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Disc Stimulation and Patterns of Referred Pain

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Study Design. Prospective, within-subjects, observational experimental design.

Objectives. To determine the pattern of pain response to noxious stimulation of the intervertebral disc.

Summary of Background Data. Experimental studies have demonstrated that noxious stimulation of interspinous ligaments, facet joints, and paravertebral muscles causes referred pain into the extremity, with the distal extent of radiation dependent on the intensity of stimulation. Analogous studies have not been performed on the lumbar intervertebral disc.

Methods. A total of 25 consecutive patients meeting inclusion criteria completed a pain diagram before undergoing the intradiscal electrothermal annuloplasty procedure. The location, intensity, and familiarity of any pain provoked during disc heating were correlated with presenting symptoms and duration of heating.

Results. During disc heating, 68% of patients reported exact reproduction of their presenting pain, in both pain quality and location. None of the patients experienced unfamiliar pain during the procedure. The pattern of pain reproduction was consistent; pain originated proximally and progressed distally as stimulus intensity increased.

Conclusion. Noxious stimulation of the intervertebral disc may result in low back and referred extremity in patients presenting with these symptoms. The distal extent of pain produced depends on the intensity of stimulation. Disc stimulation may reproduce pain that extends to below the knee. [Key words: intervertebral disc, pain diagrams, referred pain] **Spine 2002;27:2776–2781**

Radicular pain results from irritation of axons of a spinal nerve or neurons in the dorsal root ganglion.[5] In contrast to radicular pain, referred pain results from activation of nociceptive free nerve endings (nociceptors) in somatic or visceral tissue, a common example being upper extremity pain resulting from cardiac ischemia. The physiologic basis for referred pain is convergence of afferent neurons onto common neurons within the central nervous system. The central nervous system may not be able to distinguish which part of the body is responsible for the input into these common neurons.[6]

In the case of the lumbar spine, afferents from the innervated somatic structures, including the muscles, ligaments, synovial joints, and discs, converge on the same neurons in the dorsal horn as the afferent nerves from the lower extremity.[14,19] Theoretically, noxious stimulation of any of these spinal structures can be associated with referred pain into the extremity.[27] Experimental studies have confirmed that noxious stimulation of interspinous ligament,[23] facet joint,[29] and paravertebral muscles[12] causes referred pain that can radiate into the distal extremity and can extend below the knee. Furthermore, in each of these studies, the association between the intensity of the noxious stimulus and the pattern of pain provoked was similar, as pain originated proximally and spread distally as stimulation intensity increased. One would expect to see the same pattern with noxious stimulation of the intervertebral disc; however, analogous studies have not been performed.

Intradiscal electrothermal annuloplasty (IDET) has recently been introduced as a treatment for low back pain.[10,21,31] The procedure involves introducing a wire electrode into the disc that, when heated, ostensibly denatures collagen and coagulates nerve endings in the anulus.[32] Although there is considerable controversy regarding both the mechanism of action and efficacy of IDET,[17] there is no doubt that IDET delivers a noxious stimulus, *i.e.*, heat, to the disc, and that the stimulus is highly localized and precisely controllable. Accordingly, IDET offers an opportunity to study the pattern of referred pain provoked by noxious stimulation of lumbar intervertebral discs, and in particular to correlate the pattern of pain with the intensity of the stimulation. The purpose of the current study was to determine if noxious stimulation of the intervertebral disc by IDET resulted in the same observed pattern of referred pain as noxious stimulation of other somatic structures of the spine; *i.e.*, back pain with lower levels of stimulus intensity and radiation of pain distally with increasing intensity of stimulation.

Methods

Data were gathered prospectively from a consecutive series of patients who were enrolled in a concomitant outcome study on the IDET procedure for the treatment of low back pain.[10] The efficacy of IDET procedure was not the concern of the present study; therefore, no attempt was made to correlate treatment outcomes with any of the variables defined in the present study. All patients underwent a clinical evaluation, magnetic resonance imaging (MRI), and lumbar discography. The inclusion criteria were as follows: 1) low back pain with or without lower extremity pain; 2) extremity pain, if present, was poorly localized, aching pain, which was less bothersome than the patient's low back pain; 3) no tension signs in response to straight-leg raising; 4) no neurologic deficits; 5) no evidence of nerve root compression on MRI; 6) no significant loss of disc height; 7) discography positive at one level only, with a positive disco-

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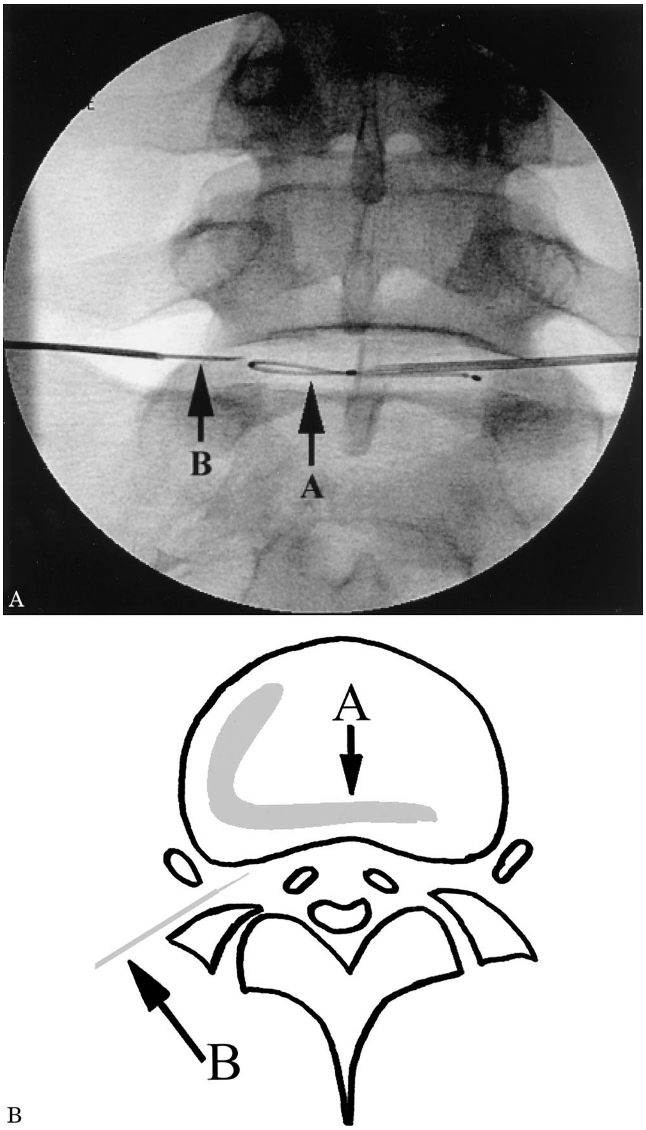

Figure 1. **A,** Radiograph of catheter (A, arrow) and temperature probe (B, arrow) in place. **B,** Disc area heated (A, arrow) and temperature probe (B, arrow) placement (epidural space).

gram defined as concordant pain provocation at a level of >6/10, a significant structural abnormality (anular tear or disc degeneration), and a negative control level; and 8) no previous surgery.

Intradiscal heating was performed using a navigable intradiscal catheter with a thermal resistive coil. The 30-cm catheter (SPINECath, Oratec Interventions, Menlo Park, CA) has a 6-cm active tip and was inserted into the disc *via* a 17-gauge introducer, using standard discographic technique. The active tip was advanced anterolaterally inside the disc and directed to turn posteriorly. If the catheter incorporated the entire posterior anulus (Figure 1), position was considered ideal. If the catheter position was less than ideal, the patient was excluded from the study. The catheter was connected to a generator that produces electrical current that is converted to heat on encountering the resistive tip of the catheter. The generator continuously displays the actual temperature of the catheter tip during heating. Once placed, the catheter temperature was increased incrementally according to a standardized protocol. The mean ± SD end temperature was 87 ± 14 C and the mean ± SD duration of heating was 13.5 ± 3.7 minutes.

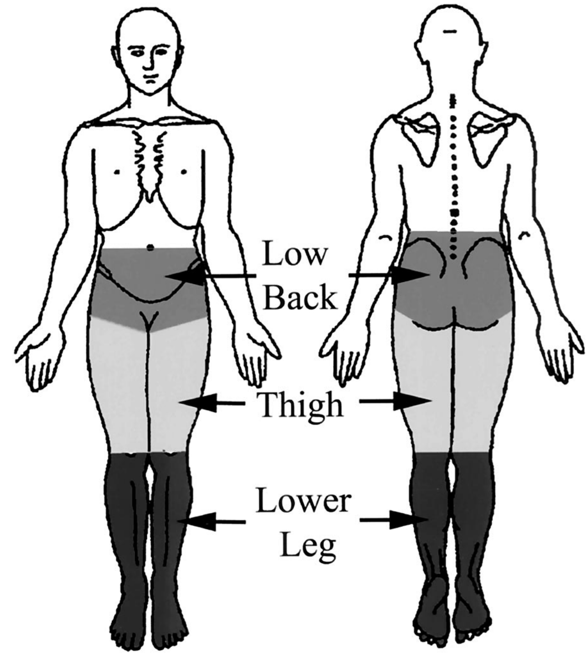

Figure 2. Primary pain zones: low back (including hip/buttock), proximal leg (thigh), and lower leg (below the knee).

Immediately before the procedure, each patient completed a pain diagram. Three primary pain zones were defined: low back (including hip/buttock), proximal leg (thigh), and lower leg (below the knee) (Figure 2). Before IDET, pain was scored as present or absent for each location. During the procedure, pain location, intensity, and quality were assessed at 30-second intervals. Patients, although under light sedation, remained lucid and capable of providing the necessary responses during the procedure. Pain location was defined as present or absent for each of the predetermined pain zones. Pain intensity was scored using a standard analogue 10-point numerical rating scale: 0 = no pain; 10 = worst possible pain. Pain quality was defined as familiar or unfamiliar. Pain that was familiar was defined as concordant, whereas unfamiliar pain was defined as nonconcordant.

A pain threshold is the intensity of a stimulus that is required to produce pain of a certain intensity.[16] The intensity of pain produced by heating of a tissue is a function of nociceptor temperature.[38,39] The temperature of a nociceptor depends on a variety of different factors, including the magnitude of the applied heat, the distance from the thermal energy source to the nociceptor, the heat transfer characteristics of the tissues intervening between them, and time of heating.[39] For this reason, the intensity of stimulus applied during experimental heating studies may be defined as either the applied temperature or the duration of heating.[8,39] For each of the three primary pain zones, two pain thresholds were defined. The temperature threshold was defined as the temperature of the catheter tip, at which pain of >6/10 was provoked, whereas the time threshold was the duration of heating before pain of >6/10 was provoked.

To ensure that heat was not being transferred from the catheter to the neural elements of the spinal canal, a temperature probe was inserted into the epidural space in the first 14 patients and the epidural temperature at maximum catheter temperature recorded (Figure 1).

Table 1. Number of Patients With Certain Pattern of Presented and Reproduced Pain

		Provoked Pain Location During IDET		
Pain Drawing Pain Location		Low Back Only (Including Buttocks/Hip)	Low Back and Thigh	Low Back, Thigh, Lower Leg
Low back only (including buttocks/hip)	9	9	—	—
Low back and thigh	11	6	5	
Low back, thigh, lower leg	5	1	1	3

IDET = intradiscal electrothermal annuloplasty.

The Statistical Package for the Social Sciences (SPSS 9.0.0) was used for statistical data analysis. Chi-square tests were applied to the patterns of presenting pain and pain provoked during the procedure. Spearman correlations were applied to patterns of presenting and provoked pain. Paired-samples *t* test was used to show differences in pain thresholds for different sites of pain.

Results

Presenting Pain Locations

Of a total of 33 patients enrolled in the concomitant IDET study, 25 patients satisfied the inclusion criteria of the current study. The initial pain diagrams revealed 9 patients with low back pain only, 11 patients with low back and thigh pain, and 5 patients experiencing back, thigh, and lower leg pain (Table 1).

Pain Provoked During IDET

All pain provoked during IDET was concordant. Low back pain was provoked in all patients. None of the patients had provocation of pain during IDET in a location where they did not have it before the procedure; *i.e.*, only patients who presented with extremity pain had provocation of extremity pain during the procedure. Other than pain, there were no neurologic sensations elicited during the procedure (*e.g.*, numbness, paresthesiae). Overall, 68% of patients (n = 17) had exact reproduction of their presenting symptom complex (Table 1). No patient reported pain in a location where it was not experienced before. Pearson χ^2 test demonstrated a significant association between the presenting pattern of pain and the pattern of pain provoked during IDET ($\chi^2 = 15.4$, $P = 0.004$). Spearman correlation between presenting pain and provoked pain during IDET were significant both for thigh (correlation coefficient [CC] = 0.56, $P = 0.003$) and for lower leg (CC = 0.74, $P < 0.0005$). A significant correlation was also found between provoked thigh pain and provoked lower leg pain (CC = 0.49, $P = 0.012$).

Pain Thresholds

Both the temperature and time thresholds for the low back varied considerably between subjects. The mean ± SD threshold temperature for low back pain was 81.7 ± 16.4 C, and the mean ± SD time threshold for low back pain was 5.8 ± 2.9 minutes.

The temperature and time thresholds for thigh pain also varied considerably between subjects. However, for those patients who had provocation of thigh pain, both the temperature threshold and the time threshold for thigh pain were always higher than the thresholds for back pain. The mean ± SD temperature threshold for thigh pain was 97.7 ± 25.4 C, and the mean ± SD time threshold for thigh pain was 10.1 ± 4 minutes. Paired samples test showed a significant difference between temperature thresholds for low back and thigh (t value with 8 degrees of freedom = −3.8, $P = 0.005$) as well as for time thresholds between low back and thigh (t value with 8 degrees of freedom = 5.4, $P = 0.001$).

Among the three patients who experienced reproduction of lower leg pain, the temperature threshold for lower leg pain was higher than the threshold temperature for thigh pain in two subjects and the same in one subject. However, in each of those three patients, the time threshold for the lower leg was higher than the thigh, which was higher than the back. Among these three patients the mean ± SD temperature threshold for low back pain was 81.7 ± 19.4 C, thigh pain 90.0 ± 26.4 C, and for lower leg 92.7 ± 26.4 C. Although revealing a trend, the differences between these temperatures were not statistically significant because of the small number of patients. The average time threshold for low back pain in these patients was 4.5 ± 1.8 minutes, for thigh pain was 8.3 ± 5.3 minutes, and for lower leg pain was 11.8 ± 5.3 minutes. The difference in time threshold between lower leg and thigh was marginally significant (t value with 2 degrees of freedom = 2.6, $P = 0.1$), whereas the difference in time threshold between low back and thigh was not significant ($P = 0.22$).

Consequently, in all cases, back pain was reproduced before any leg or thigh pain. Moreover, in those patients in whom pain extended along the entire lower limb, pain was consistently reproduced in the order back, thigh, and leg.

Discussion

This study demonstrated that noxious stimulation of the intervertebral disc results in low back and referred extremity pain, with the distal extent of pain produced depending on the intensity of stimulation. These results are remarkably consistent with a number of experimental studies on referred pain resulting from noxious stimulation of deep somatic spinal structures.[12,23,29]

There have been a number of previous studies on the pattern of pain response resulting from noxious stimulation of the intervertebral disc. However, in contrast to the present study, none of those studies attempted to correlate the intensity of the stimulus with the location of pain provoked.

The two principal methods of stimulating the disc used in previous studies on pain provocation have been internal stimulation by injection and external stimulation by probing at the time of operation under local anesthesia. Although disc injection studies have not correlated pain location with intensity of stimulation, the results from these studies are consistent with ours, in that they demonstrated that radiating pain into the extremity can be reproduced with disc injection, in the absence of nerve root compression.[3,18,28,33] In some cases, the pain provoked by disc injection has extended to below the knee.[3,28] A potential criticism of these studies is that disc injection may stimulate not only the nerve endings in the disc, which would be expected to cause referred pain, but may also stimulate the nerve root and/or dorsal root ganglion, which would be expected to result in radicular pain. Disc injection could result in radicular pain either by leakage of dye or nuclear material onto a nerve root or dorsal root ganglion[7] or in bulging of the disc[30] with mechanical neural irritation.

Disc probing under direct vision on awake patients undergoing surgery ensures that there is no possibility of radicular pain secondary to unintended neural irritation. The results from disc probing studies have yielded contradictory results. Older studies[11,13,35] showed that pain radiating into the extremity commonly occurs during disc stimulation. However, a more recent, widely quoted, study by Kuslich *et al*[25] found little extremity pain provocation with disc probing. The method of disc stimulation used in the present study, intradiscal thermal stimulation, is similar to disc probing in that no fluid is injected into the disc, avoiding both disc bulging and leakage of chemicals onto the nerve root as sources of leg pain. It has an important advantage over disc probing, however, as the noxious stimulus applied to the disc was controlled and quantified, allowing correlation between the intensity of the stimulus and the pain location. It is entirely possible that the results of Kuslich *et al*[25] would be similar to those of other investigators if a standardized stimulus of sufficient intensity had been applied.

The neural mechanisms responsible for peripheralization of pain with increased stimulus intensity can only be postulated. The location of pain perceived in response to a stimulus is ultimately determined by what area of the cerebral cortex is activated. One explanation for our findings could be that although the majority of free nerve endings in the disc project to cortical neurons corresponding to the back ("back cortical neurons"), a lesser number project to cortical neurons corresponding to the thigh ("thigh cortical neurons"), and an even smaller number project to cortical neurons corresponding to the lower leg ("lower leg cortical neurons").

For a particular cortical neuron to fire, it must be brought to threshold. In general terms, this can happen in two ways: through spatial summation (a large number of afferent units projecting to the neuron firing at relatively low frequencies) and/or temporal summation (a small number of afferent units projecting to the neuron firing at high frequencies).[37]

If the majority of free nerve endings in the disc project to "back" cortical neurons and a lesser number to "thigh" and "lower leg" cortical neurons, then at low levels of noxious stimulation to the disc, one would expect that "back" cortical neurons would be brought to threshold, *via* spatial summation, whereas the "thigh" and "lower leg" cortical neurons would not. With increased intensity of stimulation "thigh" and eventually "lower leg" cortical neurons could be brought to threshold, despite the relatively low number of disc free nerve endings projecting to them because of the increased firing frequency of the individual neurons, leading to temporal summation.

One interesting finding in this study is that there was a significant correlation between the location of pain before the IDET and the pain provoked during the IDET. The intensity of pain provoked by stimulation of a structure will depend on two factors: the intensity of the stimulus and the sensitivity of the structure.[34] The sensitivity of a structure will depend on a number of factors, an important one being the sensitivity of the nociceptors in the structure being stimulated. Under pathologic conditions, nociceptors in tissue become sensitized, manifested as an increased response by neurons to noxious stimuli,[2] a phenomenon called primary hyperalgesia.[6] Given that all the patients in the study had chronic low back pain because of disc pathology, one would expect that the nociceptors in their discs would be sensitized but that the degree of sensitization would be highly variable, depending on the severity of pathology. The more sensitized the nociceptors in the discs, the greater the firing frequency for a given level of stimulus and, therefore, the greater the degree of temporal summation. One hypothesis for the correlation seen between presenting pain and provoked pain is that those who presented with extremity pain had more sensitized nociceptors; therefore, "lower leg" cortical neurons were more likely to be activated. In support of this hypothesis is the observation that those patients who presented with back, thigh, and leg pain had provocation of thigh pain at lower levels of stimulation than those patients who presented with back and thigh pain only. This would suggest more highly sensitized nociceptors in those patients, which was manifested not only by provocation of lower leg pain but also by provocation of thigh pain at a relatively low level of stimulation.

Although referred pain from noxious stimulation of disc nociceptors is the most likely explanation for the pattern of perceived pain observed in this study, another potential explanation is radicular pain resulting from heating of spinal nerves. This is unlikely for two reasons. First, temperature mapping studies have demonstrated that the temperature reached in the outer anulus during IDET is not significantly greater than ambient temperature.[24,36] This finding was confirmed in the present study, as temperatures recorded in the anterior epidural space were normal. Second, if nerve root heating were the mechanism responsible for extremity pain, all patients should have been equally affected, whether or not they had extremity pain to begin with. This was not the case, as none of the patients that presented with back pain only had provocation of extremity pain during IDET. Furthermore, if extremity pain were a result of nerve heating, we would expect that the quality of the pain would reflect neural irritation rather than referred pain, *i.e.*, the pain would be sharp and lancinating rather than dull and diffuse. All of the patients who had provocation of extremity pain felt that it was familiar pain, *i.e.*, dull, aching, and poorly localized, indicating that this represented provocation of referred pain rather than radicular pain.

Being able to differentiate between referred pain and radicular pain in patients with disc disorders is important because these two types of pain have different causal mechanisms and therefore may require different treatment.

If a patient presents with disc herniation and nerve root compression on imaging studies, radicular pain is often assumed. However, a number of studies have demonstrated that the correlation between nerve root compression and pain is poor.[4,9,20,26] It is possible that leg pain in some patients with disc herniation may be referred pain, particularly in those individuals with small, contained herniations or bulges, where the degree of nerve root compression is less than in those with extrusions.

One criterion that has been suggested to differentiate between radicular and referred pain is the extent of distal radiation, with a common clinical axiom being that pain radiating below the knee represents radicular pain rather than referred pain.[22]

However, there is evidence to suggest that the extent of distal radiation of pain is not a valid indicator of nerve root pathology. In a comprehensive study that correlated distal extent of pain with a variety of diagnostic studies for nerve root pathology, Haldeman *et al* demonstrated that radiation of pain below the knee did not correlate with a positive straight-leg raise test, neurologic deficits, or nerve root compression on imaging studies.[15]

Despite the evidence to the contrary provided by Haldeman *et al*,[15] recent studies have continued to define pain radiating below the knee as radicular.[22] The fact that experimental noxious stimulation of the disc can produce referred pain radiating into the extremity, as demonstrated in the present study, indicates that noxious stimulation secondary to pathologic disc lesions (*i.e.*, naturally occurring noxious stimulation resulting from chemical or mechanical events in the disc) can do the same. This is consistent with the evidence of Haldeman *et al*[15] and is further support for not using the distal extent of radiation as a diagnostic tool. The importance of not relying on the distal extent of pain in surgical decision-making is illustrated by Atlas *et al*, who found no difference in surgical outcomes between patients with proximal extremity radiation, distal extremity radiation, and nerve root compression, in patients undergoing discectomy.[1] One possible explanation for their findings is that some of the patients with distal radiation of pain may have had referred pain, which one would not expect to improve following partial disc excision.

■ Conclusion

Noxious stimulation of the intervertebral disc can result in referred pain that extends into the lower extremity and can extend distally below the knee. This confirms the suggestions of a number of previous investigations that the intervertebral disc can refer pain into the lower extremity and that pain radiating below the knee is not necessarily a result of nerve root compression. Future research in this area should concentrate on improving understanding of the pathophysiology of referred and radicular pain, improving diagnostic strategies for differentiating between the two, and correlating the outcome from such diagnostic strategies with treatment.

■ Key Points

- Noxious stimulation of the intervertebral disc may result in low back and referred extremity pain.
- The distal extent of pain produced depends on the intensity of stimulation.
- Disc stimulation may reproduce pain that extends to below the knee.

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