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Lumbar disc high-intensity zone: the value and significance of provocative discography in the determination of the discogenic pain source

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Abstract Disagreement still exists in the literature as to the significance of the high-intensity zone (HIZ) demonstrated on magnetic resonance imaging (MRI) as a potential pain indicator in patients with low back pain. A prospective blind study was therefore conducted to evaluate the lumbar disc high-intensity zone with the pain provocation response of lumbar discography. Consecutive patients with low back pain unresponsive to conservative treatment and being considered for spinal fusion were subjected to MRI followed by lumbar discography as a pre-operative assessment. The discographer was blinded to the results of the MRI scans. We used the chi-squared test to analyse our results. Ninety-two HIZs were identified in 73 patients, mainly occurring at L4/5 (48%) and L5/S1 (35%). Significant correlation

was found between abnormal disc morphology and the HIZ ($P < 0.001$). In morphologically abnormal discs (grades 3, 4 and 5), there was a significant correlation between the HIZ and exact or similar pain reproduction ($P < 0.001$). The sensitivity, specificity and positive predictive value for pain reproduction were high, at 81%, 79% and 87% respectively. The nature of the HIZ remains unknown, but it may represent an area of secondary inflammation as a result of an annular tear. We conclude from our study that the lumbar disc HIZ observed on MRI in patients with low back pain is likely to represent painful internal disc disruption.

Key words Low back pain · High-power field MRI · High-intensity zone · Discography

Introduction

Aprill and Bogduk first described what was to become known as the high-intensity zone (HIZ) seen on magnetic resonance imaging (MRI) of the lumbar spine [2]. This was a 'high-intensity signal (bright white) located in the substance of the posterior annulus fibrosus, clearly dissociated from the signal of the nucleus pulposus in that it is surrounded superiorly, inferiorly, posteriorly and anteriorly by the low-intensity (black) signal of the annulus fibrosus and is appreciably brighter than that of the nucleus'. Provocative discography revealed that the HIZ represented painful internal disc disruption with a positive predictive value of 86%.

There have been two subsequent published studies describing the significance of the HIZ. Schellhas et al. (1996) confirmed the above findings with a similar rate of pain concordance (87 vs 86%) [9], while Ricketson et al. (1996) concluded that the HIZ is not necessarily associated with a concordant pain response [6]. Therefore, debate still exists as to the significance of this MRI radiological entity.

With the more powerful 1.5-T superconducting magnets at our disposal, similar to that used by Schellhas et al. (1996) [9], the resolution of MRI scans has greatly increased, and HIZs have become easier to detect. The purpose of our prospective blind study was to further evaluate the value of discography on HIZs observed on high-

power field MRI scans of the lumbar spine in patients with low back pain.

Materials and methods

We undertook a prospective analysis of consecutive patients with the predominant symptom of low back pain. These patients had failed conservative treatment and were being considered for spinal fusion. They were first subjected to high-power field MRI and subsequently to awake lumbar discography.

MRI evaluation was performed by one of our two spinal radiologists, both of whom have considerable experience in spinal imaging and the ability to interpret the HIZ according to the criteria as originally described [2]. A second evaluation of the MRI scans was later conducted by one of the authors prior to discography results. We utilised a 1.5-T superconducting magnet (Siemens) to consistently obtain high-resolution images using sagittal 4-mm-thick, fast spin echo, T2-weighted images (TR 3500–4500, TE 90–100). These provided excellent contrast between the nucleus pulposus and the outer annulus, and allowed recognition of the presence of HIZs (Fig. 1). Using a modified version of Thompson's classification [11], the degree of disc dehydration of each individual disc level subjected to discography as seen on MRI was graded as 0 (normal), 1 (mild), 2 (moderate) or 3 (severe).

Between July 1995 and June 1996, discography was performed by one of our authors, who had considerable experience in the technique. The discographer was blinded to the MRI scans and HIZ findings, and asked to study the appropriate levels of lumbar intervertebral discs. One percent lignocaine deep regional anaesthesia was employed, with the occasional use of mild intravenous sedation as required. All patients received 1 g cephadrine antibiotic 1 h prior to the procedure. A standard postero-lateral extrapedicular approach using a two-needle technique was used (26-G × 6-inch needle threaded through a 22-G × 5-inch needle). The final

DISCOGRAPHY

1) Level: L2/3, L3/4, L4/5, L5/S1 Other: _____

2) Contrast material: _____
Volume contrast injected: _____ mls

3) Resistance to injection: high / low pressure

4) Morphology:
(Please circle/tick)

Annular	
Unilobed	
Bilobed	Grade 1 – Cottonball
Fissuring (anterior)	2 – Bilobed
(posterior)	3 – Fissuring
Extravasation (anterior)	4 – Multiple fissures
(posterior)	5 – Rupture

5) Pain assessment/response:
(Please circle/tick)

Intensity			
Before	After		
5	5	+ ve	Spontaneous behaviours Guard/Brace/Withdraw Rubbing Grimacing Sighing Verbalising
4	4		
3	3		
2	2		
1	1		
0	0	- ve	

PAIN RESPONSE

SIMILAR Dissimilar Negative

Fig. 2 Discogram proforma for the assessment of intervertebral disc morphology and pain concordance

Fig. 1A,B Mid-sagittal T2-weighted magnetic resonance (MR) images (TR 3500, TE90) of the lower lumbar spine of patients with chronic lumbar back pain. **A** shows a uni-segmental degenerate disc at L5/S1 with a high-intensity zone (HIZ) in the posterior annulus (arrow); **B** shows a three-level degenerate disc (L3/4, L4/5 and L5/S1), with a corresponding HIZ at each level in the posterior annulus (arrows). Subsequent discography revealed that there was exact reproduction of low back pain at each HIZ level

needle position was confirmed by antero-posterior and lateral fluoroscopic imaging, following which the disc was injected using a 5-ml syringe containing Iohexol nonionic contrast (Omnipaque, Nycomed (UK) Ltd).

Each level was assessed and only considered positive for pain reproduction (pain concordance) by following the flow chart on our standardised pain assessment proforma (Fig. 2). Patients were asked to rate their average daily level of back pain on a scale of 0 (no pain) to 5 (unbearable pain), and were then reassessed again at each individual disc level during the procedure, using the same pain scale. A score of 3 and above was deemed significant for pain reproduction.

During discography, the subjective experience of pain provocation for each injected disc level was divided into three categories: no pain, untypical/dissimilar pain and typical/similar pain. Simultaneous review of the pain-related behaviour from start to end of the contrast injection was observed, as was described by Keefe et al. [5], and modified by Spratt et al. [10]. A positive pain-related behavioural response was recorded if two or more of the following five responses were observed: guard/brace/withdraw, rubbing, grimacing, sighing, or verbalisation. The procedure was terminated at each disc level when

1. A firm end point was reached (usually 2 ml contrast volume had been introduced), or
2. There was frank reproduction of pain symptoms, or

Morphological grade (Pathology: normal/abnormal)		Degree of disc degeneration as seen on discography
1. Cottonball (NORMAL)		Regular and smooth, uniformly appearing discogram
2. Lobular (NORMAL)		Slightly irregular, bilobed, 'hamburger' appearance representing early degeneration
3. Fissuring (ABNORMAL)		Degenerate but contained disc usually with posterior and radial annular tear or fissuring
4. Multiple fissuring (ABNORMAL)		More advanced but contained degenerate disc with multiple fissuring throughout
5. Ruptured with leakage (ABNORMAL)		Advanced and grossly degenerate, ruptured disc with contrast extravasation throughout

Fig.3 The radiological appearance, as revealed by in vivo discograms, of the different morphological stages of disc degeneration (modified from Adams et al. [1])

3. Gross extra-discal leakage of contrast occurred, usually posteriorly into the epidural space (5 ml or more injection volume being usual in these cases)

At least two discs were evaluated, including the disc with the HIZ. We graded the radiological appearance of the discograms using a morphological grading system for the stages of disc degeneration, a modification of the version that was described by Adams et al. [1]. The radiological grading system went from grade 1 – no degeneration – to grade 5 – a ruptured, non-contained disc with gross dye leakage (Fig. 3). Grades 1 and 2 are considered morphologically normal, whereas grades 3, 4 and 5 represent disc degeneration with annular fissuring (posterior), multiple annular fissures and disc rupture respectively (Figs.4,5). Computed tomography (CT) was not performed.

Results were tabulated and the chi-squared test was implemented for the analysis of statistical significance, because the data collected were non-parametric, and there were no underlying assumptions about the data being normally distributed. The *P*-value was set at $P < 0.05$ and the null hypothesis (H_0) states that "there is no difference between the presence or absence of the lumbar disc high-intensity zone and pain reproduction on discography, and any observed pain reproduction is merely chance variations from the random presence of the HIZ".

Results

In total, there were 144 patients subjected to high-power field MRI followed by lumbar discography, with 305 lumbar intervertebral disc levels injected. Of these, 73 patients demonstrated at least one HIZ(+ve) disc, which would suggest that HIZs occurred in 51% of our patients with low back pain referred for discography. A sub-total of 170 intervertebral disc levels was injected in these

Fig.4 **A** Mid-sagittal T2-weighted MR image (TR 3500, TE90) of the lower lumbar spine of a patient with chronic lumbar back pain, demonstrating two-level HIZs at L4/5 and L5/S1 (arrows). **B** Lateral projections of three-level discographic images demonstrating a normal-looking grade 2 morphology at L3/4, grade 3 degeneration at L4/5 and grade 4 degeneration at L5/S1. At both L4/5 and L5/S1, the HIZs corresponded exactly to the patient's back pain symptoms

Fig.5A,B Examples of lateral and antero-posterior projections of discographic images, showing a grade 4 morphologically abnormal L4/5 disc and a grade 5 grossly degenerate L5/S1 disc. The introduction of contrast into each disc level reproduced the patient's back symptoms. More than 6 ml contrast volume was injected into L5/S1, resulting in multi-directional para-discal extravasation of contrast, indicating that the disc had ruptured

73 patients: 2 were annular injections and entry was not achieved in 13. Discography was therefore performed on 155 disc levels. Ninety-two of these levels exhibited a HIZ, of which 87 levels were degenerate, 3 were post-discectomy levels and 2 had corresponding spondylolysis.

The average age of the patients with a HIZ was 42 ± 9 years (mean $\pm$ 1 SD), with a male to female ratio of approximately 5:2. All patients had a predominance of low

HIZ frequency

Fig. 6 Bar histogram showing the location of the 92 intervertebral disc HIZs identified in 73 patients

back pain symptoms of at least 6 months' duration refractory to conservative treatment, with or without a pseudo-radicular component and/or minimal radicular symptoms. The subjects were suffering from moderate to severe low back disability (mean Oswestry Disability Index = 55; 95% CI = 52, 58).

HIZs occurred mainly at L4/5 (48%) and L5/S1 (35%), were infrequent at L3/4 (14%), rare at L2/3 (2%) and not seen at L1/2 (Fig. 6). One lumbarised S1 segment (L6/S1) exhibited a HIZ. Fourteen patients had HIZs at two disc levels and four patients had HIZs at three disc levels.

Almost all HIZ(+ve) discs were morphologically abnormal on discography; 48% (44/92) exhibited grade 3 morphology, 40% (37/92) grade 4 morphology, and 11% (10/92) grade 5 morphology (Table 1). A small proportion of HIZ(-ve) discs also showed annular tear(s) and fissuring, but the majority were morphologically normal. There was a significant correlation between abnormal disc morphology and the presence of the HIZ ($P < 0.001$). The respective sensitivity, specificity and positive predictive value (PPV) of the HIZ as an indicator of abnormal disc morphology (grades 3, 4 or 5) were high, at 77%, 97% and 99% (Table 1).

Table 1 Outcome table showing the relationship between lumbar disc morphology and high-intensity zones (HIZs) in the 155 disc levels investigated in 73 patients

HIZ	Discogram grading				
	1	2	3	4	5
+ve	0	1	44	37	10
-ve	14	22	10	13	4

$df = 4$, $P < 0.001$

For grades 3, 4 and 5 abnormal morphology, sensitivity = 77% (91/118), specificity = 97% (36/37), and positive predictive value = 99% (91/92)

No intervertebral disc that exhibited a HIZ had a normal level of disc hydration, as seen on the T2-weighted MRI images (Table 2). There was a statistically significant correlation between the presence of the HIZ and disc degeneration ($P < 0.001$). The sensitivity of HIZ(+ve) discs, either grade 1, 2 or 3, for showing disc dehydration was moderate at 68%, whilst the specificity and PPV were both very high at 100% (Table 2), i.e. all HIZ(+ve) discs were invariably dehydrated.

There was a significant correlation between the presence of the HIZ and exact (or typical) pain reproduction on discography ($P < 0.001$). For exact pain reproduction, the respective sensitivity, specificity, and PPV were all high at 78%, 78% and 83% (Table 3).

Table 2 Outcome table showing the relationship between the level of disc dehydration, as seen on magnetic resonance imaging (MRI), and the presence of HIZs in the 155 disc levels investigated in 73 patients

HIZ	Disc degeneration on MRI			
	0	1	2	3
+ve	0	10	28	56
-ve	19	19	15	10

$df = 3$, $P < 0.001$

For MRI disc dehydration (grades 1, 2, and 3), sensitivity = 68% (92/136), specificity = 100% (19/19), and positive predictive value = 100% (92/92)

Table 3 Outcome table showing the pain reproduction on discography and the disc HIZ status in the 155 intervertebral disc levels investigated in 73 patients

HIZ	Pain reproduction		
	Exact/typical	Similar/untypical	None
+ve	76	5	11
-ve	21	2	40

$df = 2$, $P < 0.001$

For exact (or typical) pain reproduction, sensitivity = 78% (76/97), specificity = 78% (42/58), and positive predictive value = 83% (76/92)

Table 4 Combined outcome table showing the relationship between disc morphology, HIZ status and pain reproduction in the 155 intervertebral disc levels investigated in 73 patients

HIZ	Pain reproduction			
	Grade 3,4,5 with exact or similar pain	Grade 3,4,5 with no pain	Grade 1,2 with pain	Grade 1,2 with no pain
+ve	80	11	1	0
-ve	19	8	3	33

$df = 3$, $P < 0.001$

For grades 3, 4 and 5 abnormal morphology with exact or similar pain reproduction, sensitivity = 81% (80/99), specificity = 79% (44/56), and positive predictive value = 87% (80/92)

It was evident that not all grade 5 morphologically abnormal discs were painful. For this reason, we created a contingency table looking at the relationship between the HIZ(+ve) discs and pain reproduction according to the morphological grade. The combined table demonstrated that for morphologically abnormal discs (grades 3, 4 and 5), there was a significant correlation between HIZ(+ve) discs with exact or similar pain reproduction ($P < 0.001$). The overall sensitivity and specificity of HIZ(+ve) discs for being painful on discography were high, at 81% and 79% respectively, as was the PPV at 87% (Table 4).

Discussion

State of the art MRI scanners are now equipped with powerful 1.5-T superconducting magnets. We have two such scanners at our unit, and consequently HIZs have become more readily recognisable. A greater overall awareness has also developed that the HIZ is a pain indicator [2, 9]. Therefore, the enhanced detection capability combined with the increased focus on the HIZ has resulted in a higher reporting rate and consequently an increased prevalence rate of 51% in our patients. However, our patients were a highly select group who had been considered for spinal fusion, and the increased prevalence reported may not represent the true prevalence of this condition. The prevalence of HIZs has been previously reported in one study group as 28% in patients attending a spinal radiology practice [2].

Previous studies have reported that pain is consistently reproducible in discs exhibiting a HIZ. Aprill and Bogduk, and Schellhas et al. calculated the PPV to be as high as 86% and 87% respectively [2, 9]. However, Ricketson et al. were not able to show this correlation [6]. The small number of HIZs identified in the Ricketson study could explain the negative correlation they observed. We conducted a prospective blind study and detected a large number of HIZs, i.e. 92 HIZs detected in 73 patients. Statistical analysis revealed that, in the presence of a HIZ, the PPV for exact pain reproduction was high, at 83% (Table 3).

Our study differed from the others because we did not utilise the Dallas discogram classification for internal disc disruption [2, 6, 8, 9]. CT following discography was not routinely performed for the following three reasons. Firstly, the current financial climate restricts its use; secondly, we feel that the high dose of radiation exposure seems unnecessarily dangerous; and thirdly, the grading system [1] utilised provided us with an adequate method for classifying disc disruption and degeneration.

Applying our modified grading system [1], there was a significant correlation between the presence of HIZ and grades 3, 4, and 5 abnormal disc morphology (Table 1). The sensitivity, specificity, and PPV were all high, at 77%, 97% and 99% respectively. We believe that this modified grading system for classifying the stages of disc

disruption [1] is very similar to the Dallas discogram classification, and is a useful tool when applied to discography images, particularly if CT is not indicated.

We observed that some degenerate discs had gross extravasation of contrast, indicating that the annulus had ruptured, i.e. grade 5 morphology. Consequently, the intradiscal pressure was not maintained and pressure nociceptors within the annulus were not stimulated to produce pain. This observation is more commonly seen in post-discectomy discs; a condition that was not investigated in our study. Abnormal as they may be, grade 5 discs with or without the presence of a HIZ may therefore be painless. Taking this into consideration, we constructed a contingency table, Table 4, which shows that for morphologically abnormal discs (grades 3, 4 and 5) there was a significant correlation between HIZ(+ve) discs with exact or similar pain reproduction ($P < 0.001$) and a PPV of 87%. Our PPV value mirrors that of Aprill and Bogduk, and Schellhas et al. [2, 9].

The nature of the HIZ is as yet undetermined. The grading system utilised in our study suggests that the majority of HIZ(+ve) discs demonstrated either a grade 3 or grade 4 abnormal disc morphology. These HIZ(+ve) discs, which exhibit radial tears and fissuring, may be the MRI representation of the type II radial fissures that were described by Yu et al. in cadaveric discs [14]. The HIZ has also been proposed to be a fluid-filled zone, possibly of nuclear origin, but because it enhances more than the nucleus or annulus, it may represent an area of secondary inflammation as a result of the annular tear(s) with ensuing oedema [2, 6, 9, 12]. In vivo and in vitro studies of prolapsed intervertebral discs, showing areas of neovascularity and granulation tissue formation that enhances with gadolinium-DTPA, may offer us further clues as to the true nature and significance of the lumbar HIZ [3, 4, 7, 13]. Histological examination of en bloc specimens of the posterior annulus excised at the time of posterior interlaminar fusion procedures may provide us with additional clues as to the nature of the HIZ.

Although discography remains an invasive procedure, its use is still generally considered an invaluable adjunct as a preoperative investigation to evaluate the intervertebral disc as a pain source, and prevails as the only dynamic test for this form of investigation.

We conclude from our study that the significant correlation of the lumbar disc HIZ with pain reproduction during discography implicates the HIZ as a pain indicator. The lumbar disc HIZ appears to represent symptomatic posterior annular tears and fissuring within the intervertebral disc. Its sensitivity and specificity as a sign of either annular disruption or pain was high, and its PPV for a disrupted, symptomatic painful disc was 87%.

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