BMC Medical Imaging

RESEARCH

Open Access

Intra-discal vacuum phenomenon with advanced lumbar spine disc degeneration: complementary findings from both MRI and CT

Derek T. Cawley[2*], Aoibhín McDonnell[1], Andrew Simpkin[1], Thomas Doyle[1], Mohammed Habash[1], Conor McNamee[1], Cliona Nic Gabhann[1], Padraig O'Reilly[1], David O'Sullivan[1], Robert Woods[1] and Aiden Devitt[1]

Abstract

Objective Intra-Discal Vacuum phenomenon (IDVP) is associated with advanced disc degeneration, representing persistent intra-segmental movement. Our objective is to further characterise IDVP patterns from both MRI and CT thus informing on an otherwise poorly understood phenomenon.

Methods An observational analysis was performed, including an over-60s population sample of 325 lumbar discs in 65 subjects (29 M, 36 F) with low back pain +/- leg symptoms, with MRI of the lumbar spine and concomitant CT abdomen. Exclusion criteria were those with insufficient quality, non-degenerative or destructive spinal pathology, previous neuromodulation or spine instrumentation.

Results 49 subjects (94 levels) displayed IDVP, including 11/184 Pfirrmann grade 3/IVDP positive, 49/79 grade 4/IVDP positive and 34/39 grade 5/IVDP positive discs. Increased severity of IDVP significantly correlated with increased Pfirrmann grade and decreased disc height ($p < .05$). Affected IDVP levels within the L1L2 & L2L3 region when compared to the L4L5 & L5S1 region, displayed similar Pfirrmann grade (4.1 v 4.3) and disc height (0.52 v 0.51) but with greater severity of IDVP in the latter (1.5 v 1.98, $p < .002$). While 83/105 (81%) of levels with Pfirrmann 4/5 with reduced disc height, displayed IDVP, a small minority did not, where instead they displayed a significantly higher risk of adjacent IDVP ($p < .05$).

Conclusion CT and MRI complement each other through the identification of IDVP, allowing the diagnostician further insight on disc degeneration. Worsening severity of IDVP on CT correlates with increased disc degeneration and reduced disc height on MRI, particularly in the lower lumbar spine. A small minority of advanced degenerate discs do not display IDVP and quiesce, mostly where there is presence of an adjacent IDVP.

Clinical trial number Not applicable.

Keywords Low Back Pain, Vacuum, Disc degeneration, CT, MRI

*Correspondence:
Derek T. Cawley
derekcawley@hotmail.com
[1]University of Galway, Galway, Republic of Ireland
[2]Mater Private Hospital, Dublin, Republic of Ireland

Introduction

Advanced intervertebral disc degeneration is demonstrated on multiple imaging modalities, each with their own niche, most commonly radiograph and MRI. Erect radiograph of the lumbar spine outlines disc height loss, osteophyte formation and endplate sclerosis [1]. MRI identifies loss of signal intensity, disc structure, distinction between nucleus and anulus, and disc height [2]. CT adds little further information and not considered a primary imaging modality to investigate back pain [3], but in advanced disc degeneration best demonstrates intra-discal vacuum, a phenomenon (IDVP) not well understood.

On MRI, most degenerate discs are graded as Pfirrmann grade 3 or 4, because of reduced signal from the dehydrated disc and sclerotic end plates. However, the Pfirrmann classification was based on a cohort of average age of 40 years, not necessarily reflective of a degenerative spine population and where IDVP was characterised as "rare" [2], despite being widely prevalent in over-60 year old populations [4]. Thus advanced disc degeneration is not well characterised, with high levels of intra-observer disagreement [2, 5] and in practice, often limited to one imaging modality.

An IDVP occurs where a disc cavity opens when supine, lowering intra-discal pressure and generating a nitrogen gas bubble [6]. This represents a surrogate marker for persistent intra-segmental movement [7–9]. A previous correlative study of CT and MRI outlined coexistent facet arthrosis, endplate changes and spinal stenosis [10]. Unlike a radiograph or MRI scan, CT will reliably reveal IDVP [11]. Intervertebral disc injury at an index level has implications for inflammation at adjacent levels [12]. However, the well described cascade of adjacent degeneration has not been correlated with IDVP.

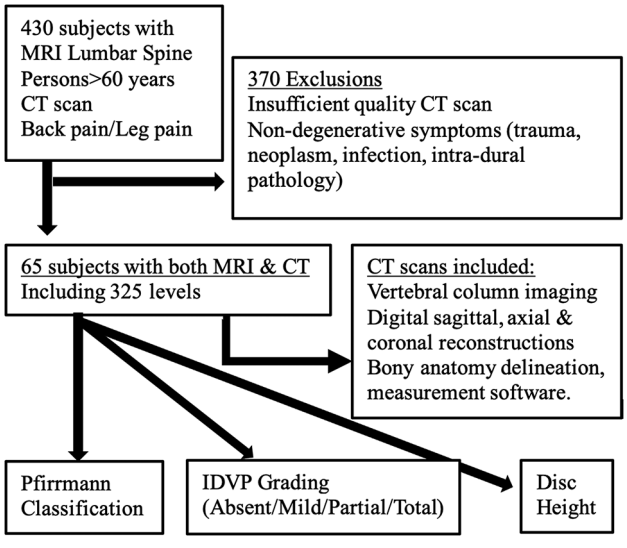

Fig. 1 Study design

There has been more recent interest in this topic with as many publications on IDVP both before and since 2010. However, there remains a lack of insight on progression of disc degeneration and grade discrimination, as it goes beyond MRI-based classifications of disc degeneration, with IDVP as a central aspect to this. Our objective is to identify correlative CT and MRI findings of degenerate discs in the lumbar spine.

Methods

This study was designed using retrospective data, using the national medical imaging platform. All patient data was pseud-anonymised at source, then image interpretation data were collected in a secure database. Randomisation was performed through inclusion of all subjects, over 60 years of age, over a historic three month period (2014) with complete imaging until a total cohort of 65 random subjects were gathered. This was an evaluation of 325 levels, including 29 male and 36 female subjects with a mean age of 73 years (SD 8), similar in size to quoted studies [2, 5]. The study design is outlined in Fig. 1. Inclusion criteria for subjects were symptomatic back pain, with or without leg pain or weakness, included with.

- MRI scans of the lumbar spine, for persistent back pain with or without leg pain.
- Concomitant CT abdominal scan (over six month period).

Exclusion criteria were those with insufficient quality or detail, non-degenerative or destructive spinal pathology (neoplasm or infection), previous neuromodulation or previous spine instrumentation.

All scans were assessed using Change HealthcareTM software across scanners from eight hospitals. CT scans were performed on multiple 64-MDCT scanners (Fig. 1), with the subject in a supine position, with slice thickness of 1 mm, as part of an abdominal protocol. MRI data were acquired with a 1.5-T imaging systems with a maximum gradient strength of 30 mT/m, without intravenous contrast. Selected scans had full visualisation of L1L2 to L5S1. CT and MRI scans were simultaneously assessed by two clinicians (with at least two-year post qualification experience), who underwent IVDP-specific training in a consensus reading for the presence, location and severity of intervertebral IDVP, and repeated at six weeks.

Categorisation of IDVP was followed as per the classification of Wilhuber et al. [13], including Mild (air/ disc ratio l: 2), Partial (1:1 equal) and Total (air/disc ratio 2:1). Disc height was recorded from the CT scan and categorised into 1 (normal), 0.6 and 0.3 as a fraction of the disc height [1]. Discs on MRI scans were graded using the Pfirrmann classification [2].

Given the known association of advanced disc degeneration with IDVP, a subset analysis of Pfirrmann grade 4 or 5 discs, with reductions in disc height but without IDVP, was also performed on the index and adjacent levels.

Statistics

All patient data were analysed with the statistical software Rv4.1 [Core Team (2021)]. The reliability of the CT & MRI evaluations was estimated using agreement percentage and Fleiss' kappa (for multiple raters) statistics within raters (intra-observer reliability, across all raters) and Cohen's Kappa within raters (inter-observer reliability, six weeks apart). The presence and severity of IDVP (none, mild, partial, total) was modelled using ordinal logistic regression to investigate associations with age (years), gender (male, female), disc height category and Pfirrmann grade. Sensitivity and specificity of presence or absence of IDVP were calculated with respect to Pfirrmann grade and reductions in disc height (fused levels were excluded). Each of disc height and Pfirrmann grade were modelled as exposures separately, and then combined in a mutually adjusted model. Models were applied to the vertebrae level data, i.e. five observations per subject. To account for clustering within and between patients, a random intercept was included. One-Way ANOVA, including Tukey HSD was calculated for upper versus lower lumbar regions. A contingency table was prepared to calculate chi-square for IDVP negative cases.

Results

49/65 (75%) of subjects displayed IDVP in 94/325 (29%) of levels (Fig. 2) including 11/184 Pfirrmann grade 3/IVDP positive, 49/79 grade 4/IVDP positive and 34/39 grade 5/IVDP positive discs (Fig. 3). Average age was 49.3 years, including 39 female and 26 males. All but one subject were Caucasian. For the rating (none/mild/partial): Fleiss' Kappa = 0.79 for Reading 1 and 0.36 for Reading 2, with a mean value of 0.59. For the presence (IDVP v none): Fleiss' Kappa = 0.80 for Reading 1 and 0.48 for Reading 2, mean 0.65. For intra-rater, Cohen's Kappa = 0.46 for the rating (none/mild/partial) and 0.66 for the presence of IDVP.

The mutually adjusted model with both Pfirrmann grading and disc height identified their independent correlations with IDVP progression (Table 1). Independent models demonstrated similar findings (For every 1-point increase in Pfirrmann grade, the odds of IDVP progression increased by 7 times and for every 1% decrease in disc height, the odds of IDVP progression increased by 3%, (both $p < .05$) and demonstrated a higher correlation with Pfirrmann ($R^2 = 0.56$) compared to disc height ($R^2 = 0.49$). No IDVP was observed with Pfirrmann grades 1 or 2. Grade 3 displayed mostly Mild IDVP, grade 4 displayed mostly Partial IDVP and grade 5 displayed mostly

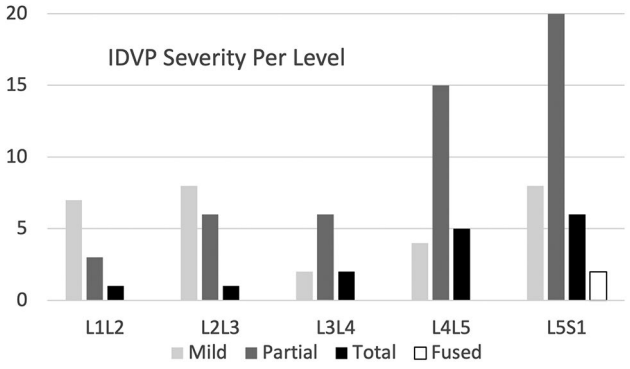

Fig. 2 Severity of IDPV levels

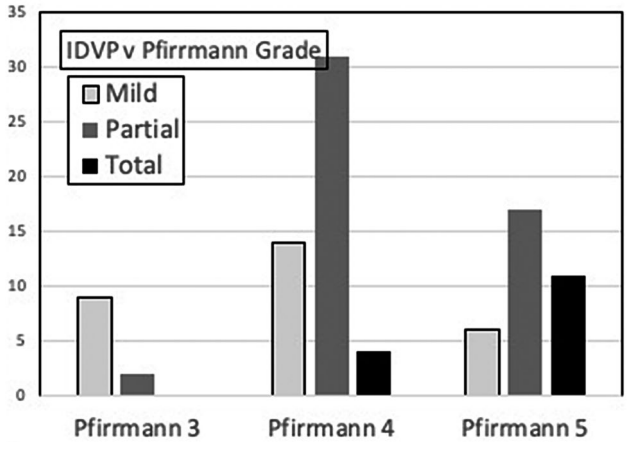

Fig. 3 Severity of IDVP compared with Pfirrmann grades

Table 1 Correlations for IDVP with Pfirrmann grade and disc height

Predictors	IDVP		
	Odds ratios	CI	*p* value
Increased Pfirrmann Gr	6.65	2.89–15.29	**< 0.001**
Reduction of Disc Height	0.97	0.95–0.99	**0.003**
Age	1.04	0.98–1.09	0.193
Gender	1.32	0.57–3.04	0.515
Observations	320		
Marginal R^2 / Conditional R^2	0.56 / 0.66		

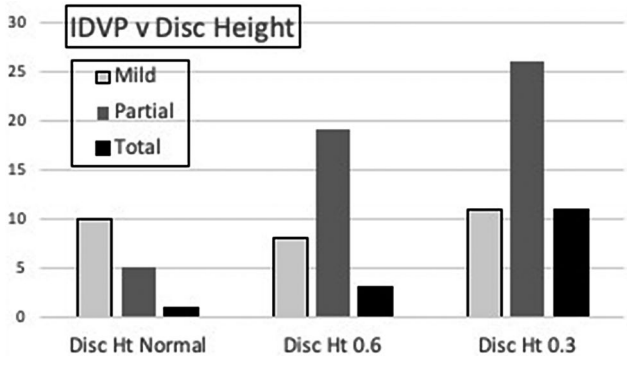

Fig. 4 Disc height categories and IDVP

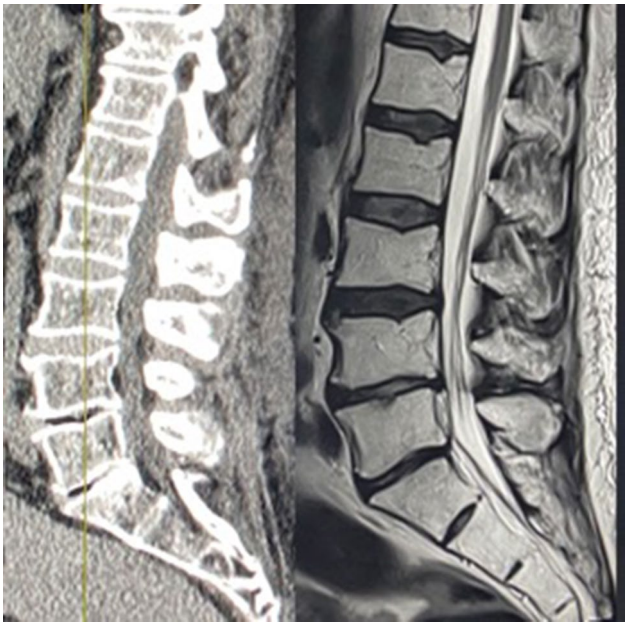

Fig. 5 62 M, low back and right leg L5 pain. L45 L5S1 levels with increased resonance of IDVP on MRI, with 0.3 disc height at both levels with Partial central IDVP at L45 and with Partial but obliterated IDVP at L5S1

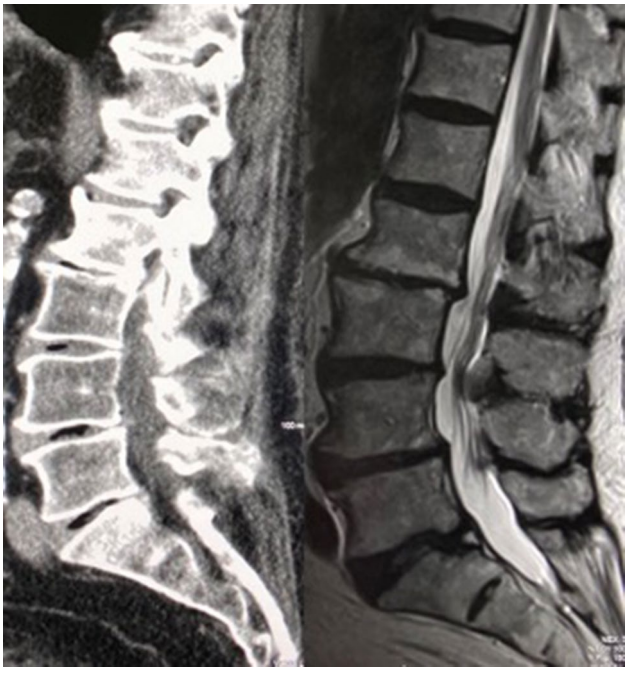

Fig. 6 68 M, low back pain, high BMI, reduced exercise tolerance. Multi-level lumbar disc degeneration with greatest severity of IDVP in the lower lumbar region

Partial with increased Total IDVP compared to grade 4 (Fig. 4 and 5). As no IDVP was evident in a normal disc, the false positive rate was 0% and specificity was thus 100%. Sensitivity of diagnosing IDVP in degenerate discs was 72.8%.

Where IDVP was displayed, analysis of regional effects demonstrated a different behaviour in upper (L1L2, L2L3) levels when compared to lower (L4L5, L5S1) lumbar levels. As expected, there were more lower lumbar levels involved than upper (58 v 26). With similar Pfirrmann grades (4.1 v 4.3) and disc heights (0.52 v 0.51), the IDVP was significantly more severe for the lower lumbar segments (1.5 v 1.98, $p < .002$) (Table 2; Fig. 6).

The risk of developing IDVP with evidence of Pfirrmann Grade 4 or 5 was high. 83/120 (70%) of Pfirrmann Grade 4 or 5 discs displayed IDVP. When excluding discs with a normal height (11) and autofusions (4 congenital), then this increased to 83/105 (81%) prevalence of IDVP in degenerate discs. The remaining 22 (IDVP negative Pfirrmann 4/5, reduced disc height) levels included 17 with adjacent IDVP and five without IDVP. The latter included two adjacent fractures, one L34 IDVP with low PI and two without explanation. The risk of adjacent IDVP was significantly higher in IDVP negative Pfirrmann 4 or 5 levels (Table 3; Fig. 7).

Table 3 Subjects without IDVP

	Adjacent IDVP	Nil adjacent	Totals
No IDVP	17 (11.22) [2.97]	5 (10.78) [3.1]	22
IDVP	8 (13.78) [2.42]	19 (13.22) [2.52]	27
Totals	25	24	49

The chi-square statistic is 11.01. The p-value is 0.000906. Significant at $p < .05$

Discussion

This study investigates correlations of findings of disc degeneration between MRI and CT, identifying a 29% prevalence of IDVP on CT in all lumbar levels in subjects over 60 years of age, all from a symptomatic population. With each increase in Pfirrmann grade on MRI, IDVP severity increased by a factor of 7 and disc height decreased by a factor of 3. IDVP was observed in 81% of discs with reduced height and advanced degeneration. When comparing upper and lower lumbar regions, accepting a greater incidence of disc degeneration in the latter, affected IDVP levels showed similar Pfirrmann

Table 2 Regional differences for upper (L123) V lower (L45S1)

Level	L1L2L3	L45S1	Inter-Observations SS	Intra-Observations SS	F-ratio	*p* value
Incidence	26	58				
Pfirrmann Grade	4.11	4.28	0.4623	34.2401	1.10721	0.296
Disc Height	0.52	0.51	0.001	5.7022	0.01475	0.904
IDVP Severity	1.5	1.98	4.1839	33.4828	10.24648	**0.002**

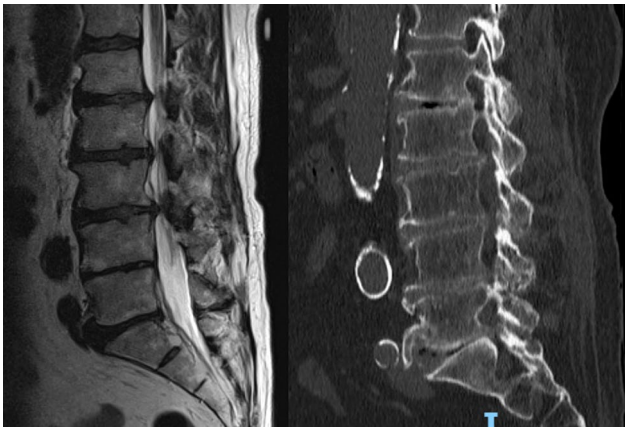

Fig. 7 70 F, with persistent low back pain and stooped posture. IDVP absent at L45, L34 and L23 despite Pfirrmann Grade 4 and 4 disc degeneration with adjacent IDVP at L5S1 and L12

grades and disc heights, but with greater severity of IDVP in the lower lumbar (L4L5 & L5S1) region. IDVP-negative degenerate discs (19%) displayed a significantly higher prevalence of adjacent IDVP than IDVP-positive degenerate discs without adjacent IDVP. The authors do not suggest that CT evaluation is needed as part of a diagnostic work-up but instead, recognise and infer what one is likely to expect on MRI as a result of these analyses of both MRI and CT.

The evolution of IDVP matched the Pfirrmann progression of disc degeneration, particularly where it highlighted Pfirrmann 3 as an inflection point where IDVP first starts to appear. Prevalence was greatest as Pfirrmann 4, with Partial IDVP being most common, even in discs displaying Pfirrmann 5. These were similar to findings by Murata et al. [14], who analysed the intra-discal shape and distribution of IDVP, showing discs with linear and island shaped IDVP had a significantly higher proportion of Pfirrmann 5 discs, particularly where an IDVP involved both the central but also the anterior aspect of the disc.

While IDVP is a radiological finding, cadaveric analysis has shown that at a histological level, there is a progression to trans-discal tears with advanced degeneration [15] and complete healing of large tears is not possible owing to constant motion between the tear margins [16, 17]. As a surrogate marker, IDVP signifies persistent degenerative movement [8, 9]. Cadaveric studies have shown an increase in segmental motion (widening of the neutral zone) in moderate disc degeneration but with a restabilization with severe disc degeneration. This is reflected as increased motion up to grade IV, but decreases when disc degeneration advances to grade V [18].

It is evident that IDVP behaved differently in the lower compared to the upper lumbar spine. Previous work has shown two distinct entities of disc degeneration in the upper versus lower lumbar spine, with endplate-driven disc degeneration in the upper and annulus-driven degeneration in the lower lumbar spine [19]. Recent studies have outlined the roles of regional sagittal alignment characteristics of the lumbar spine, where increased pelvic incidence correlates with increased upper lumbar lordosis [20, 21]. There may be a greater role for the compensatory effects of IDVP-associated movement, i.e. extension moment on IDVP discs in the lower lumbar spine or greater requirements for intra-discal movement, prompting increased severity of IDVP.

As advanced disc degeneration, including transdiscal clefts and reduced disc height, is closely associated with IDVP, the absence of IDVP in degenerate discs was found to be 19%. Kanna et al. maintained that not all degenerate discs or listhesis develop IDVP [7]. However, we suggest that all degenerate discs develop IDVP and where no longer positive, the presence of an adjacent IDVP, or non-contiguous IDVP is the most common explanation for this. Movement nearby may allow quiescence of the degenerate disc with reductions in height, without persistent movement, accepting the cascade of disc degeneration in a cephalad sequence. The clinical implications are particularly relevant in surgical decision making, where the focus is often on the worst disc, yet it may be adjacent to a more mobile and more symptomatic disc. Thus where an MRI is routinely indicated as part of the standard work-up, a recent CT abdomen (or spinal radiograph) has relevance as a complementary study. Furthermore, where intra-discal height reconstruction is employed, the extent of IDVP can signify intersegment instability and conversely, correctability. End-plate sclerosis (and therefore integrity) is also a key marker for the role of intra-discal cage placement. This is also particularly relevant for novel intra-discal techniques, such as cement discoplasty, where identification of IDVP serves as a correctable void that confers stability, increases disc height and lordosis and off-loads painful facet joints, as has been shown in the elderly [22–24].

The presence of IDVP in degenerate discs is best highlighted on the multi-plane utilities of CT scan, optimised by digital sagittal reconstructions and not reliant on orthogonal gantry. Using CT spine for this study was not considered wise as most CT spine scans are either indicated for trauma evaluation or for pre-surgical planning, both of which would skew results. Spinal CT studies for the purposes of research, in an asymptomatic population do not exist. By contrast, retrospective analysis of subjects undergoing unrelated CT scanning is considered appropriate, as shown previously [25–27]. This study also highlights the usefulness of CT abdomen scans for the purposes of analysing for co-existent spinal conditions.

There were some limitations in this study. It is a small cross sectional study, and while inclusive of data on back pain, there were no other demographic factors or

co-morbidities used. Greatest inter-observer disagreements from the Pfirrmann classification are with regard to disc height, signal of the nucleus and for lumbosacral transitional vertebrae, particularly between grades 3 and 4 [2]. Further Pfirrmann modifications by Griffith et al. included grade progressions of disc height collapse, signifying directionality of height collapse as the pathogenesis [4]. Advanced degeneration in both classifications included a hypointense nucleus signal, whereas with IDVP, disagreement can arise from an intense intradiscal signal consistent with fluid imbibement. In contrast, CT based imaging becomes more accurate in these cases, demonstrating accompanying end-plate sclerosis and differentiates between water and vacuum.

In conclusion, analysis of disc degeneration with CT and MRI brings further findings to what would traditionally be limited to those seen on MRI, allowing new insights to the role of IDVP. With increased disc degeneration and decreased disc height, IDVP becomes more apparent, particularly in the lower lumbar spine, plateauing mostly as a partial severity and less likely in the presence of an adjacent IDVP.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12880-025-01635-y.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Acknowledgements

The authors wish to thank the radiology departments at Mayo University Hospital, Naas General Hospital, Waterford University Hospital, Tipperary University Hospital, Wexford General Hospital, Limerick University Hospital, Our Lady of Lourdes Hospital Drogheda, Mater Misericordiae University Hospital and Mater Private Hospital in the Republic of Ireland for their co-operation and/or access to historical images.

Author contributions

The corresponding author is responsible for ensuring that the descriptions are accurate and agreed by all authors • The role(s) of all authors should be listed, using the relevant above categories • Authors may have contributed in multiple roles • CRediT in no way changes the journal's criteria to qualify for authorship. Conceptualization: DTC, Methodology: DTC, Investigation: DTC, TD, MH, CMN, CNG, POR, DOS, RW Formal analysis: AS Writing - Original Draft DTC, Writing - Review & Editing DTC, Supervision AD.

Funding

There was no funding allocated to this study.

Data availability

Anonymised data available on request (DTC). All data were anonymized at the source and maintained for the purpose of research as an electronic database available for scrutiny.

Declarations

Ethical approval

Approval was granted from the Mater Misericordiae & Mater Private Hospitals Institutional Research and Ethics Board in accordance with the Declaration of Helsinki (Ref: 1/378/2366). Given the historic nature of the data, informed consent to participate was waived by the Mater Misericordiae & Mater Private Hospitals Institutional Research and Ethics Board.

Consent for publication

Informed consent to participate was provided by the subjects who provided images for use in the study. No recognisable attributes. Permission to reproduce copyrighted materials or signed patient informed consent forms: not required.

IRB approval/Research ethics committee

Approved. Low Back Pain; Vacuum; Disc degeneration; CT; MRI

Competing interests

The authors declare no competing interests.

Received: 23 October 2024 / Accepted: 12 March 2025
Published online: 20 March 2025

References

1. Wilke HJ, Rohlmann F, Neidlinger-Wilke C, et al. Validity and interobserver agreement of a new radiographic grading system for intervertebral disc degeneration: part I. Lumbar spine. Eur Spine J. 2006;15(6):720–30.
2. Pfirrmann CW, Metzdorf A, Zanetti M, et al. Magnetic resonance classification of lumbar intervertebral disc degeneration. Spine. 2001;26(17):1873–8.
3. Kalichman L, Kim DH, Li L, Guermazi A, Hunter DJ. Computed tomography-evaluated features of spinal degeneration: prevalence, intercorrelation, and association with self-reported low back pain. Spine J. 2010;10(3):200–8.
4. Cawley DT, Simpkin A, Abrahim E, Doyle T, Elsheikh N, Fallon J, et al. Intradiscal vacuum phenomenon matches lumbar spine degeneration patterns in an ageing population. Eur Spine J. 2024;33(5):2014–21.
5. Griffith JF, Wang YX, Antonio GE, et al. Modified Pfirrmann grading system for lumbar intervertebral disc degeneration. Spine. 2007;32(24):E708–12.
6. Magnusson W. Über die Bedingungen des hervortretens der Wirklichen gelenkspalte auf dem Röntgenbilde. Acta Radiol. 1937;18:733–41.
7. Kanna RM, Hajare S, Thippeswamy PB, Shetty AP, Rajasekaran S. Advanced disc degeneration, bi-planar instability and pathways of peri-discal gas suffusion contribute to pathogenesis of intradiscal vacuum phenomenon. Eur Spine J. 2022;31(3):755–63.
8. Sun ZM, Jiang C, Xu JJ, et al. Vacuum facet phenomenon in computed tomography imaging: A sign of instability in degenerative spondylolisthesis?? World Neurosurg. 2019;129:e393–400.
9. Ohtori S, Yamashita M, Inoue G, et al. Rotational hypermobility of disc wedging using kinematic CT: preliminary study to investigate the instability of discs in degenerated scoliosis in the lumbar spine. Eur Spine J. 2010;19:989–94.
10. Ekşi MŞ, Özcan-Ekşi EE, Akkaş A, et al. Intradiscal vacuum phenomenon and spinal degeneration: a cross-sectional analysis of 219 subjects. Curr Med Res Opin. 2022;38(2):255–63.
11. D'Anastasi M, Birkenmaier C, Schmidt GP, et al. Correlation between vacuum phenomenon on CT and fluid on MRI in degenerative disks. Am J Roentgenol. 2011;197(5):1182.
12. Li Y, Dai C, Wu B, Yang L, Yan X, Liu T, et al. Intervertebral disc injury triggers neurogenic inflammation of adjacent healthy discs. Spine J. 2024;24(8):1527–37.
13. Camino Willhuber G, Bendersky M, De Cicco FL, Kido G, Pereira Duarte M, Estefan M, Petracchi M, Gruenberg M, Sola C. Development of a new therapy-oriented classification of intervertebral vacuum phenomenon with evaluation of intra-and interobserver reliabilities. Global Spine J. 2021;11(4):480–7.
14. Murata K, Akeda K, Takegami N, et al. Morphology of intervertebral disc ruptures evaluated by vacuum phenomenon using multi-detector computed tomography: association with lumbar disc degeneration and Canal stenosis. BMC Musculoskelet Disord. 2018;19(1):1–3.

15. Vernon-Roberts B, Moore RJ, Fraser RD. The natural history of age-related disc degeneration: the pathology and sequelae of tears. Spine. 2007;32(25):2797–804.
16. Hirsch C, Schajowicz F. Studies on structural changes in the lumbar annulus fibrosus. Acta Orthop Scand. 1953;22:184–231.
17. Schmorl G, Junghanns H. The human spine in health and disease. New York: Grune & Stratton; 1971.
18. Mimura M, Panjabi MM, Oxland TR, et al. Disc degeneration affects the multidirectional flexibility of the lumbar spine. Spine. 1994;19(12):1371–80.
19. Adams MA, Dolan P. Intervertebral disc degeneration: evidence for two distinct phenotypes. J Anat. 2012;221(6):497–506.
20. Anwar HA, Butler JS, Yarashi T, et al. Segmental pelvic correlation (SPeC): a novel approach to Understanding sagittal plane spinal alignment. Spine J. 2015;15(12):2518–23.
21. Pesenti S, Lafage R, Stein D, et al. The amount of proximal lumbar lordosis is related to pelvic incidence. Clin Orthop Relat Res. 2018;476(8):1603.
22. Varga PP, Jakab G, Bors IB, et al. Experiences with PMMA cement as a standalone intervertebral spacer. Orthopade. 2015;44:1–8.
23. Yamada K, Nakamae T, Shimbo T, et al. Targeted therapy for low back pain in elderly degenerative lumbar scoliosis: a cohort study. Spine. 2016;41(10):872–9.
24. Camino Willhuber G, Kido G, Pereira Duarte M, et al. Percutaneous cement discoplasty for the treatment of advanced degenerative disc conditions: a case series analysis. Global Spine J. 2020;10(6):729–34.
25. Lang N, Yuan HS, Wang HL, et al. Epidemiological survey of ossification of the ligamentum flavum in thoracic spine: CT imaging observation of 993 cases. Eur Spine J. 2013;22:857–62.
26. Chaput CD, Siddiqui M, Rahm MD. Obesity and calcification of the ligaments of the spine: a comprehensive CT analysis of the entire spine in a random trauma population. Spine J. 2019;19(8):1346–53.
27. Kalichman L, Hodges P, Li L, Guermazi A, et al. Changes in paraspinal muscles and their association with low back pain and spinal degeneration: CT study. Eur Spine J. 2010;19:1136–44.

Publisher's note