Nucleus Signal	Prolapse Detection	Bone Marrow Signal
A	No signal loss	No prolapse	No intensity change
B	No signal loss	Prolapse	No intensity change
C	No signal loss	No prolapse	Intensity change
D	No signal loss	Prolapse	Intensity change
E	Moderate signal loss	No prolapse	No intensity change
F	Moderate signal loss	Prolapse	No intensity change
G	Moderate signal loss	No prolapse	Intensity change
H	Moderate signal loss	Prolapse	Intensity change
I	Total signal loss	No prolapse	No intensity change
J	Total signal loss	Prolapse	No intensity change
K	Total signal loss	No prolapse	Intensity change
L	Total signal loss	Prolapse	Intensity change

Adapted from Frobin et al.[29]

is supported by numerous studies showing disc immunoreactivity to substance P and calcitonin gene-related peptide,[33,34] as well as elevated levels of nitric oxide,[31] prostaglandin E2,[31,35] interleukin (IL)-2,[31] IL-6,[35] IL-8,[35] phospholipase A2,[36-40] leukotriene B4,[41] thromboxane B2,[41] and tumor necrosis factor-α (TNF-α)[42,43] in diseased intervertebral discs.

Taken together, these factors work in concert to provide a mechanical and biochemical explanation for the basis of discography. As one might expect, acute exacerbations of pain are best explained by the preponderance of inflammatory mediators around the sensitized disc. In this scenario, even low pressures may provoke intense pain during discography. This is the basis for the concept of "chemically sensitized" discs (see technical aspects of discography, Table 4). When the disruption is less acute, the disc may tolerate greater amounts of pressure and react to stimulation only at higher loads, at which point the nerve fibers of the degraded annulus are stretched to the point of pain induction. This scenario describes the "mechanically sensitized" disc. In practical terms, a patient with a chemically sensitive disc might experience almost constant LBP, whereas someone with a mechanically sensitized disc may have pain only with prolonged sitting or lifting. Another way to consider these 2 concepts is that a chemically sensitive disc is analogous to allodynia, whereas a mechanically sensitive disc is more comparable to hyperalgesia. In the latter stages of disc disease, the annulus becomes functionally incompetent. In these cases, the injection of contrast fails to generate high intradiscal pressures. Depending on the patient, pathology, and interpreter, these discograms may be read as positive, negative, or indeterminate. Normal discs resist pain with stimulation because they lack both the chemical sensitization and mechanical overloading seen in diseased discs. In practice, these examples represent an idealized diagnostic paradigm that does not take into account the multitude of genetic, social, cultural, and psychological factors that affect pain perceptions. To optimize treatment outcomes, these factors must be taken into account when performing any pain-provoking procedure.

The Controversy Over Discography: False-Positive Pain Provocation

Originally used as a diagnostic tool for HNP, provocative discography is no longer used to routinely evaluate radiculopathy, having been largely replaced by the advent of noninvasive, more sensitive tests such as CT scanning and MRI. The evidence that these modalities are not only safer but more accurate than plain discography in detecting herniated nuclear material is irrefutable. In a prospective study by Jackson et al.[44] comparing myelography, CT myelography, plain discography, and CT discography with surgical findings in 231 discs explored at surgery, the authors found CT discography to be the most accurate test (87%) and discography to be the least accurate (58%). Disco-CT ranked highest in sensitivity for HNP (92%) compared with 78% for myelo-CT, 72% for CT, 70% for myelography, and 81% for plain discography. For specificity, CT-disco was also the most accurate (81%) followed by CT (76%), CT-myelo (76%), myelography (70%), and discography (31%).

In the first phase of a 2-part experiment, Yasuma et al.[45] studied 181 lower thoracic and lumbar cadaver discs discographically and histologically. Their findings revealed 32 true-positive, 15 false-positive, 122 true-negative, and 12 false-negative discograms. Discograms were designated as false positive when the injected contrast was noted to extend beyond the peripheral vertebral margin, but histologic sectioning of the disc was negative for protrusion. False-negatives were defined as a negative discogram despite a histologically confirmed disc protrusion. In the second phase of this study, the authors retrospectively analyzed the cases of 77 discography patients who were subsequently found to have a herniated disc during surgical exploration.

The discograms were falsely interpreted as negative in 32% of the 59 patients with a protruding disc and 56% of the 18 patients with a prolapse.[45] In a previous study, Yasuma et al.[46] found that false-positive discograms were more likely to occur when fissures or cysts were present in a degenerated annulus but did not establish continuity with the nuclear cavity. MRI, which is more sensitive than CT for disc pathology, is also more accurate than discography in diagnosing acute disc herniation.[47] In most studies, discography has been found to be more sensitive than specific.

Proponents of discography argue that it is the only diagnostic modality that attempts to correlate pathology with symptoms. This point seems reasonable given the fact that close to two thirds of asymptomatic subjects have been found to have abnormal findings on MRI scans of their lumbar spines.[48] Opponents of discography question both the significance of discographic pathology and the validity of provoked symptoms. These criticisms are supported by the relative lack of specificity of discography, the inherent difficulty in validating provoked symptomatology, and the large number of studies showing false-positive discograms in patients without low back symptoms.

The first study to question the validity of discography was published in 1968 by Holt,[49] who found false-positive results in 37% of 30 asymptomatic prisoners. Over 20 years later, Walsh et al.[50] performed CT discography in 10 asymptomatic male volunteers and 7 "control" patients with chronic LBP, 2 of whom were female. In the control group, 65% of the 20 discs injected were radiologically abnormal, with all 7 patients having at least 1 degenerated disc. In the study group without back pain, CT discograms were interpreted as abnormal in 17% of the 35 discs injected and half of the 10 subjects. However, none of these 5 patients met the other criteria for a positive discogram, which was a concordant pain response coupled with pain-related behavior (e.g., grimacing, guarding, withdrawing, verbalizing, and so on). Thus, the false-positive rate in this study was 0%.

In 1999 and 2000, Carragee et al.[51-53] published a series of studies attempting to identify patients at high risk for false-positive discograms. In the first study, 8 patients without baseline low back symptoms who had undergone recent iliac crest bone grafting for non-thoracolumbar spine procedures were studied with provocative discography of their 3 most caudal discs.[51] Among the 8 study subjects, 4 experienced severe LBP concordant with their postoperative bone graft discomfort during injection of at least 1 disc. All symptomatic discs had an abnormal morphologic appearance. In the second study, 26 individuals without low back symptoms were divided into 3 groups: those who were pain free (n = 10), those with chronic neck and arm pain but no back symptoms (n = 10), and those with somatization disorder (n = 6).[52] Each patient had at least their 3 most caudad lumbar discs injected, with 5 patients having the L2-3 disc done as a control. The incidence of false-positive discography, as defined by moderate or severe pain during contrast injection in at least 1 disc, was 10% in the pain-free group, 40% in the chronic cervical pain group, and 83% in the somatization disorder group. In this study, none of the 31 radiographically normal discs were associated with pain during injection. In the last study, 3-level discography was performed in 47 patients who had undergone single-level discectomy.[53] Twenty of these subjects were asymptomatic, and 27 patients had recurrent low back or leg symptoms. In the asymptomatic participants, positive injections occurred in 8 of 20 (40%) operated discs. In the "control" patients with symptoms, positive injections occurred in 17 of the 27 operative discs (63%), with the pain being concordant in 15 of these. All positive discs contained radiographic abnormalities. Consistent with their second study, patients with normal psychometric scores were less likely to have false-positive injections than those with abnormal scores (43% vs 70%). Possible causes of false-positive discograms include inadvertent annular injection, contrast-induced irritation of nervous tissue, endplate deflection resulting from suboptimal needle placement, and stimulation of pressure receptors when excessively high pressures are generated.[54,55] Whereas the findings of Carragee et al.[51,52] and others are frequently cited as evidence against the routine use of lumbar discography before operative intervention, an inherent flaw in these studies is that the authors cannot consider true pain concordance in subjects without pre-existing low back symptoms. In the past 2 decades, this criterion has become a defining characteristic of a positive discogram. Given the high propensity for false-positive findings in patients with previous back surgery, psychopathology, or somatization symptoms, positive discograms should be viewed with caution in these individuals. To optimize specificity, we suggest obtaining 2 adjacent control discs, a recommendation previously put forth by Endres and Bogduk[56] in an attempt to improve accuracy in patients at high risk for false-positive discography. Although it may seem intuitive that this would enhance specificity and/or improve outcomes, these issues have yet to be addressed in the literature.

Table 3. Studies Comparing Lumbar Discography With CT Scanning or MRI in Patients With Degenerative Disc Disease

Author, Year	Number of Subjects	Nature of Study	Results	Comments
Sandhu, 2000[62]	53 patients with LBP, 133 discograms	Retrospective analysis comparing discography with vertebral endplate signal changes on MRI.	No significant correlation between discography and endplate signal changes.	41% of discs with (+) endplate changes were (+) discograms vs. 27% without. Among (+) discograms, only 23% exhibited T2-weighted MRI endplate changes.
Brightbill, 1994[2]	7 patients with LBP	Clinical case series involving pts with discrepancy between discography and MRI who underwent surgery and were found to have internal disc disruption.	All 7 subjects had normal MR imaging and (+) discography.	Did not consider surgical outcomes.
Yu, 1989[63]	8 cadavers, 36 discs	Compared MRI and discography against cryomicrotomy anatomic sectioning for detecting annular tears.	Discography identified 15 radial fissures, 10 of which were seen on MRI. Two of the 15 annular fissures were missed on cryomicrotomy.	Included a newborn and 2-year-old. Considered only radial tears of annulus. Could not correlate findings with symptoms.
Kakitsubata, 2003[64]	24 discs from 5 cadavers	Compared MRI and MR discography with anatomic correlation for detecting annular tears.	Sensitivity of MR-discogr was 100%, 57%, and 21% for radial, transverse and concentric, tears in annulus, respectively, vs. 67%, 71%, and 21% for conventional MRI.	Could not correlate findings with symptoms.
Zucherman, 1988[65]	18 patients with LBP with or without radicular symptoms	Clinical case series. In most cases discography was followed by CT scanning.	All patients had normal MRI and abnormal discograms	Normal MRI and abnormal discograms were basis for inclusion.
Horton, 1992[66]	25 patients with non-radicular LBP, involving 63 discograms	Comparative study between MRI and discography for discogenic LBP.	19 patients had (+) discograms. Of the different MRI patterns, only 'dark/torn', 'dark/bulged' or 'speckled/flat' were more likely to be associated with (+) rather than (−) discograms.	MRI findings classified by pattern, not presence or absence of pathology.
Collins, 1990[59]	29 patients, 73 discograms	Compared MRI and discography in pts with axial LBP.	57 discs were abnormal on discogr, with 13 producing concordant pain in 12 pts. Discogr findings correlated with MRI in 90% of cases. 4 discs showed degeneration on discogr w/ nml MRI, and 4 had abnormal MRI w/ nml discography.	The 12 pts with (+) discograms underwent spinal fusion, with 9 reporting clinical improvement at 9-month f/u.
Schneiderman, 1987[61]	36 pts with LBP, with or without leg pain, 101 discograms	Compared MRI and discography.	MRI accurate in assessing disc morphology in 100 of 101 levels. Of 52 discs with nml MRI, only 1 had (+) discogram. Of 49 discs with decreased MR signal, only 2 discograms nml.	Used only T2-weighted MRI. CT-discography used on 39 levels.
Milette, 1999[67]	45 pts, 132 discs	Evaluated MRI and discography results in pts with chronic LBP.	On MRI, 71% of discs showed nml contour, and 64% nml signal intensity. Only 40% of discograms were radiographically nml. Discogr demonstrated stage 2 and 3 disc disruptions in 26% of discs w/nml contour on MRI, and 13% of discs with both nml contour and signal.	Used only T2-weighted MRI. Study was designed to assess differences between disc protrusions, bulges, & loss of signal intensity on MRI, not to compare imaging studies.
Linson, 1990[60]	50 pts, 97 discs	Compared MRI and discography in pts with chronic LBP.	91% correlation for disc degeneration between MRI and discogr.	5 of the 6 discs with negative correlation were read as nml by MRI and abnormal by discography. No mention of control discs during discogr.
Simmons, 1991[58]	164 pts, 371 discs	Compared CT-discography and MRI in pts with chronic LBP with or without radiculopathy.	55% correlation based on pts, 80% based on discs.	MRI nml and discogram abnormal in 34 discs. Discogram nml and MRI abnormal in 60 discs. 37% of discs abnormal on MRI were asymptomatic on discogr. Did not include outcomes in 76 pts who underwent surgery.

Table 3. (Continued)

Author, Year	Number of Subjects	Nature of Study	Results	Comments
Gibson, 1986[57]	22 pts, 50 discs	Compared MRI and discography in pts with mechanical LBP.	Agreement between studies in 44 of 50 discs.	Discography results based on radiographic findings only as pts were sedated. In the 6 discs that didn't correlate, MRI was superior to discography.
Yoshida, 2002[68]	23 pts, 56 discs	Examined correlation between MR images and pain response on discography.	Sensitivity, specificity, positive predictive value, and negative predictive value of T2-MRI were 94%, 71%, 59%, and 97%, respectively.	Did not specifically compare discography and MRI. T2-weighted MRI superior to gadolinium-enhanced images.
Birney, 1992[69]	90 pts, 264 discs	Examined correlation between MRI and discography for DDD and HNP. Compared surgical findings with discogr in 57 pts.	Agreement between MRI and discogr in 86% of discs. MRI more accurate for HNP; Discogr slightly superior to MRI for DDD (MRI missed 1 disc, discogr 100% sensitive).	Considered pts with LBP and radicular pain. Surgical findings correlated with diagnostic studies at 63 of 76 levels.
Osti, 1992[70]	33 pts, 114 discs	Compared MRI and discography in pts with LBP.	All 54 discs identified as abnormal on MRI showed abnormal discogram patterns. 6 of the 60 discs identified as nml on MRI were abnormal on discogr. Of the 39 discs that provoked concordant pain on discogr, 27 were abnormal on MRI. 33 of the 39 asymptomatic discs by discogr had nml MRI signals, with 24 having nml discographic patterns.	Six of 46 discs classified as degenerate on MRI were asymptomatic at discography. Concluded discography is more accurate than MRI for detecting annular pathology. Pt population not well-defined.
Schellas, 1996[71]	63 pts, 100 discs with HIZ on T2 MRI in pts with LBP and/or radicular pain.	Retrospective analysis analyzing the significance of HIZ zones in predicting (+) discography.	All 100 discs with HIZ were discographically abnormal, with 87 showing concordant pain. In 17 asymptomatic control pts, MRI scans revealed only 1 HIZ disc.	37 pts had prior back surgery. Also included pts with radiculopathy.
Loneragan, 1994[72]	18 pts with chronic LBP thought to be discogenic (43 discs).	Compared MRI and CT-discogr in the diagnosis of DDD and HNP.	MRI missed 3 of 10 discs with early degenerative changes, and 1 of 3 herniations.	In no cases did MRI offer more information than CT-discogr.
Aprill, 1992[73]	41 pts (105 discs) with chronic LBP with or w/o radicular symptoms.	Compared HIZ on T2-weighted MRI with CT-discography.	In all pts who exhibited an HIZ on MRI, CT-discogr revealed either a grade 3 or 4 annular disruption. A grade 3 or 4 disruption was also present in 34 pts w/o an HIZ.	Concordant pain provocation with discogr was present in 38 of 40 HIZ discs, and 22 of 78 discs w/o an HIZ. CT-discogr performed in only 41 out of 500 pts in whom MRI was examined.

NOTE. Discography refers to discograms performed without CT scanning.

Abbreviations: DDD, degenerative disc disease; IDD, internal disc disruption; HIZ, high-intensity zone on MRI; HNP, herniated nucleus pulposus; LBP, low back pain; nml, normal; pts, patients.

Correlation of Discography With Radiologic Studies

Although there is strong evidence that discography, with or without CT scanning, may overestimate the prevalence of clinically significant internal disc disruption, it is equally clear that, even when correctly performed and analyzed, discography may fail to detect disc pathology seen with other radiologic studies. In a study by Gibson et al.[57] comparing MRI and discography in the diagnosis of DDD, agreement between the 2 techniques was found in 44 of 50 discs studied. In the 6 discs in which a discrepancy occurred, evidence of IDD was missed in 5 discograms and 1 MRI. In the 5 cases in which discography failed to detect disc pathology, 2 were because of incorrect placement of the discography needle in the annulus, with failure to detect early signs of degeneration accounting for the other 3. Although the authors recorded symptoms produced by disc injections, discography results were based on radiologic findings only.

In a similar study by Simmons et al.,[58] the authors compared CT-discography with MRI in 164 patients with chronic LBP, some of whom suffered radicular symptoms. Correlation between the 2 techniques was seen in 55% of cases. In 13% (n = 60) of discs, MR images were abnormal but discograms normal. Among all the discs classified as abnormal on MRI, 37% (n = 108) were asymptomatic during disc injection. In 7% of discs (n = 34), MRI showed normal and discography abnormal findings. In 21 of these 34 discs, injection of contrast

Table 4. Interpretation of Disc Stimulation

Disc Classification	Intradiscal Pressure at Pain Provacation	Pain Severity	Pain Type	Interpretation
Chemical	Immediate onset of pain occurring as <1 mL of contrast is visualized reaching the outer annulus, or pain provocation at <15 PSI above opening pressure	≥7/10	Concordant	Positive
Mechanical	Between 15 and 50 PSI above opening pressure	≥7/10	Concordant	Positive (but other pain generators may be present; further investigation is warranted)
Indeterminate	Between 51 and 90 PSI	≥7/10	Concordant	Further investigation warranted
Normal	>90 PSI	No pain or pressure	NA	Negative

Abbreviation: PSI, pounds per square inch.
Modified from Derby et al.[84]

into the disc elicited exact pain reproduction. In a comparative study evaluating MRI and discography in patients with axial LBP, Collins et al.[59] found that imaging characteristics for the 2 diagnostic procedures correlated in 65 of 73 discs. In the other 8 cases, 4 disc levels showed evidence of early degeneration on discography but appeared normal on MRI, whereas the other 4 showed decreased signal intensity on T2-weighted MR images but were discographically normal. In the 12 patients with concordant pain on discography, spinal fusion was performed. At their 9-month follow-up, 9 of 12 patients reported clinical improvement.

Several studies have shown a much stronger correlation between MRI and discography. In a study by Linson and Crowe,[60] findings between the 2 investigative modalities were in agreement in 91 of 97 discs studied in 50 patients. In the 6 discs in which a discrepancy was present, 5 were read as normal by MRI but abnormal by discography. In an earlier study by Schneiderman et al.,[61] MRI and discography positively correlated in 100 of 101 levels. Overall, discography appears to be comparable or slightly more sensitive for the detection of IDD than MRI or CT scanning, especially with regard to radial annular fissures. In discs read as degenerative on MRI, approximately 15% will fail to provoke concordant pain on discography. The main problem with correlative studies is that when an incongruity exists, it is impossible to determine whether or not the discrepancy is caused by a lack of sensitivity (false negatives) or specificity (false positives) in one of the diagnostic procedures (Table 3).

Correlation With Lumbar Spinal Fusion Outcomes

Axial back pain is one of the most challenging problems confronted by physicians. There are many disorders besides DDD that can cause axial LBP, with 2 of the more common ones being facet arthropathy and myofascial pain. In a porcine study by Indahl et al.,[74] the authors determined that there is significant overlap between the neuromuscular connections of the intervertebral discs, zygapophyseal joints, and paraspinal muscles, such that the relative contributions to LBP of each of these structures may be difficult to estimate. It is thus likely that in many, if not most patients suffering from chronic LBP, several different pain generators exist concurrently.

Several authors have attempted to determine the prevalence of discogenic pain in patients suffering from back symptoms. In one of the most cited studies, Schwarzer et al.[75] found the incidence of IDD to be 39% in 92 patients with chronic LBP. Notwithstanding the fact that many patients with DDD suffer from other concomitant causes of back pain that may not respond to operative intervention, the surgical treatment of DDD is itself mired in controversy. Although outcome studies for spinal arthrodesis vary widely, they are generally acknowledged to be less beneficial than surgery for radicular pain, with success rates ranging from less than 50% to almost 90%.[76] These quoted success rates must be considered in light of the fact that no fusion studies have ever been conducted under controlled, blinded conditions. Moreover, a recent Cochrane database review concluded there was no scientific evidence supporting any form of surgical decompression or fusion in the treatment of DDD.[77] The presence of other possible pain generators in patients with discogenic pain, along with the mixed clinical outcomes even when arthrodesis is technically successful,[77,78] are factors that must be considered when evaluating clinical studies examining the correlation between discography results and surgical outcomes.

Several investigators have attempted to correlate discography results with surgical findings and outcomes. Colhoun et al.[4] evaluated surgical outcomes in 162 patients who underwent preoperative discography for axial LBP. In the 137 patients whose discography provoked pain, 89% had a favorable outcome (mean follow-up period for study patients was 3.6 years). In the 25 patients whose discs showed morphological abnormalities but no provocation of symptoms, only 52% reported significant benefit. Of note, the authors did not measure pressure during discography and the surgical treatments used were predominantly spinal fusions.

Not all outcome studies have been as positive as Colhoun's.[4] In a prospective study by Esses et al.,[79] the authors assessed the role of external spinal fixation in predicting the success of subsequent arthrodesis in patients with chronic LBP. Thirty-two of the 35 subjects underwent provocative discography before fixator placement. Of the 21 patients whose discography showed radiographically degenerated discs, 17 experienced complete or significant pain relief with the external fixator. In the 13 patients for whom results were available, 9 went on to obtain significant relief after spinal fusion.

In the 11 patients with normal-appearing discs, 8 experienced complete or significant relief with spinal fixation, with 6 of the 8 who went on to surgery deriving clinical benefit from their fusion. Among the 15 patients with concordant pain on discography, 8 experienced complete relief and 5 significant relief after external spinal fixation. In the 10 patients with concordant pain who underwent spinal fusion, 3 obtained complete pain relief, whereas another 3 experienced significant relief. Of the 17 patients with non-concordant or no pain on discography, 5 experienced complete relief and 7 experienced significant relief after fixator placement. In the 12 patients with no or nonconcordant discography pain who went on to definitive surgery, 3 obtained complete pain relief, with another 6 reporting significant relief. The follow-up period after posterior spinal fusion is not mentioned in the manuscript. Although determining the predictive value of discography on surgical success was not the main objective of Esses' study, their outcomes suggest positive discograms do not predict therapeutic response.

The predictive value of provocative discography on surgical outcome was also assessed in a study by Madan et al.[6] involving 73 patients with chronic LBP. Thirty-two patients underwent spinal fusion based on pain provocation during discography, with 41 patients having surgery without the benefit of discography. In the discography group, 75.6% of patients had satisfactory outcomes at a minimum 2-year follow-up versus 81.2% in the group who did not have preoperative discography. In summary, the lack of strong evidence for the use of fusion to treat DDD,[77,78] and the methodological flaws in the existing studies makes interpretation of the data exceedingly difficult. For the data that does exist, the results are mixed as to whether or not preoperative discography improves surgical outcomes in patients with discogenic LBP. The results of studies evaluating discography as a predictive tool for surgery are presented in Table 5.

Correlation With Intradiscal Electrothermal Therapy and Disc Replacement Surgical Outcomes

In recent years, the advent of intradiscal electrothermal therapy (IDET) and total disc replacement surgery have generated intense interest in the medical community. As a treatment for discogenic pain, the outcomes for IDET vary widely, ranging from minimal benefit[86] to success rates approaching 80% for single-level procedures.[87] Most studies report improvement rates in the 50% range.[88,89] Because all published studies have used preprocedure discography as a screening test for IDET candidates, the effect the procedure has on outcomes cannot be assessed.

The concept of disc arthroplasty was introduced by Fernstrom in 1966,[90] who described using a stainless steel ball as a vertebral spacer to restore lost disc height and preserve motion. Over the last decade, there has been renewed interest in disc replacement surgery, with most studies coming from Europe.

The studies assessing disc replacement surgery are almost equally divided between those that have routinely used preoperative discography as a screening test and those that have not. Unfortunately, methodological flaws in these uncontrolled studies, wide variability in outcome criteria, and the absence of any direct comparisons between patients who underwent preoperative discography and those who did not preclude any meaningful conclusions from being drawn. Based on the limited data that are available, it does not appear that preoperative discography confers any significant benefit in patients being considered for total disc replacement. These studies are summarized in Table 6.

Discography Versus Bony Vibration Test

Proponents of discography claim the procedure is indispensable, being the only diagnostic tool that

Table 5. Clinical Studies Evaluating Effect of Preoperative Discography on Surgical Outcomes

Study, Year	Number of Patients	Type of Study	Results	Comments
Gill, 1992[80]	53 patients with predominantly axial LBP and IDD at L5-S1.	Retrospective study involving L5-S1 fusion.	50% of pts with type I discogram and normal MRI scans improved vs 75% of pts with types II or III discogram and abnormal MRI.	Abnormal discogram was the basis for surgery. Average follow-up 20 months.
Colhoun, 1988[4]	162 patients with axial LBP.	Prospective observational study.	Of 137 pts in whom discogram revealed DDD and provoked concordant pain, 89% had favorable outcome. Only 52% of those pts in whom discogr showed DDD but provoked no pain had a favorable outcome.	Mean follow-up 3.6 years.
Parker, 1996[81]	23 patients with mechanical LBP and positive discography.	Prospective case series involving spinal fusion and/or instrumentation.	39% of pts reported good outcomes, 13% fair outcomes, and 48% had poor results.	Abnormal discogram was basis for surgery. Mean follow-up 47 months.
Esses, 1989[79]	35 patients with chronic LBP and FBSS who underwent ESF before arthrodesis.	Prospective study evaluating effect of ESF prior to spinal fusion. 32 pts also underwent pre-op discography.	Among the 15 pts with concordant pain on discography, 13 experienced significant or complete pain relief with ESF. 6 of these 10 pts had significant relief after arthrodesis.	Study not designed to evaluate predictive value of discography on surgical success. Not all pts underwent preoperative discography.
Kostuik, 1979[82]	350 pts with painful scoliosis who underwent spinal instrumentation.	Retrospective study	Pre-operative discography improved success rate from 65%-70% to 85%.	Used L5-S1 discography to determine whether anterior or posterior instrumentation should be used.
Wetzel, 1994[7]	48 pts with axial LBP who underwent lumbar arthrodesis following provocative discography.	Retrospective study	At first follow-up (mean 5.3 wks), 66% had satisfactory outcome. At final follow-up (mean 35 months), 46% had satisfactory outcome.	CT-discography used in all but 1 pt. Not all pts had a control disc (26 pts had single-level discography).
Madan, 2002[6]	41 pts who underwent spinal arthrodesis without pre-op discography and 32 pts who underwent surgery based on (+) discography.	Not indicated	81% of pts who had surgery based on MRI and clinical findings had satisfactory outcome vs. 76% of pts who underwent arthrodesis based on (+) discogram.	Mean follow-up 2.4 years in discography group and 2.8 years in MRI/clinical group.
Knox, 1993[83]	22 pts who underwent anterior spinal fusion for discogram-concordant LBP	Retrospective study	Poor results in all 5 pts with 2-level fusions. In single-level fusions, 35% of pts had good results, 18% fair, and 47% poor outcomes.	Strong correlation between subjective (clinical improvement) and objective (fusion success) results.
Derby, 1999[84]	96 pts who underwent discography for LBP	Retrospective study	In pts with chemically sensitized discs ($\geq$6/10 concordant pain @ $<$ 15 psi above opening pressure, n = 36), success rates were 89% for interbody/combined fusion, 20% for posterior inter-transverse fusion and 12% for no surgical rx.	Mean follow-up for surgical pts 28 months. No difference between outcomes for interbody/combined fusion and posterior intertransverse fusion for surgical sample as a whole.
Vamvanij, 1998[85]	56 pts with discogenic LBP confirmed by CT-discography who underwent 1 of 4 fusion techniques.	Not indicated	Overall rate of pt satisfaction 46%.	Success rate for pts who had anterior lumbar fusion with cage and facet fusion 63%. Success rates for the other 3 groups ranged from 36% to 46%.

NOTE. Type I discogram designated as internal disc disruption (IDD) without extravasation of contrast associated with concordant pain reproduction. Types II and III denote the presence of annular disruption with spread of contrast to the periphery and epidural space, respectively.

Abbreviations: DDD, degenerative disc disease; ESF, external spinal fixator; IDD, internal disc disruption; LBP, low back pain; pts, patients.

purports to correlate symptoms with pathology.[104,105] However, this distinction no longer holds true. The bony vibration test (BVT), which entails compressing a blunt, vibrating object (usually the shaft of an electric toothbrush) against the skin overlying successive spinous processes to provoke pain, has been purported to be a quick, safe, and painless method for diagnosing discogenic pain. In a study by Yrjama and Vanharanta[106] conducted in 57 patients with LBP, the authors found the sensi-

Table 6. Summary of Outcome Data for Lumbar Disc Replacement Surgery Based on Preoperative Discography Screening

Study, Year	Preoperative Discography?	Number of Disc Replacement Patients	Type of Surgery	Outcomes
Blumenthal, 2003[91]	Yes	57	Total disc replacement	63% of pts improved at 2-year follow-up (based on > 20 pts improvement on VAS score).
Shim, 2003[92]	In pts with DDD at more than 1 level.	46	Partial disc replacement	Mean VAS score 8.5 pre-op, 3.1 at 1-year follow-up. 11% had excellent and 67% good results.
Van Ooij, 2003[93]	Yes	27	Total	Good outcome obtained in 12 of 26 pts, with variable f/u period (range 1 month-10 years).
Tropiano, 2003[94]	No	53	Total	87% of pts "entirely satisfied". Mean Oswestry disability score 56 pre-op, 14 at last f/u (mean 1.4 years).
McAfee, 2003[95]	Yes	41	Total	Mean VAS score 73.5 pre-operatively, and 30.4 at 1–3 year f/u.
Kim, 2003[96]	Not mentioned except for (−) discogram being a contraindication.	11 pts with juxtafusional DDD	Total	Of the 5 pts followed for > 6 months, mean Oswestry disability index decreased from 64% to 24%.
Zeegers, 1999[97]	In 36 of 50 pts.	50	Total	32 of 46 pts followed for 2 years had a positive clinical result. Did not provide separate data for pts having discography.
Bertagnoli, 2002[98]	No	108	Total	Results "excellent" in 91%, "good" in 7%, "fair" in 2%, and poor in no (0%) patients at 3-month to 2-year follow-up.
Hochshuler, 2002[99]	Yes	56	Total	52.7% improvement in mean VAS scores at 6-week follow-up. In the 22 pts followed for ≥ 1 year, improvements in VAS and Oswestry scores were maintained.
Mayer, 2002[100]	No	34	Total	Mean VAS score decreased from 6.3 pre-op to 3.4 at 1-year follow-up (not all pts followed for 1 yr). 61% of pts "completely satisfied," and 22% "satisfied."
Jin, 2003[101]	No	45	Partial	Mean Oswestry disability index decreased from 52.2% to 16.5% in the 30 pts seen at their 6-month f/u. 87% of pts were clinically improved.
Zigler, 2003[102]	Not routinely	28	Total	Decrease in VAS score from approximately 7.8 to 5.6 after 6 months.
Enker, 1993[103]	Yes	6	Total	4 of 6 patients had satisfactory results (1 excellent, 2 good, 1 fair).

NOTE. Table does not include studies lacking information about patient selection criteria.
Abbreviation: f/u, follow-up; pts, patients.

tivity and specificity of BVT to be 0.71 and 0.63, respectively, compared with provocative discography. When patients with failed back surgery syndrome and painful herniated discs were excluded (n = 40), the sensitivity jumped to 0.96 and the specificity to 0.72. In 2 follow-up studies comparing BVT findings with MRI and CT-discography, the authors found similarly high sensitivities and specificities when failed back surgery syndrome patients and those with complete annular tears were excluded.[107,108] The main problem with these studies is that they fail to distinguish patients with discogenic pain from those with radicular symptoms. Presently, there are no published articles correlating BVT findings with surgical outcomes. Until these studies are conducted, it is unlikely BVT will supplant discography as a diagnostic tool for discogenic LBP.

Literature Review on the Technical Aspects of Discography

Indications and Pain Referral Patterns. The indications for discography have been previously outlined in numerous guidelines and reviews.[56,105,109-118] These include the following:

1. Evaluation of patients with unremitting spinal pain, with or without extremity pain, of greater than 4 months duration that has been unresponsive to conservative therapy.
2. Patients with persistent symptoms in whom other diagnostic tests have failed to reveal clear confirmation of a suspected disc as the source of pain.
3. Evaluation of persistent pain in the postoperative patient whose symptoms may be arising from intervertebral disc degeneration, recurrent herniation, or pseudoarthrosis of a spinal fusion.
4. To determine the number of levels to be fused in spinal surgery and/or determination of the primary symptomatic disc.
5. If the patient prima facie satisfies the criteria for treatment by intradiscal electrothermal therapy, in which case pain is provoked to detect discogenic pain. In these cases, CT discography may be undertaken to assess disc morphology to determine whether or not an (IDET) electrode can be navigated in the disc and, if so, where it should be placed.
6. For assessment of minimally invasive surgical candidates to confirm contained disc herniations or to investigate dye distribution before chemonucleolysis or other percutaneous decompression procedures.

Current International Spinal Injection Society guidelines recommend that 2 control levels be obtained for adequate interpretation of disc stimulation.[56] However, many authors do not adhere to these strict guidelines.[105,110,119] Recently, Ohnmeiss et al.[120] described patterns of pain provocation for positive discograms. For L3-4 injections, discograms were more likely to be positive if patients described their pain as involving the lumbar region with radiation into the anterior but not posterior thigh (71.4%). For L4-5 discs, the most common pain description was that of lumbar pain with more equivalent proportions of anterior and posterior thigh pain (>63%). In L5-S1 discogenic pain, the referral pattern tended to involve the lumbar region with posterior thigh or leg pain (>75%). Pain limited to the low back and buttocks was usually associated with the absence of disc pathology (58.3%).

There are numerous ways to perform discography, and no one method for needle placement has ever been shown to be superior. Interspinous and interlaminar approaches have been advocated after fusion with paraspinal bone graft but are otherwise rarely used because of the necessity of dural penetration. At L5-S1, a modified double-needle technique is often necessary because of the iliac crests, which prohibit a trajectory aimed directly at the center of the disk. Entry into this level is subject to higher failure rates, which may be substantially reduced by using a curved-needle technique.[121] Although recommended by some,[56,105,122] an approach from the side contralateral to a painful referral pattern has not been shown to affect the rate of false-positive discograms.[123]

Because of the possibility of inadvertent intrathecal administration, only nonionic contrast material should be injected. Nonionic dye also minimizes the risk of allergic reaction, which can be delayed until contrast material is systemically absorbed from the disc. In patients with known prior contrast reactions, premedication is necessary. Another option is the use of gadolinium as the contrast agent.[124] For the technical aspects of discography, readers are referred to other reviews.[56,105,110,119,121,122,125,126]

Disc Stimulation and Interpretation. Once all needles have been properly positioned, the patient is prepared for the injections. The sequence of disc injection depends on the discographer's expectation for pain provocation at each level. Once severe pain is produced, the patient may be less able to tolerate or judge subsequent injections. Therefore, the level considered likely to cause the most intense pain should be injected last.

Normal discs take <1 mL of contrast before firm resistance is reached (high-pressure endpoint). Degenerated discs generally accept larger volumes of contrast and show moderate or soft resistance to injection (low-pressure endpoint). If the disc communicates with the epidural space because of complete annular disruption, unlimited contrast volume can be injected with little to no resistance (volume endpoint). When severe symptoms are provoked, the injection must be stopped even if minimal contrast has been injected (pain endpoint).[127]

Injection pressures can be measured using specialized, commercially available devices, and are recommended by the International Spinal Injection Society.[56] Others have not endorsed the use of these devices,[110,118,125] claiming that an experienced discographer can determine relative pressures using only a syringe. Proponents of manometry state that a pressure recording device allows for the objective designation of painful discs as chemically or mechanically sensitive.[84,87,112] Although it is true that manometry can provide an objective measure of disc sensitivity, it does not ensure that a patient will respond promptly and accurately to disc injection.

If manometry is used, one should first determine the opening pressure of the disc, which in practical terms is the pressure at which contrast is first visualized entering the disc (usually <15 pounds per square inch [PSI]). Once opening pressure is determined, the disc is slowly filled with contrast, in aliquots of 0.5 to 1 mL. The endpoint is usually a high-pressure endpoint at around 100 PSI or the point at which pain is experienced. In cases of severely degenerative discs, it may not be possible to achieve pressures above 50 PSI. If either 100 PSI or 50 PSI above opening pressure is reached without pain being noted, the disc is considered negative and can serve as a control. Generating pressures >100 PSI greatly increases the risk of iatrogenic injury. If pain is noted at low pressures (<15 PSI above opening pressure), the disc is considered chemically sensitive. If pain is noted between 15 and 50 PSI above opening pressure, the disc is considered mechanically sensitive and the discogram may or may not be positive. If pain is noted at >50 PSI above opening pressure, "the response cannot be considered clinically significant."[56] Pain at higher pressures may be caused by mechanical irritation, end-plate deflection, or the stimulation of pressure receptors. There are no studies assessing whether or not the use of manometry affects surgical outcomes.

Numerous discography classification systems have been advocated, both with and without pressure monitoring. No single set of criteria is universally accepted as standard (Tables 4 and 7). In a large, multicenter study by Derby et al.,[84] the authors showed that patients with chemically sensitized discs (i.e., concordant pain at <15 PSI above opening pressure) were more likely to obtain good results with interbody fusion surgery.

Some authors have advocated videotaping to document patient reactions during disc injections.[110,126] Videotaped findings are later correlated with fluoroscopy or compared with simultaneous changes in physiological parameters such as heart rate and blood pressure. If relevant, the videotape can then be made available to the referring surgeon.

Image Interpretation. For morphologic interpretation of the fluoroscopic images, although discography is clearly inferior to CT-discography, useful information may nevertheless be garnered from the overall appearance of the contrast spread. A small central "cotton ball" accumulation of contrast usually indicates a normal painless disc. Normal discs may also appear to have a central bilobular appearance, like a "hamburger in a bun." A thin line of contrast that extends to the posterior edge of the disc is consistent with an annular tear, and it is not unusual for the patients to complain of pain when the contrast moves posteriorly. More diffuse posterior contrast spread indicates a large annular tear. Spread of contrast into the epidural space is consistent with a complete tear of the annulus and loss of integrity of the outer annular wall. Diffuse spread in all directions, with or without spread into the epidural space, indicates a severely degenerated disc.

Table 7. Interpretation of Discograms

Unequivocal discogenic pain
1. Stimulation of the target disc reproduces concordant pain.
2. Pain intensity is rated as being at least 7 on a 10-point visual analog scale.
3. Pain is reproduced at a pressure of less than 15 PSI above opening pressure.
4. Presence of 2 adjacent control discs that are nonpainful.
Definite discogenic pain
1. Stimulation of target disc reproduces concordant pain.
2. Pain intensity is rated as being at least 7 on a 10-point visual analog scale.
3. Pain is reproduced at a pressure of less than 15 PSI above opening pressure.
4. Presence of 1 adjacent control disc that is nonpainful.
or
1. Stimulation of the target disc reproduces concordant pain.
2. Pain intensity is rated as being at least 7 on a 10-point visual analog scale.
3. Pain is reproduced at a pressure of less than 50 PSI above opening pressure.
4. Presence of 2 adjacent control discs that are nonpainful.
Probable discogenic pain
1. Stimulation of the target disc reproduces concordant pain.
2. Pain intensity is rated as being at least 7 on a 10-point visual analog scale.
3. Pain is reproduced at a pressure of less than 50 PSI above opening pressure.
4. Presence of 1 adjacent control disc that is nonpainful, and a second adjacent control disc that produces nonconcordant pain at a pressure of greater than 50 PSI.

Abbreviation: PSI, pounds per square inch.
Adapted from Endres et al.[56]

Fluoroscopy can show morphological differences between normal and degenerated discs but poorly characterizes the locations of annular tears and their relationships to nerve roots. Disc architecture is much better assessed by CT because of its cross-sectional acquisition of thin slices parallel to the disc spaces. Thus, many annular tears seen on CT images are invisible at fluoroscopy. For this reason, we perform procedures requiring a functional annulus such as nucleoplasty only after CT discography.[128]

The most commonly used terminology of disc disease was adapted for MRI. This terminology is difficult to apply to CT discography because it only addresses contour abnormalities, such as diffuse or focal disc bulge, protrusion, extrusion, and sequestration. Internal disc abnormalities that cannot be detected on MR become obvious on CT because they are filled with contrast material. The Dallas discogram scale was originally developed to describe and grade annular tears and has subsequently undergone several modifications.[110,127] By using this modified scheme, disc morphology is graded from 0 to 7 (Table 8 and Fig 2).[110]

Table 8. CT Classification of Discography

Type 1: The discogram is normal manometrically, volumetrically, radiologically, and produced no pain. The CT discogram showed contrast to be centrally located in both axial and sagittal projections.
Type 2: Identical to type 1 except it is positive for pain reproduction.
Type 3: The annular tears lead to a radial fissure. This group can be further subdivided into:
Type 3a: The radial fissure is posterior
Type 3b: The fissure radiates posterolaterally and
Type 3c: The fissure extends lateral to a line drawn from the center of the disk tangential to the lateral border of the superior articulating process.
Type 4: When the radial fissure reaches the periphery of the annulus fibrosus, nuclear material protrudes causing the outer annulus to bulge.
Type 5: When the outer annular fibers rupture, nuclear material may extrude beneath the posterior longitudinal ligament directly contacting either the dura or a nerve root.
Type 6: When the extruded fragment is no longer in continuity with the interspace it is said to be sequestrated. Manometrically, volumetrically, and radiologically, these discograms are always abnormal. Concordant pain may be reproduced only if enough pressure is generated against the free fragment to cause stimulation of pain-sensitive structures.
Type 7: The end stage of the degenerative process is internal disc disruption, in which multiple annular tears occur. The discograms are abnormal manometrically and volumetrically, and familiar pain may or may not be reproduced. Radiologically, the contrast usually fills the entire interspace in a chaotic fashion. The CT-discogram shows contrast extravasation throughout multiple annular tears.

Adapted from Bernard Jr et al.[110] and Sachs et al.[127]

The final interpretation of lumbar discography reflects the synthesis of disc stimulation data and morphology. Only rarely is pain reproduced in a disc that is morphologically, manometrically, and volumetrically normal. In these cases, the discographer must carefully consider the patient's entire clinical picture, including historical and physical examination findings, the presence of spinal and psychological pathology, additional radiologic and supplemental diagnostic tests, and the technical success of the discogram before deciding on a treatment course.

Complications

Because of the poor blood supply of the intervertebral discs, discitis is the most feared complication of discography. Any patient who complains of worsening pain 1 week postprocedure warrants reevaluation. At minimum, the postdiscography workup should include a focused history, physical examination, and laboratory screening tests. Erythrocyte sedimentation rate and C-reactive protein are the most sensitive indicators of discitis, but elevation usually does not occur until 3 weeks after the procedure.[129,130] If the ESR is >50, then a bone scan or MRI is indicated to rule out discitis. The most common etiologic agent in postprocedure discitis is *Staphylococcus aureus*.[130]

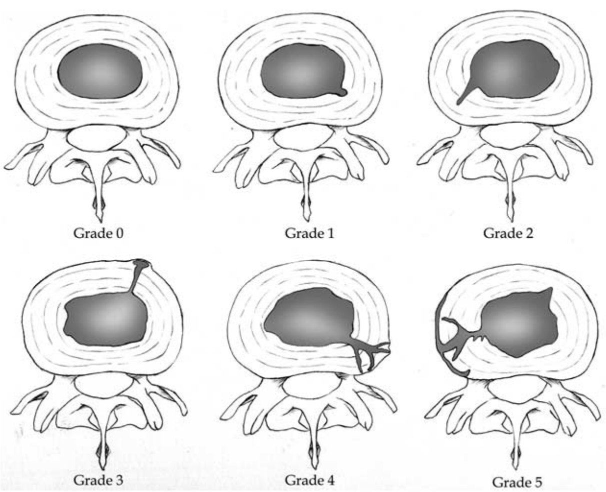

Fig 2. Modified Dallas discogram scheme for the classification of annular tears by CT discography. (Modified from Sachs et al.[127] Drawings by Jee Hyun Kim.)

In a study by Fraser et al.,[131] the authors found the incidence of discitis was reduced from 2.7% to 0.7% by using a through-and-through double-needle technique. In a review by Guyer and Ohnmeiss,[132] the authors found an incidence of discitis between 0.1% and 0.2%, with most of the studies analyzed not administering prophylactic antibiotics. After a 2-part study assessing the efficacy of intradiscal cefazolin in sheep and humans, Osti et al.[133] advocated mixing 1 mg/mL cefazolin with the injected contrast as a safe and effective means of preventing discitis. A recent in vitro study by Klessig et al.[134] supports the prophylactic use of intradiscal antibiotics in lieu of systemic therapy for patients undergoing provocative discography.

The prophylactic use of antibiotics is by no means universal. Willems et al.[135] conducted a comprehensive review of the incidence of postdiscography discitis without the use of prophylactic antibiotics in conjunction with 200 of their own patients. Among the 4,981 patients included in the analysis, the incidence of discitis was 0.25% (0.09% of 12,770 discograms). The authors concluded that the low risk of discitis when the double-needle technique is used does not warrant the routine use of prophylactic antibiotics. Considering the inherent difficulties in treating discitis and low doses of antibiotics used, the authors believe the use of prophylactic intradiscal antibiotics is justified. Collectively, we have performed over 2,000 discograms using intradiscal antibiotics, with a 0% incidence of discitis (unpublished data, Cohen and Larkin, 1999-2004).

Can discography cause or worsen existing LBP or injure the intervertebral disc? In a study assessing whether discography is associated with long-term back symptoms in asymptomatic subjects, Carragee et al.[136] found the incidence of persistent LBP to be 0% in patients without chronic neck pain or somatization disorder, 20% in patients with chronic neck and shoulder pain, and 66% in patients with somatization disorder 1 year after lumbar discography. However, in 2 other studies assessing the long-term effect of discography, both Johnson[137] and Flanagan and Chung[138] found no evidence of intervertebral disc injury. The results of Carragee et al.[136] have not been supported by subsequent studies, and it is likely their findings are germane only to the subpopulations they tested. In a follow-up study by Carragee et al.,[139] the authors found psychological distress and preexisting chronic pain to be strong predictors of future LBP in asymptomatic volunteers undergoing experimental discography. In contrast, painful disc injection did not predict LBP or any other functional outcome measure. As previously alluded to, persistent pain after discography can result from high pressures causing microinjury to the disc(s), which may be more likely to occur without the use of manometry.

In a study analyzing 146 lumbar discograms in 52 patients, Tallroth et al.[140] found that 2% of patients experienced nausea, 4% convulsions, and 6% severe back pain during the procedures. A day after the procedure was performed, 10% of patients reported a severe headache and 81% worsening LBP. The headaches were attributed to neuraxial leakage of contrast. In a large, retrospective study assessing adverse outcomes in 1,357 patients undergoing 4,400 cervical discograms, Zeidman et al.[141] reported complications occurring in 0.6% of patients and 0.16% of disc injections. The complications included 7 cases of discitis and 1 abscess. Prophylactic antibiotics were only administered to those patients at high risk for infection. Other possible complications of discography include meningitis, spinal headache, subdural or epidural abscess, intrathecal hemorrhage, arachnoiditis, nerve root injury, paravertebral muscle pain and contusions, postprocedural pain exacerbation, vasovagal reactions, allergic reactions, and damage to the disc including but not limited to herniation.[54,105,142-145]

Table 9. Cost-Benefit Analysis of Lumbar Discography as a Screening Test for Spinal Fusion

1. Average cost of 3-level lumbar discography without computed tomography or conscious sedation—$1,140
2. Average cost of lumbar spinal fusion surgery—$33,800
3. Total cost of discography plus spinal fusion 100 patients with suspected discogenic pain and an expected positive discographic confirmation rate of 83%—($33,800 × 83) + ($1140 × 100) = $2,919,400
4. Total cost of the same 100 patients proceeding directly to surgery—($33,800 × 100) = $3,380,000
5. Total savings by using lumbar discography as a presurgical screening tool—($3,380,000 − $2,919,400)/100 = $460,000, or $4,600 per patient.

NOTE. This analysis is based on the following assumptions:
1. All patients presenting for discography have abnormal MRIs and would otherwise undergo spinal fusion.
2. All patients have failed more conservative efforts to treat their pain.
3. Disc stimulation is performed according to the standards presented in Table 4.
4. The rate of positive confirmatory disc stimulation is 83%, based on a previously published study conducted at Walter Reed Army Medical Center.[123]
5. All patients with positive discography will undergo spinal fusion.
6. The costs of discography and lumbar spine fusion are based on the reimbursement rates Walter Reed receives from the Dept. of Veterans Affairs, and loosely resembles the DRG payment schedule of TRICARE (Fall 2004).

Cost Analysis of Lumbar Discography

To accurately assess the cost-effectiveness of discography, one needs to account for a multitude of variables that inevitably play into the calculation. These include but are not limited to the screening of discography patients to eliminate patients without discogenic LBP and those at high risk for false-positive results; the rate of positive discography; the likelihood patients with positive discograms will proceed to surgery; the type and success rate of the surgical procedure done in patients with positive discograms; and the total cost of discography that reflects the number of discs injected, the use of CT scanning, and whether or not sedation is used. Table 9 represents a very simplified cost-benefit analysis of lumbar discography as a screening test for spinal fusion.

Future Areas of Investigation

Wherein lies the future of clinical research on discography? The main issue that needs to be resolved is what effect discography has on surgical outcomes. This includes not only open surgical procedures but also minimally invasive procedures such as IDET and nucleoplasty. Once this question is answered, the next step would be to determine how best to improve specificity without compromising sensitivity. One way to accomplish this would be to conduct a randomized, prospective study comparing surgical outcomes in patients who have undergone preoperative discography screening with and without manometry. Another might be to determine whether or not correlating discographic findings with behavioral characteristics (e.g., facial expressions and withdrawal response) and/or physiological parameters (change in heart rate) has any effect on accuracy. Behavioral signs have been previously reported to enhance the objectivity of the physical examination in LBP patients.[146,147] Although previously used during discography,[50,110,126] their effect on accuracy has not been formally studied. The association between heart rate changes and pain response during disc stimulation is an area we are currently investigating.

Another promising area of discography research involves the injection of analgesic substances into the disc, thereby rendering the procedure therapeutic. Recent animal studies have shown that nerve roots exposed to exogenous tumor necrosis factor-α (TNF-α) mimic the histologic changes observed with herniated discs[43] and that the administration of intramuscular or intravenous anti–TNF-α can prevent nucleus pulposus-induced spinal nerve injury.[148] In a prospective open-label study by Karppinen et al.,[149] the authors infused 2 mg/kg of the anti–TNF-α agent infliximab in 10 patients with severe sciatica secondary to disc herniation. After 3 months, 90% of the study group reported >75% decrease from baseline pain. TNF-α inhibitors may also prove effective in discogenic back pain. In a retrospective review of 20 patients who received the TNF-α antagonist etancercept subcutaneously (average number of doses 1.8, range 1-5) for cervical or lumbar discogenic pain, Tobinick and Britschgi-Davoodifar[150] reported a significant decrease in the Oswestry Disability Index, from a mean score of 54.5 at baseline to 9.8 at latest follow-up (mean 230 days). A larger follow-up study by the same authors conducted in patients with both axial and radicular low back and neck pain yielded similarly promising results.[151] The doses used in these clinical trials were the same as those used to treat rheumatoid arthritis and inflammatory bowel disease and may be associated with significant side effects. Injecting these drugs intradiscally at 1/50th or 1/100th of the systemic dose would be expected to minimize the incidence of side effects and maximize the benefit.

Conclusions

So where do we stand with discography, and what are its prospects for the future? Although it is true that discography, with or without CT, is the only imaging tool that allows a clinician to relate pathology with symptoms, the significance of this remains unclear. In regards to symptomatic disc herniations, the enhanced accuracy and safety of MRI has made discography an archaic procedure for this purpose. For internal disc disruption, CT-discography is a more accurate diagnostic tool than plain MRI,[2,60,69,72] although T2-weighted MR images may detect some pathology missed on plain discograms.[57] Based on cadaver studies, discography seems to be more sensitive for detecting radial rather than transverse or concentric tears in the AF.[63,64]

When assessing discographic pathology, it is necessary to correlate provoked pain with anatomic abnormalities. Disc stimulation should always be evaluated in the context of the high risk for false-positive discograms in some patients.[52,53] In such patients, we would recommend injecting 2 adjacent control discs.

The critical element for the future of discography lies in its ability to improve patient outcomes as a screening test, and presently the evidence for this is lacking. In the 2 studies directly comparing fusion outcomes between patients who underwent preoperative discography and those who had not, the results are conflicting.[4,6] For IDET, all published studies have routinely used preoperative discography so that no conclusions can be drawn. With disc replacement surgery, although the studies are split as to whether discography was used during preoperative assessment, the differences in outcome measures, length of follow-up, surgical technique used, and methodological flaws render any comparisons futile.

What is clear is that there is a wide discrepancy in the use of lumbar discography to treat discogenic LBP. The routine use of discography as a screening measure before IDET, a minimally invasive surgical procedure, and the sporadic use of the procedure before spinal arthrodesis is inconsistent. The authors speculate that given the low risk and unique information discography provides, the procedure should be cautiously used before invasive surgical procedures designed to treat discogenic LBP except when the evidence implicating a particular disc(s) as the pain generator is overwhelming. However, this recommendation presumes that the results of disc stimulation must be considered in the context of other diagnostic screening tests and with consideration to the propensity of patients with preexisting psychopathology and somatization symptoms to have false-positive pain provocation. Clinical studies are needed to better elucidate the role discography will assume in the diagnosis of disc pathology in the future and to determine what effect, if any, it has on the surgical treatment of discogenic pain.

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