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ORIGINAL ARTICLE

Reconsidering high intensity zones: its role in intervertebral disk degeneration and low back pain

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Abstract

Purpose High intensity zones (HIZ) in the lumbar intervertebral disk (IVD) can be associated with degenerative changes which may ultimately manifest as low back pain (LBP). However, the relationship between the prevalence of HIZ and lumbar degenerative parameters is still unclear. The purpose of this study was to determine the prevalence of HIZ in the lumbar spine, analyze the independent relationship between HIZ and lumbar degenerative parameters measured on MRI and X-ray and determine the association between HIZ and the presence of LBP.

Methods A retrospective review of MRI data, X-ray data, and radiology reports for 136 consecutively recruited patients, above 18-years-age and with both lumbar MRI and X-ray scans was conducted. 57 patients with HIZ were identified. Patients without HIZ (n = 79) made up the control group.

Results HIZ was prevalent in 41.9% of patients and in 11.0% of all lumbar IVDs. The odds of developing HIZ were 6.4 (Exp(B) 6.4, 95%CI [3.157–12.988]) and 3.0 (Exp(B) 3.0, 95%CI [1.603, 5.674]) times higher in IVDs with disk bulge/protrusion and nucleus degeneration, respectively. Odds of HIZ was also increased in disks with larger IVD angle (Exp(B) 1.1, 95%CI [1.034, 1.169]). The odds of patients presenting to imaging with LBP was 3.0 (OR 3.0, 95%CI [1.478–6.338]) times higher in the HIZ compared to the control group.

Conclusions HIZ was prevalent in 41.9% of participants that were recruited in this study. Nucleus degeneration, disk bulge/protrusion and increased IVD angle were found to be independently associated with HIZ and since there is an increased likelihood of LBP, we posit that HIZ is likely a symptomatic and clinically meaningful diagnostic tool in the assessment of LBP.

Keywords Low back pain · High intensity zone · Disk degenerative disease · Intervertebral disk degeneration · Lumbar spine

Introduction

Many degenerative classifications of the lumbar spine have been devised to try and illustrate the degenerative process and provide insight on the symptomatic intervertebral disk (IVD). High intensity zones (HIZs), originally defined as a bright white signal in the posterior annulus fibrosus (AF) on T2 weighted (T2W) MRI are thought to be pathognomonic of a symptomatic IVD [1] (Fig. 1). However, literature regarding HIZ and its predictive value as the cause of discogenic LBP remains controversial.

Studies have found HIZ to be related to LBP [2–4]. Contrarily, other studies have observed HIZ in asymptomatic patients and found non-significant relationships between HIZ and LBP, leading researchers to question the significance of HIZ as a marker for LBP [5, 6]. To explain this Bogduk postulated that low intensity zones are asymptomatic fissures

IRB approval was obtained from the Human Research Ethics Committee of the University of New South Wales (NRR-HC210515) for retrospective collection of anonymized patient's lumbar MRI scans, X-ray scans, radiology reports, and demographic data from digital archives of St.

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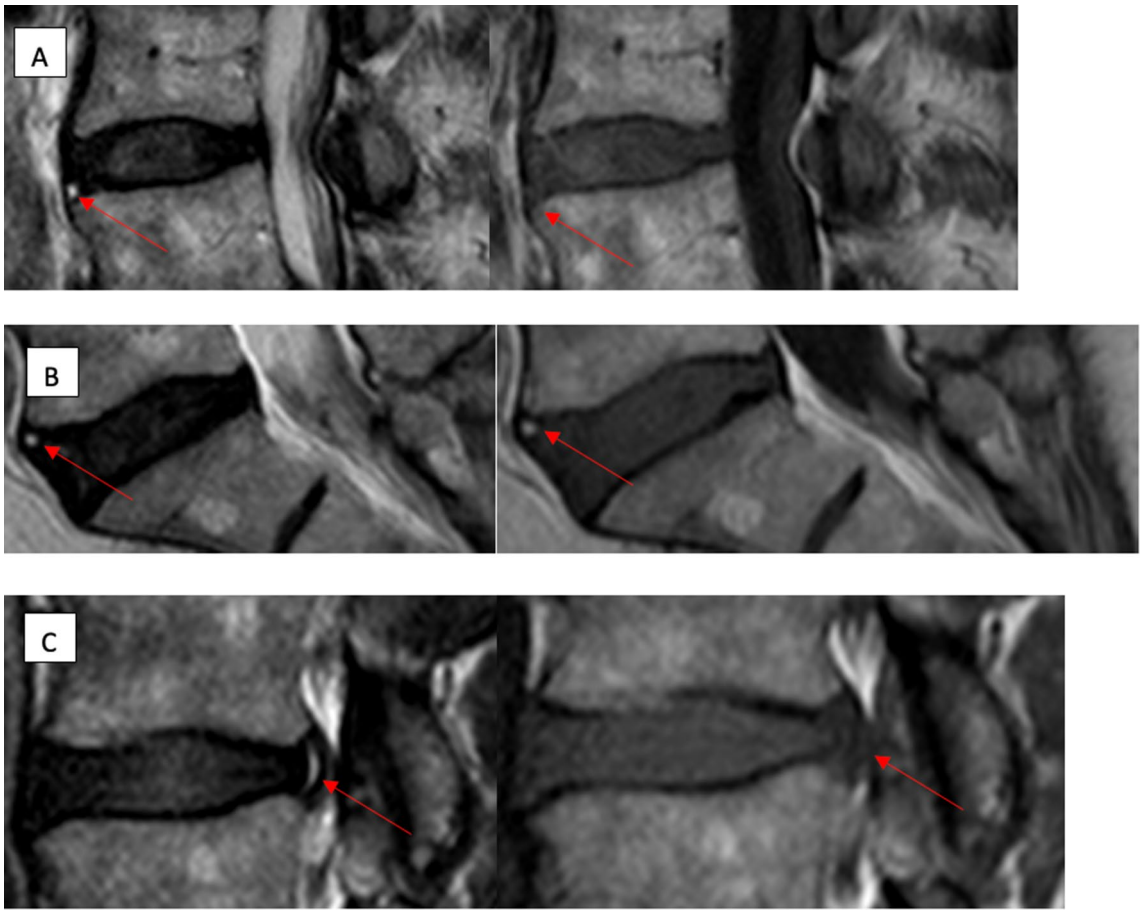

Fig. 1 Example High Intensity Zones on T1 and T2-weighted Magnetic Resonance Imaging. A sagittal slice from the magnetic resonance imaging (MRI) of three different patients with high intensity zones (HIZ) with different T1-weighted MRI classifications. (**a**) Represents an anterior HIZ on T2W MRI with corresponding isointense signal on T1W MRI, (**b**) Represents an anterior HIZ on T2W MRI with corresponding hyperintense signal on T1W MRI and (**c**) Represents a posterior HIZ on T2W MRI with corresponding hypointense signal on T1W MRI

that need to be activated to form symptomatic HIZs. Subsequently, Liu et al. observed that symptomatic HIZs were significantly associated with a signal intensity of ≥ 50% of the cerebrospinal fluid (CSF) [3]. Many authors have suggested that HIZ is a part of the disk degeneration process, finding significant associations between HIZ and degenerative changes, whilst others have not [1, 4–7].

To date, discography is still regarded as the gold standard for diagnosing LBP, however, it is highly invasive. Recent advances in literature regarding the pathogenesis of HIZ and using T1 weighted (T1W) MNRI scans have provided insight into the clinical significance of HIZ as a diagnostic indicator for LBP. Studies have observed HIZs exist circumferentially around the IVD, adding to the original definition that HIZs are posterior radial tears [1, 7]. HIZ has been proposed by authors to be fluid-filled zones in the AF resulting from inflammatory oedema [8]. Gadolinium DTPA-MR imaging has demonstrated enhanced signal intensity surrounding HIZs, positing HIZ's association with extradural inflammation [9]. Histological studies have also backed up the presence of granulation tissue and resulting oedema [8]. Additionally, cadaveric studies have found that HIZs were generated by mucoid fluids containing fat [10]. Therefore, a single-subject multimodal approach was necessary to produce a more detailed definition of different HIZ phenotypes which can provide a higher clinical significance.

The studies mentioned previously have a variety of limitations, including inconsistency in the field strength of MR, no uniform consensus on the true definition of HIZ, and selection basis. As a result, the prevalence of HIZ and its relationship with LBP and lumbar degenerative parameters is still heavily debated. No studies to date have evaluated the relationship between HIZ and degenerative parameters observed on X-ray as potential risk factors. Hence, we performed a retrospective cohort study to assess the prevalence of HIZ in the lumbar spine, establish the independent relationships between IVDs with HIZs and

lumbar X-ray and MRI degenerative parameters and identify the association between patients with HIZs and LBP.

Materials and methods

Study design and patient population

The study was IRB approved and conducted as a retrospective cohort study of adult patients (over 18 years of age) who had both lumbar MRI and X-ray scans conducted between January 2000 and May 2021 from our imaging centre. Written consent was obtained from all patients to be included in the study. The most recent MRI and X-ray scans were used if multiple scans of the same patient were available in the database. All MRI scans, X-ray scans, radiology reports, and demographic data were consecutively extracted. Patients were excluded if they had a history of lumbar spinal surgery prior to imaging or was diagnosed with a specific spinal pathology (i.e., vertebral fracture, malignancy, spinal infection, spondylarthritis, cauda equina etc.).

Data collection

The standing lateral X-ray images, axial and sagittal T1W and T2W MRI scans of the lumbar spine were assessed, and data points were collected before reading the radiology report. SS was trained by an experienced spine surgeon and back pain researcher with extensive experience in interpreting radiological images (XC). HIZ was defined as a lesion observed on T2W MRI where the signal intensity is at least 50% of the cerebrospinal fluid, contained within the AF and distinctly apart from the signal of the nucleus pulposus (NP) (Fig. 1) [3]. The location of the HIZ was classified as either anterior or posterior. X-ray degenerative parameters measured include disk heigh index, transforaminal height, IVD angle, sagittal alignment, sagittal translation, and the presence of bony spurs [5–8]. MRI degenerative parameters include nucleus degeneration, endplate changes, IVD protrusion/bulge, IVD extrusion, spinal stenosis, foraminal stenosis, and paraspinal muscle fatty infiltration. The specific measurement protocols of the lumbar degenerative parameters are outlined in Table 1. The radiology reports were prepared by board certified radiologists. The presence of LBP was defined as the inclusion of "LBP", "Lumbar pain", etc. in the radiological notes by the referring doctor as a clinical indication for MRI.

Data points for thirteen patients were also measured by a second rater (CS) to evaluate inter-rater reliability, and for a second time three weeks after initial extraction by the first author (SS) to evaluate intra-rater reliability. To enhance the quality and applicability of this study, each rater was blinded to their own measurements and findings of the other.

Table 1 Measurement protocols for lumbar degenerative MRI and X-ray parameters

MRI parameter	**Protocol**
Nucleus degeneration	Pfirmann grade ≥ 3 was classified as nucleus degeneration
Endplate changes	Hypointense and hyperintense bone marrow and vertebral endplate lesions visible on T1W and T2W MRI
IVD bulge/protrusion	Disk displacement beyond posterior edges of the adjacent vertebral edges. Disk protrusion was defined as NP displacement beyond the AF
IVD extrusion	Diameter of displaced disk material was larger than the length of the base of the displaced disk material
Spinal stenosis	Lee Y.G. et al. classification (grade 0 = no lumber stenosis, grade1,2&3 = lumbar stenosis) [11]
Foraminal stenosis	Lee S. et al. classification (grade 0 = no foraminal stenosis, grade1,2&3 = foraminal stenosis) [12]
Paraspinal fatty infiltration	Protocol described by Mandelli et al. [13]. Lean cross-sectional area (LCSA), total CSA and fatty CSA (FCSA) given by Image J. Lean fraction (LCSA/CSA) and fat fraction (FCSA/CSA) were calculated
X-ray parameter	**Protocol**
Disk height index	Ratio of sum of anterior and posterior IVD height to the sum of the superior and inferior endplate length [14]
Transforaminal height	Maximum distance between the inferior border of the superior pedicle and the superior border of the inferior pedicle
IVD angle	Angle between the inferior endplate of the superior vertebrae and the superior endplate of the inferior vertebrae
Sagittal alignment	Lumbar lordotic angle. Sacral horizontal angle. Pelvic tilt. Pelvic incidence (sum of sacral horizontal angle and pelvic tilt)
Sagittal translation	White and Panjabi method was used to measure anterior and posterior IVD slip percentage. Sagittal translation was classified as > 15% IVD slip [15]
Presence of bony spurs	Syndesmophytes and osteophytes observable on sagittal X-ray

Note: MRI magnetic resonance imaging, *IVD* intervertebral disk, *T1W* T1 weighted, *T2W* T-2 weighted, *NP* nucleus pulposus, *AF* annulus fibrosus, *CSA* cross sectional area

Statistical analysis

An independent t-test was used to analyze the difference in continuous radiological parameters between the two groups. Cohen's d plot was used to calculate the effect size of the difference between two continuous groups [16]. Odds ratio (OR) with 95% confidence intervals (95%CI) was calculated to estimate risk. Pearson Chi-Square test was used to assess the independence of association and Phi and Cramer V was used to assess the strength of association between HIZ phenotypes and degenerative parameters and the presence of LBP. Logistic regression models were used to analyse the confounding status of lumbar degenerative parameters to determine the independent relationships between radiological parameters and HIZs. Inter-rater reliability was assessed using the intraclass coefficient estimates (ICC) based on single-rating, consistency, 2-way random effects model, and intra-rater reliability was assessed using ICC based on single-rating, absolute agreement, 2-way fixed effects model. ICC values of < 0.05, 0.5–0.75, 0.75–0.90, and > 0.90 indicated poor, moderate, good, and excellent reliability, respectively [17]. Statistical analyses were conducted using the commercially available software SPSS (version 20, IBM Corporation, New York, USA). The level of statistical significance was set at 5% ($\alpha = 0.05$).

Results

Demographics

A flowchart depicting patient inclusion, exclusion, and separation into groups is shown in Fig. 2. Table 2 shows the demographic and clinical information of the included patients. Out of the 136 patients included in the study, 57 met the criteria for HIZ. The remaining 79 patients without HIZ were chosen as controls to compare with the cohort of HIZ patients. There were 40% more males than females who had HIZ (34 vs. 23, $P < 0.005$).

Prevalence of HIZ

HIZs were noted in 57 (41.9%) patients. Out of the 680 lumbar IVD levels analyzed, 75 (11.0%) had HIZs. There was a higher number of posterior HIZ (n = 48) compared to anterior HIZ (n = 27). Posterior HIZs were more prevalent in lower lumbar levels compared to anterior HIZs in higher lumbar levels. The overall prevalence of anterior and posterior HIZ in each lumbar level is shown in Fig. 3.

Comparison of IVDs with and without HIZs

Disk levels with HIZs had more disk bulges/protrusion (84% vs. 37%, $p < 0.0001$), nucleus degeneration (76% vs. 38%, $p < 0.001$), and foraminal stenosis (40% vs. 25%, $p < 0.01$), and higher IVD angle (9.5 ± 4.2 vs. 8.2 ± 3.9, $p < 0.005$) when compared to disk levels without HIZs. The mean IVD angle for disks with HIZ was 0.35 standard deviations above disks without HIZ (Cohen's d = 0.349, 95%CI [0.112, 0.621]). The Gardner-Altman estimation plots for IVD angle was shown in Fig. 4. The was no significant association and difference when comparing anterior and posterior HIZ (Table 3). HIZs and nucleus degeneration, disk bulge/protrusion, and foraminal stenosis were strongly (χ^2=39.088, phi and cramer V = 0.240, $p < 0.001$), very strongly (χ^2=60.365, phi and cramer V = 0.298, $p < 0.001$) and moderately (χ^2 =7.534, phi and cramer V = 0.105, $p < 0.01$) associated, respectively.

Independent relationship between HIZ and radiological parameters

The binary logistic regression model was statistically significant, $\chi^2(4) = 82.390$, $p < 0.001$. Disks with protrusion and nucleus degeneration were 6.4 (Exp(B) 6.404, 95%CI [3.157–12.988]) and 3.0 (Exp(B) 3.016, 95%CI [1.603, 5.674]) times more likely to have HIZ than healthy disks, respectively. Foraminal stenosis was non-significant. Increasing IVD angle was associated with an increased likelihood of HIZ (Exp(B) 1.100, 95%CI [1.034, 1.169]) (Table 4).

HIZ and low back pain

Patients with HIZs had a higher prevalence of LBP referral for MRI compared to the control (72% vs. 46%, $p < 0.005$). HIZ and LBP referral was very strongly positively associated (χ^2=9.367, phi and cramer V = 0.262, $p < 0.005$). The odds of having LBP were 3.1 times higher in HIZ patients when compared to the control group (OR 3.061, 95%CI [1.478–6.338]) (Table 5).

Intra-rater and inter-rater reliability

The intra-rater reliability for all measurements methods of the lumbar degenerative parameters included in this study was good-to-excellent from 0.764 (0.629–0.852) to 0.983 (0.972, 0.989) apart from sagittal translation which only had a moderate ICC of 0.579 (0.393, 0.720). The inter-rater reliability of the measurement methods was good-to-excellent from 0.776 (0.657, 0.857) to 0.982 (0.969, 0.989) apart from sagittal translation and sacral slope which both

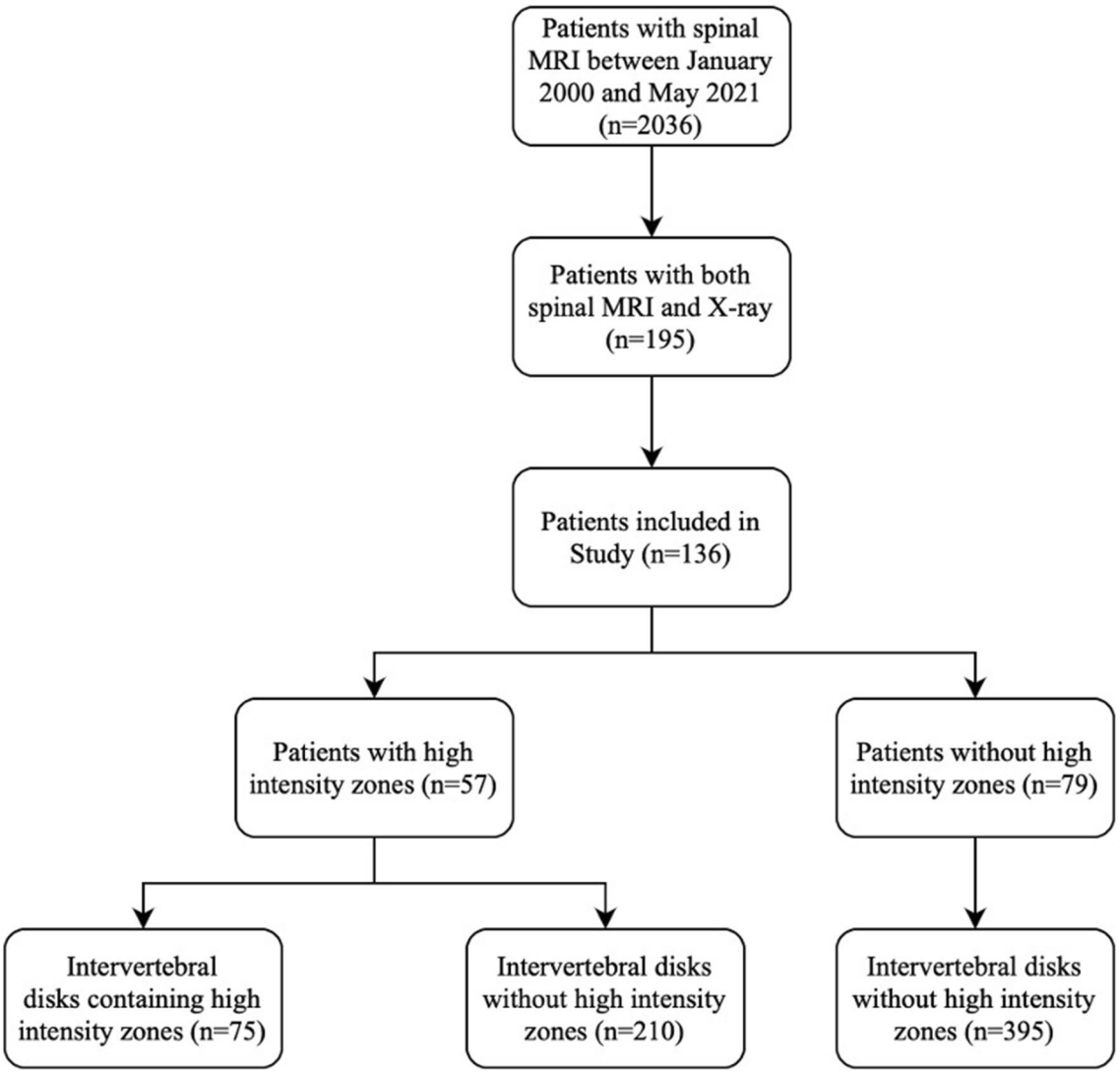

Fig. 2 Flowchart Depicting Patient Inclusion, Exclusion and Separation of Patients and Intervertebral Disks. Flowchart representing the process of patient inclusion and exclusion of the study with specific data on the number of patients included/excluded at each step. It also shows how the patients included in the study were divided at a population-based level and a disk based level

had moderate reliability with an ICC of 0.703 (0.556, 0.808) and 0.734 (0.331, 0.911), respectively (Table 6).

Discussion

To our knowledge, this is the first cohort study that reports the independent relationship between recumbent MRI-based HIZ, gravity-loaded standing x-rays, degenerative MRI parameters and clinical variables via a logistical regression. The prevalence of HIZ reported in studies has varied greatly. Our results showed that the prevalence of HIZs in this consecutively selected population was approximately 41.9%, with 11.0% of IVDs affected. Posterior HIZ was most common at the lower lumbar levels of L5/S1 (21/25) followed by L4/L5 (12/18), replicating many previous published results [2, 5, 6]. Dissimilar to other papers, we found 36% of the total HIZ to be anterior, with the most occurring at L3/L4 followed by L2/L3. This supports the postulation that upper lumbar (L1-L4) IVD degeneration has a developmental origin whilst lower lumbar (L4-S1) abnormalities are associated with aging and BMI [18]. However, this study cannot validate previous results as previous studies did not perform pan-disk analysis and did not have a uniform definition for HIZ.

This study was the first to introduce sagittal alignment measurements on X-ray. However, none were significantly associated with HIZ which demonstrates that HIZ is possibly a local disk based segmental issue with no associations to sagittal imbalance. The logistic regression model

Table 2 Patient demographic radiological, and clinical information

Parameter	HIZ	Controls	P-value	Total
Number of patients	57	79		136
Age (mean ± SD) (years)	66.4 ± 15.0	67.3 ± 15.0	0.729	66.96 ± 14.9
Gender (M/F)	34/23	26/53	**< 0.005***	60/76
Presence of IVD degeneration (n)	123			
No IVD degeneration	13			
One level	28			
Two levels	35			
Three levels	28			
Four levels	23			
Five levels	9			
Lumbar levels with HIZ (n)	75			
L1/2	1			
L2/3	13			
L3/4	18			
L4/5	18			
L5/S1	25			
LBP indication for MRI	41 (72%)	36 (46%)	**< 0.005***	77 (57%)

Note: *IVD* intervertebral disk, *LBP* low back pain, *HIZ* high intensity zone, *SD* standard deviation, *M* male, *F* female, *MRI* magnetic resonance imaging, *n* number of patients, *parameters that are statistically significant ($P < 0.05$)

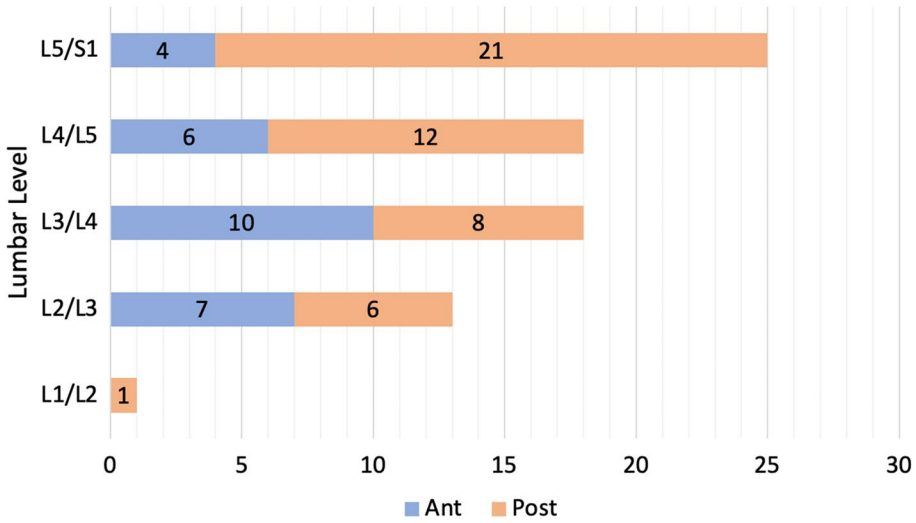

Fig. 3 Prevalence of Anterior and Posterior High Intensity Zone Based on Lumbar Level. Bar chart illustrating the prevalence of anterior and posterior high intensity zones based on the lumbar level

showed that the odds of developing HIZ was 6.4 and 3.0 times higher in disks with disk bulge/protrusion and disk degeneration, respectively. Increasing IVD angle was also found to increase the risk of developing HIZs. When confounding for factors, foraminal stenosis was found to be non-significant. These results support the view that degenerative findings can be a precursor to HIZ. The pathophysiological basis behind these associations can be attributed to the altered biomechanics of a degenerative disk. Many cadaveric studies have found reduced stiffness and increased range of motion in disks with HIZ. Instability in the disk results in increased fluid movement through the annular tear into the outer annulus causing disk degeneration and bulging/protrusion and consequently the formation of a HIZ [19]. Many articles have found a significant correlation between disk degeneration and foraminal width and foraminal area [20], which explains why the model has found that foraminal stenosis, independently, is not a risk factor for HIZ. Some caution is needed when interpreting these results as some technical assumptions may have been violated by the model. The measurements for each individual IVD were conducted independently, however, they were taken from the same

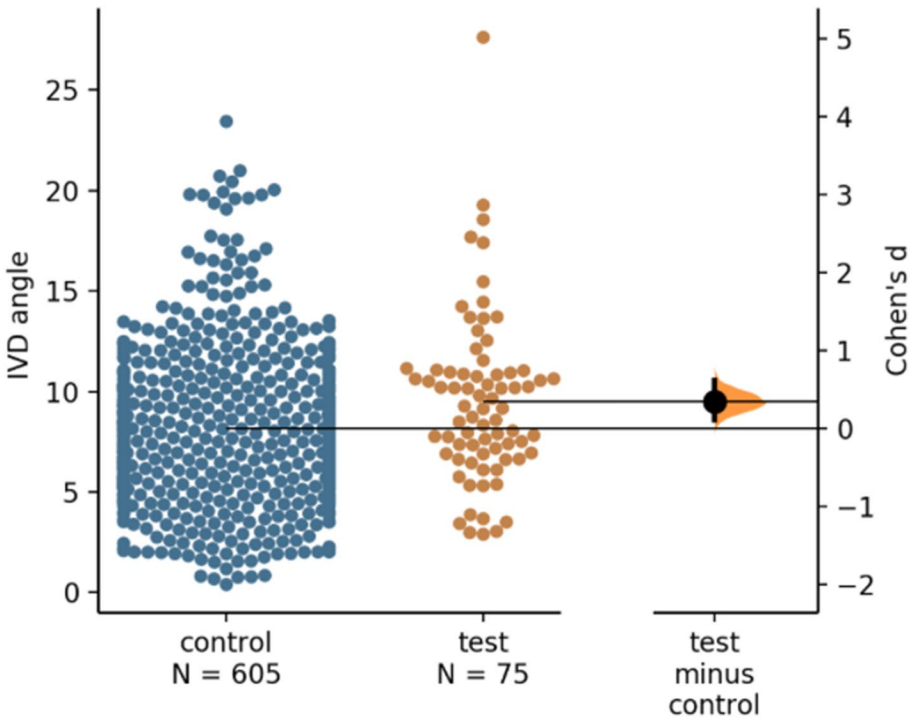

Fig. 4 Gardner-Altman Estimation Plot Comparing Intervertebral Disk Angle Between Disks with High Intensity Zones (test) and Disks without (control). Both IVD angle for disks with HIZ and disks without are plotted on the left axis. The mean difference is plotted on a floating axis on the right as a bootstrap sampling distribution and is depicted as a dot. The 95% confidence interval is indicated by the ends of the vertical error bar. Each data point is represented as a dot on the plot

patient (L1-S1) violating the independence of observation assumption [21]. This technical violation is very common in our field and many studies have found region specific differences within the lumbar spine to exist. As a result, the error due to correlated outcomes is minimized.

The clinical significance of HIZ is still heavily debated by researchers. The proportion of the population in industrial countries that have experienced LBP is at 84%. Approximately 85% percent of these cases are classified as non-specific LBP [22]. In our study, the percentage of patients with LBP in the HIZ group was higher at 72% compared to the control (46%) and the odds of having LBP were 3.1 times higher in the HIZ group compared to the control. This finding is due to the use of a qualitative definition for HIZ which allowed us to omit low intense zones [3]. It also underscores the fact LBP is only correlated to HIZs when large amounts of oedema and/or fatty infiltration occur because of inflammation or there is a large herniating process of the NP. This is supported by findings of mucoid fluids and inflammatory tissue in cadaveric and histology studies [8, 9, 23]. As a result, our results suggest that HIZ may be used independently in routine MRI and clinical assessments of patients with LBP, other degenerative parameters should be used in conjunction to formulate a diagnosis. Ultimately, HIZ may help in decreasing the number of non-specific LBP diagnoses.

Although there was higher prevalence of endplate changes in disks with HIZ compared to disks without (8% vs. 7.5%), this was not significant. Endplate changes represent severe toxic inflammatory responses in the vertebrae causing bone-oedema, re-vascularization, fatty infiltration, and subsequent repair which are all observed differently on MRI [24]. Therefore, future prospective pathohistological studies coupling T1W and T2W MRI are critical. It will allow us to further study the pathological connections between HIZ and lumbar degenerative parameters to see the progression of HIZ and determine if HIZ is a result of degeneration, if degeneration is a result of HIZ, or if HIZ and degeneration are both indications of nucleus pulposus material herniating into the annulus fibrosus meaning that there exists no functional difference between them.

The results of our studies were impacted by certain limitations. The first is that it is a retrospective cohort study that did not analyze patients' clinical and radiological trends over time. Certain demographic information such as body mass index and socioeconomic status was not recorded. The population only included patients referred for MRI imaging, therefore the prevalence of HIZ in patients who do not present to a clinical or is not imaged is difficult to assess. The mean age was high in both the case and control groups, signifying the need for further studies that only look at certain age ranges. The nature (i.e., VAS) and duration of pain as well as disability scores were not recorded. Classification of patients into groups with and without pain based on the referral letters is imperfect and may be susceptible to

Table 3 Associated variables with HIZ, position of HIZ and HIZ T1W classifications at affected lumbar levels

Parameter	HIZ	No HIZ	p-value	Posterior HIZ	Anterior HIZ	P-Value
Total disks, n	75	605		48	27	
MRI						
Nucleus degeneration, n (%)	57 (76%)	231 (38%)	**< 0.001***	38 (79%)	19 (70%)	0.392
Disk Bulge/Protrusion, n (%)	63 (84%)	224 (37%)	**< 0.001***	42 (88%)	21 (78%)	0.270
Extrusion, n (%)	1 (1.3%)	11 (1.8%)	0.764	1 (2%)	0 (0%)	0.450
Endplate changes, n (%)	6 (8%)	45 (7.4%)	0.862	5 (10%)	1 (4%)	0.304
Paraspinal lean CSA, mean% (s.d.)	75.42 (10.58)	74.81 (11.61)	0.872	74.35 (9.41)	77.37 (12.41)	0.306
Paraspinal fatty CSA, mean% (s.d.)	24.58 (10.58)	24.95 (10.78)	0.939	25.65 (9.41)	22.63 (12.41)	0.306
Spinal Stenosis, n (%)	20 (27%)	145 (24%)	0.808	13 (27%)	7 (26%)	0.988
Foraminal Stenosis, n (%)	30 (40%)	152 (25%)	**< 0.01***	20 (42%)	10 (37%)	0.694
X-ray						
IVD angle, degrees (s.d.)	9.51 (4.16)	8.16 (3.84)	**< 0.005***	9.86 (4.61)	8.88 (3.19)	0.281
DHI, mean (s.d.)	0.55 (0.11)	0.54 (0.72)	0.784	0.56 (0.12)	0.53 (0.08)	0.258
Transforaminal height, mean cm (s.d.)	19.9 (3.54)	20.2 (3.91)	0.493	19.80 (3.59)	20.08 (3.52)	0.741
Vertebral slip, mean% (s.d.)	5.85 (5.83)	5.86 (6.33)	0.994	5.63 (6.03)	6.24 (5.54)	0.658
Sagittal Translation, n (%)	3	41	0.356	3	0 (0%)	0.185
Presence of bony spurs, n (%)	27 (36%)	176 (29%)	0.221	16 (33%)	11 (41%)	0.521
Parameter	**HIZ**		**No HIZ**		**P-value**	
Total Patients, n	57		79			
Low back pain, n (%)	41 (72%)		36 (46%)		**< 0.005***	
Lumbar Lordosis, degrees (s.d.)	52.96 (12.88)		53.36 (14.17)		0.863	
Sacral slope, degrees (s.d.)	35.17 (8.14)		35.73 (10.56)		0.731	
Pelvic Tilt, degrees (s.d.)	22.25 (8.36)		21.98 (7.48)		0.850	
Pelvic incidence, degrees (s.d.)	57.42 (10.00)		57.71 (12.71)		0.882	

Note: Pearson χ^2 test, independent t-test and one way ANOVA tests were used to assess the association and compare different lumbar degenerative parameters at high intensity zone affected levels. *HIZ* high intensity zone, *T1W* T1 weighted, *IVD* intervertebral disk, *n* number of patients, % percentage, *s.d.* standard deviation, *parameters that are statistically significant (P < 0.05)

Table 4 Binary logistic regression model to determine the risk factors of HIZ

Parameter	Exp(B)	95%CI for Exp(B)	P-value
Nucleus degeneration	3.016	1.603–5.674	**< 0.001**
Disk bulge/protrusion	6.404	3.157–12.988	**< 0.001**
IVD angle	1.100	1.034–1.169	**< 0.005**
Foraminal stenosis	0.648	0.369–1.138	0.131

Note: A binary logistic regression model was used to determine the confounding status of degenerative parameters on the presentation of HIZs. *IVD* intervertebral disk, *Exp (B)* exponential value of B, *95%CI* 95% confidence interval

classification error. This would bias the reported odds ratio towards 1 and mean the true underlying association between HIZ and pain may be somewhat stronger than observed here (Electronic Supplementary Material 1: ESM_1).

Table 5 The Association Between HIZ and LBP: 2×2 Contingency Table

Patients HIZ Status	Patients LBP Status		Total
	LBP	**No LBP**	
HIZ	41	16	57
No HIZ	36	43	79
Total	77	59	136

Note: A Chi-Sqaure (χ^2) analysis was used to determine the independence of association and Phi and Cramer V was used to assess the strength of association, both were significant (χ^2=9.367, phi and cramer V = 0.262 p < 0.005). *HIZ* high intensity zone, *LBP* low back pain

Odds ratio (OR) with 95% confidence intervals (95%CI) was calculated to estimate risk. This means the odds of having LBP were 3.1 times higher in HIZ patients when compared to the control group

Table 6 Intraclass coefficients for lumbar degenerative and high intensity zone measurements

Parameter	Intra-rater analysis (ICC, (95%CI))	Inter-rater analysis (ICC, (95%CI))
HIZ presence	0.983 (0.972, 0.989)	0.916 (0.866, 0.948)
HIZ location	0.943 (0.908, 0.965)	0.803 (0.696, 0.875)
HIZ T1W association	0.916 (0.866, 0.948)	0.930 (0.887, 0.956)
Pfirmann grade	0.967 (0.948, 0.980)	0.904 (0.846, 0.940)
Nucleus degeneration	0.944 (0.910, 0.966)	0.861 (0.783, 0.913)
Disk bulge/protrusion	0.848 (0.763, 0.904)	0.911 (0.859, 0.945)
Endplate changes	0.916 (0.866, 0.948)	0.926 (0.881, 0.954)
Paraspinal lean CSA	0.960 (0.889, 0.982)	0.982 (0.969, 0.989)
Spinal stenosis	0.950 (0.919, 0.970)	0.905 (0.847, 0.942)
Foraminal stenosis	0.944 (0.910, 0.965)	0.858 (0.777, 0.911)
IVD angle	0.915 (0.864, 0.940)	0.938 (0.901, 0.962)
DHI	0.941 (0.905, 0.964)	0.890 (0.826, 0.931)
Transforaminal height	0.764 (0.629, 0.852)	0.776 (0.657, 0.857)
Vertebral slip	0.784 (0.668, 0.863)	0.850 (0.765, 0.905)
Sagittal translation	0.579 (0.393, 0.720)	0.703 (0.556, 0.808)
Presence of bony spur	0.814 (0.712, 0.882)	0.870 (0.796, 0.919)
Lumbar lordosis	0.925 (0.778, 0.976)	0.938 (0.812, 0.981)
Sacral slope	0.852 (0.585, 0.953)	0.734 (0.331, 0.911)
Pelvic tilt	0.966 (0.887, 0.990)	0.929 (0.784, 0.978)
Pelvic incidence	0.952 (0.856, 0.985)	0.928 (0.782, 0.978)

Note: HIZ high intensity zone, *T1W* T1 weighted, *CSA* cross sectional area, *DHI* disk height index, *ICC* Intraclass coefficient, *95%CI* 95% confidence interval

Conclusion

HIZ was found in 41.9% of patients. At all affected levels there was a significant association between HIZ and nucleus degeneration, disk bulge/protrusion, and foraminal stenosis on MRI and IVD angle on X-ray. The likelihood of having HIZ was 6.4 times and 3 times higher in IVDs with disk bulge/protrusion and nucleus degeneration, respectively. There was also an increased likelihood of HIZ in disks with increasing IVD angle. The odds of having LBP in patients with HIZ were 3.061 times higher than the control. According to the findings, HIZ is likely a clinically useful diagnostic parameter. However, creating a standardized definition for HIZ is essential for identifying problematic patients and minimizing harm from unnecessary management of non-specific LBP.

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