

Diagnostic Accuracy of Digital Radiography in Evaluation of Lumbar Disc Degeneration

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ABSTRACT

Background: Lumbar disc degeneration is a common structural cause of low back pain. Digital radiography is still a primary imaging modality for evaluation of structural changes in the intervertebral disc because of its easy availability and low radiation dose; however, the quantified data regarding its diagnostic accuracy compared with Magnetic Resonance Imaging (MRI) is limited.

Methods: This cross-sectional study included 120 patients aged 18-50 years with chronic low back pain who were subjected to weight-bearing PA and lateral digital radiography and MRI at Nishtar Medical University Hospital, Multan, Pakistan. Radiographic features (disc space narrowing, disc height, osteophytes, endplate sclerosis) were assessed and MRI findings were graded according to the Pfirrmann classification. Diagnostic performance measures were computed. The reporting was organized based on the STARD 2015 guidelines for diagnostic accuracy studies.

Results: Digital radiography demonstrated sensitivity of 78.41% (95% CI: 68.36–86.47%), specificity of 87.50% (95% CI: 71.01–96.49%), positive predictive value of 94.95%, negative predictive value of 57.46%, and overall diagnostic accuracy of 80.68% (Youden index 0.659; LR+ 6.27, LR– 0.25). ROC (receiver operating characteristic) analysis showed an AUC (area under curve) of 0.830 (95% CI: 0.750–0.892). The disc height on digital radiography were measured at three different levels: anterior, central and posterior. The highest diagnostic performance (AUC 0.850; 95% CI: 0.761–0.939) was obtained for posterior disc height with an optimal cut-off of ≤ 8.25 mm (sensitivity 86.4%, specificity 78.1%).

Conclusion: Digital radiography aids initial assessment of lumbar disc degeneration, while MRI detects occult pathology in symptomatic patients with normal radiographs, emphasizing its complementary diagnostic role.

Keywords: Lumbar disc degeneration; Digital radiography; Diagnostic accuracy; Magnetic resonance imaging; Intervertebral disc.

INTRODUCTION

Low back pain (LBP) or lumbago is an abnormal sensation of discomfort in between the lower edge of the 12th rib and lower fold of buttock that lasts at least a day, involving muscles, nerves and bones of the back that may or may not radiate to the legs. Low back pain (LBP) is among the most prevalent musculoskeletal conditions and a leading cause of years lived with disability worldwide, affecting 619 million individuals globally. In Pakistan, the prevalence of LBP is also a major health issue, afflicting 7,462 per 100,000 individuals in the Pakistani population.¹ While muscles, ligaments, facet joints, vertebral bodies, and neural tissues may all be involved in low back pain, the most common structural abnormality in patients with chronic or recurrent symptoms is lumbar intervertebral disc degeneration.²

The lumbar spine is subjected to significant mechanical loading and mobility. The intervertebral disc (IVD) consists of the nucleus pulposus, annulus fibrosus and cartilaginous endplates, which are structurally interdependent and are responsible for maintaining

the stability of the spine; restoration is difficult once the degeneration has started.^{2,3} The annulus fibrosus becomes fissured and the nucleus pulposus becomes dehydrated and disorganized leading to measurable loss of disc height and eventually to endplate calcification and osteophyte formation.^{4,5} This process is influenced by age, smoking, excess body weight, occupational stress, physical inactivity and genetic predisposition.^{6,7}

Imaging findings are not always associated with clinical symptoms; some patients with degenerative changes have no symptoms, while some patients with symptoms have minimal imaging abnormality.⁸ Few of the changes in IVD and vertebral body are more pronounced in symptomatic patients. If the pain persists in patients even after conservative treatment of 06 weeks, imaging is required to rule out any major abnormality.⁹ Digital radiography is the most readily available first-line imaging modality for suspected disc degeneration, due to its availability, low cost, speed of acquisition, and low radiation exposure and can



show established abnormalities including disc space narrowing, osteophyte formation, endplate sclerosis and vertebral alignment 10,11, but has limitations in detecting early internal disc change and neural compression.¹² MRI is the gold standard for the diagnosis of disc disease, as it does not use ionizing radiation, allows multiplanar imaging, has excellent soft-tissue contrast for accurate localization of the intervertebral discs, and can detect neural changes that may be associated with disc degeneration and lead to low back pain.¹³ MRI-based disc degeneration is categorized on the basis of the Pfirrmann system that is used globally to evaluate the severity of disc degeneration.¹⁴

While some previous studies have reported the radiographic and MRI characteristics of lumbar degeneration, quantitative comparisons of digital radiography with MRI as the reference standard have been limited and have focused on disc height measurements at a single anatomical level of IVD¹⁵. Moreover, the radiographic projections for taking the lumbar spine X-ray were not clearly defined in previous studies. These diagnostic parameters, when analysed in a diagnostic accuracy setting, could be used to help clinicians determine when radiography is enough and when MRI is warranted, thereby maximising the use of resources when MRI is not available. Therefore, the purpose of this study was to evaluate the diagnostic accuracy of weight-bearing PA and lateral digital radiographic views of the lumbar spine, to quantify the various performance measures of digital radiography (sensitivity, specificity, likelihood ratios), and to determine which of the three radiographic parameters (anterior, central, and posterior disc height) is the best quantitative measure for predicting MRI-confirmed lumbar disc degeneration (LDD) in a cohort of symptomatic patients with chronic LBP.

METHODOLOGY

Study Design and Setting

This was a cross-sectional study carried out in Nishtar Medical University Hospital, Multan, Pakistan, during the period of June to August 2026. The sample size was calculated using the single proportion formula and taking the sensitivity of radiography (92.7%) for evaluation of LDD recorded in the literature.¹⁶ A total of 120 patients aged 18–50 years with chronic LBP >6 weeks were included in the study. The reporting was organised based on the STARD 2015 guidelines (Supplementary file 1) for diagnostic accuracy studies.

Participants Selection

Patients with chronic LBP undergoing digital radiography and MRI were selected using a non-probability purposive sampling method. Inclusion criteria were: age 18–50 years, chronic low back pain >6 weeks despite conservative treatment, and requiring the imaging studies for evaluation. Patients with a history of spinal trauma, inflammatory spinal disease, metastatic or primary spinal neoplasm, congenital spinal abnormality, claustrophobia, or MRI contraindications due to metallic implants were excluded.

Data Collection

The data were collected using a predefined performa featuring the demographic, clinical, Digital radiography and MRI features for the evaluation of patients with LBP. Each participant was informed of the objective and procedure of the study before imaging, and informed consent was obtained. Radiographs were analysed first, followed by MRI examinations by experienced radiologists. All the radiographic and MRI findings that were included in the data analysis were interpretable and determined. No participants were excluded based on indeterminate or uninterpretable results. The data of all the participants were included based on their ability to provide valuable radiographic and MRI findings. No adverse event occurred during digital

radiography and MRI examinations.

Digital Radiography

Digital radiography was taken with Del Medical DR equipment (40–150 kVp) with participants in an erect, weight-bearing position. Both posteroanterior (PA) and lateral projections were acquired. Intervertebral disc heights were measured at the anterior, central and posterior levels. Other radiographic parameters evaluated were disc space narrowing, osteophyte formation, endplate sclerosis and vertebral alignment. The disc degeneration was considered positive on radiography when there was loss of disc height as compared to adjacent vertebrae accompanied by either osteophytes or endplate sclerosis.¹¹

MRI

MRI was performed using a 1.5 Tesla Canon Vintage scanner with sagittal and axial T1- and T2-weighted sequences (slice thickness 4 mm). The Pfirrmann classification (Grades I–V) was used to grade the disc degeneration.¹⁴

The MRI were considered abnormal for the LDD based on Pfirrmann grade (III–V) along with the presence either of other MRI findings such as Modic changes, disc protrusion, bulge, extrusion, or nerve root compression.^{17–20} The Pfirrmann grades I and II were considered normal because these result in no disc height loss as described in Table 1.¹⁴ The data regarding associated MRI findings indicative of LDD were also recorded, viz disc bulging, protrusion, extrusion, Modic changes, endplate sclerosis, facet arthropathy, central spinal canal stenosis, lateral recess compression, ligamentum flavum hypertrophy, and nerve-root compression.¹³

Table 1. Pfirrmann grading system for lumbar intervertebral disc degeneration

Grade	T2-Weighted MRI Signal	Nucleus–Annulus Distinction	Disc Height
I	Homogeneous, bright hyperintense (white)	Clearly defined	Normal
II	Inhomogeneous but hyperintense (white); possible horizontal grey band	Nucleus and annulus clearly differentiated	Normal
III	Inhomogeneous, intermittent grey signal	Distinction between nucleus and annulus unclear	Normal or slightly decreased
IV	Inhomogeneous, hypointense dark-grey signal	No distinction between nucleus and annulus	Slightly to moderately decreased
V	Inhomogeneous, hypointense black signal	No distinction between nucleus and annulus	Disc space collapsed

Statistical Analysis

Participant characteristics were summarized using descriptive statistics: continuous variables (disc-height measurements) were presented as mean ± standard deviation, and categorical variables (age group, gender, clinical presentation, radiographic and MRI findings) were presented as frequencies and percentages. The

2×2 contingency tables were used to calculate the following statistical parameters: sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, positive likelihood ratio (LR+), negative likelihood ratio (LR-), and Youden index. The area under the curve (AUC) and 95% confidence intervals were determined for anterior, central, and posterior disc-height measurements using ROC curve analysis.¹⁹ The optimal cutoff values were calculated by the Youden index.²⁰ IBM SPSS Statistics version 26 was used for analysis.

RESULTS

All 120 enrolled patients were scanned with both digital radiography and MRI and were used for the diagnostic accuracy analysis. The results were described as follows. Demographic and clinical characteristics of the cohort are described first, followed by the digital radiographic findings, the MRI findings, and finally the diagnostic performance of digital radiography compared to the MRI reference standard, including receiver operating characteristic (ROC) analysis of the three disc-height measurements.

Demographic and Clinical Characteristics

The mean age of the patients was around 35 ± 9.064 years (range 18-50 years; Table 1), and the distribution was fairly even across the three age bands (Figure 1A). The majority of the cohort were female (61.7%; Figure 1B). The most common presenting symptom was radiculopathy (78.3%), followed by numbness and weakness (Figure 1C) (Table 2).

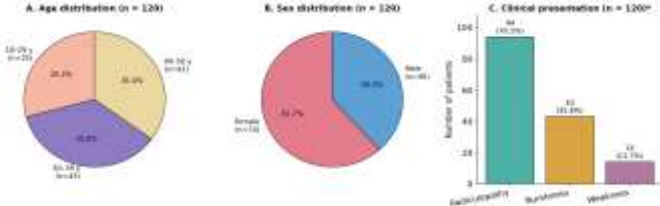


Figure 1. Demographic and clinical features of the participants (n = 120). (A) Age distribution. (B) Sex distribution. (C) Clinical presentation (*categories are not mutually exclusive, as patients could report more than one symptom).

Table 2. The demographic and clinical features of participants (n = 120)

Characteristic	n	%
Age		
Age 18–29 years	35	29.2
Age 30–39 years	43	35.8
Age 40–50 years	42	35.0
Gender		
Female	74	61.7
Male	46	38.3
Clinical Features		
Radiculopathy	94	78.3
Numbness	43	35.8
Weakness	14	11.7

Digital Radiographic Findings

On digital radiography, disc-space narrowing was the most common finding, followed by osteophyte formation and endplate sclerosis, and the three features often occurred in the same patient (Figure 2A, B; Table 2). In total, 73 radiographs (60.8%) were considered abnormal. The mean disc height was found to be decreasing from anterior to posterior (12.44 ± 1.77 mm, 9.84 ± 1.47 mm, and 7.83 ± 0.83 mm, respectively; measurement method shown in Figure 2C; Table 3).

Figure 2. Original digital radiographs of the lumbar spine.



(A) Lateral radiograph demonstrating narrowing of the disc spaces and osteophyte formation. (B) Lateral X-ray of the spine demonstrating endplate sclerosis and loss of disc space at L5–S1. (C) Lateral radiograph showing intervertebral disc-height measurement, anterior disc height (A–B), central disc height (C–D), and posterior disc height (E–F).

Table 3. Digital radiographic findings (n = 120)

Finding	n	%
Disc-space narrowing	74	61.7
Osteophyte formation	67	55.8
Endplate sclerosis	61	50.8
Abnormal radiograph (overall)	73	60.8
Normal radiograph	47	39.2

Disc-height ranges: anterior 7.20–16.70 mm, central 6.20–14.40 mm, posterior 5.00–9.90 mm.

MRI Findings

On MRI, the most common finding was moderate-to-severe disc degeneration (grades III–V) (88 patients, 73.3%) and the full distribution of Pfirrmann grades is shown in Table 3. Structural findings included disc bulging (25.0%), disc protrusion (28.3%) and disc extrusion (25.0%), with disc protrusion being the most common (Figure 3, representative case with mild spinal canal stenosis at L4–5). The neural and facet-related abnormalities, with nerve-root compression (70.8%) and lateral recess compression (67.5%) being the most common, and central spinal canal stenosis being comparatively rare (8.3%), as mentioned in Table 4. These abnormalities were at L3–4 (13.3), L4–5(34.2%) and L5–S1 (52.5%).



Figure 3. Representative sagittal T2-weighted MRI showing

moderate disc protrusion resulting in mild spinal canal stenosis at L4–5.

Table 4. MRI findings (n = 120)

Finding	n	%
Pfarrmann grade I	13	10.8
Pfarrmann grade II	19	15.8
Pfarrmann grade III	36	30.0
Pfarrmann grade IV	25	20.8
Pfarrmann grade V	27	22.5
MRI abnormal (grades III–V)	88	73.3
Disc bulging	28	23.3
Disc protrusion	34	28.3
Disc extrusion	27	22.5
Modic changes	22	18.3
MRI endplate sclerosis	55	45.8
Facet arthropathy	54	45.0
Central spinal canal stenosis	10	8.3
Lateral recess compression	81	67.5
Ligamentum flavum hypertrophy	32	26.7
Nerve-root compression	85	70.8

Diagnostic Performance of Digital Radiography

Cross-tabulation with the MRI reference standard yielded 69 true-positive, 4 false-positive, 19 false-negative, and 28 true-negative radiographs (Table 5). The sensitivity, specificity, and overall diagnostic accuracy of digital radiography were 78.41%, 87.50%, and 80.68%, respectively, with an AUC of 0.830 for the binary (normal/abnormal) classification; the complete set of performance metrics, including predictive values and likelihood ratios, is presented in Table 6. Interestingly, 19 of 47 patients (40.4%) with a normal radiograph had MRI evidence of disc pathology (15.8% of the entire cohort), highlighting the limitations of a normal radiograph in excluding disc pathology.

Table 5. Cross-tabulation of X-ray and MRI Findings

Normal/Abnormal X-Ray	Normal/Abnormal MRI		Total
	Abnormal	Normal	
Abnormal	69(TP)	4(FP)	73
Normal	19(FN)	28(TN)	47
Total	88	32	120

Table 6. Diagnostic performance of digital radiography

Measure	Estimate	95% CI
Sensitivity	78.41%	68.36–86.47
Specificity	87.50%	71.01–96.49
Positive predictive value	94.95%	—
Negative predictive value	57.46%	—
Diagnostic accuracy	80.68%	—
Positive likelihood ratio	6.27	2.49–15.79
Negative likelihood ratio	0.25	0.16–0.38
Youden index (binary test)	0.659	0.509–0.795
Binary radiographic classification AUC	0.830	0.750–0.892

The reference standard for all comparisons was MRI.

ROC Analysis of Disc-Height Measurements

All three radiographic disc-height parameters were significantly different between MRI-positive and MRI-negative patients (AUC > 0.50, $p < 0.001$ for each). Posterior disc height had the highest discrimination (AUC 0.850), followed by central (AUC 0.769) and anterior disc height (AUC 0.757), and the posterior curve was consistently higher than the other two over the range of

sensitivity (Figure 4). Optimal cutoffs and their sensitivities and specificities for each parameter are presented in Table 7, and the posterior disc height was the most informative quantitative radiographic parameter in this cohort, with a posterior disc height of ≤ 8.25 mm having the best balance of sensitivity (86.4%) and specificity (78.1%).

Figure 4. Receiver operating characteristic (ROC) curves of anterior, central and posterior disc height for the detection of MRI-defined lumbar disc pathology.

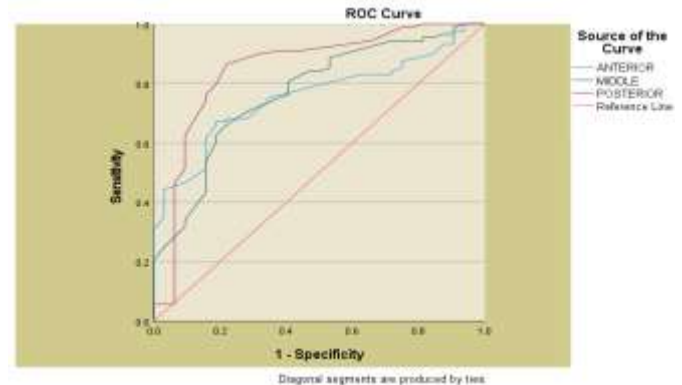


Table 7. ROC analysis of disc-height measurements (n = 120)

Measure	Estimate	95% CI
Anterior disc height AUC	0.757	0.671–0.844
Central disc height AUC	0.769	0.675–0.863
Posterior disc height AUC	0.850	0.761–0.939
Anterior cutoff (sens. / spec. / Youden)	≤ 12.47 mm (67.0% / 81.2% / 0.482)	—
Central cutoff (sens. / spec. / Youden)	≤ 10.00 mm (65.9% / 78.1% / 0.440)	—
Posterior cutoff (sens. / spec. / Youden)	≤ 8.25 mm (86.4% / 78.1% / 0.645)	—

The reference standard for all comparisons was MRI.

DISCUSSION

This study showed that digital radiography is a good diagnostic tool for the diagnosis of established lumbar disc degeneration when MRI is used as the reference standard. The sensitivity was 78.41%, specificity was 87.50%, positive predictive value (PPV) was 94.95%, negative predictive value (NPV) was 57.46%, and overall diagnostic accuracy was 80.68%. The positive likelihood ratio of 6.27 and negative likelihood ratio of 0.25 suggest that an abnormal radiograph was useful evidence of MRI-defined pathology, while a normal radiograph was not useful evidence of MRI-defined pathology. The results are consistent with the well-established advantages of radiography in the detection of existing structural abnormalities and the poor sensitivity of the technique in the detection of internal disc and neural pathology.^{10–13}

The radiographic characteristics seen in this group, namely disc-space narrowing, osteophyte formation and endplate sclerosis, are structural changes that are easily assessed on plain radiographs.^{5,11} MRI, on the other hand, can assess the signal intensity and hydration of the discs and directly assess the neural structures.^{13,14} This is the reason why radiography is effective in detecting structural changes that have occurred due to degeneration, but may not detect earlier or non-osseous changes. The AUC of 0.830 for the binary radiographic classification suggests good overall discrimination, and the NPV is lower, suggesting that a normal radiograph should be interpreted with

caution in patients with persistent or clinically concerning symptoms.

Suthar et al. also noted that plain radiography is useful for gross structural changes and MRI is useful for detailed characterization of lumbar disc pathology.¹³ The present study showed that digital radiography had a high specificity (87.50%) and a positive likelihood ratio of 6.27, which means that an abnormal radiograph gave strong evidence of MRI-defined pathology. The lower NPV (57.46%) is due to the fact that MRI showed degenerative or other pathological changes in this cohort without any obvious disc-height loss on the radiographs. The higher percentage of abnormal MRI findings in this group (40.4%) of patients with normal radiographs demonstrates the wider spectrum of abnormalities detected by MRI in this patient population. This study was based on purposive sampling, including patients with suspected LDD. Therefore, the MRI-detected abnormalities of patients could be more prevalent than in an unselected population. The PPV and NPV values are affected by the disease prevalence. Therefore, the interpretation of these parameters should be handled cautiously while dealing with a generalized population with different disease prevalence.

Posterior disc height had the highest AUC (0.850) and optimal cutoff value (8.25 mm), with a sensitivity of 86.4% and specificity of 78.1%, among the quantitative radiographic measures. Lower AUCs were obtained for anterior and central disc-height measurements (0.757 and 0.769, respectively). These results suggest that the most informative of the three parameters measured in this cohort was posterior disc height. Disc-height measurements have been studied as a radiographic indicator of disc degeneration and can be used to obtain quantitative data that can be used in conjunction with qualitative assessment.^{11, 21} Seven methods of disc-height measurement were assessed for reliability by Chen et al.,²¹ and found good to excellent reliability for most methods. The clinical relevance of the posterior disc-height measurement was supported by Lin et al.,²² who found that L4–5 posterior disc height was one of the best predictors of disc bulging or herniation on MRI. While previous studies have confirmed that disc-height measurements on radiographs are quantitative indicators of disc degeneration, there is some variation in reported thresholds, which may be due to differences in measurement technique and study population.^{11, 21, 22} The internal cutoff of ≤ 8.25 mm should thus be regarded as study-specific and needs to be validated externally.

A significant finding was that 19 of 47 participants with normal radiographs had abnormal MRI findings (40.4% of those with normal radiographs and 15.8% of the total cohort). This observation demonstrates that radiography is not very sensitive for detecting abnormalities that are seen on MRI, such as disc degeneration that has not yet been correlated with significant disc-height loss or other obvious osseous abnormalities, and neural abnormalities. Thus, normal radiographs do not rule out MRI-detectable abnormalities in symptomatic patients. The results indicate that MRI and radiography should not be used interchangeably, but rather MRI can be used to complement the clinical findings and/or to provide additional information when clinical findings remain or indicate pathology that is not well characterized by radiography.^{10, 12, 13}

The MRI revealed Pfirrmann grade III–V degeneration in 73.3% of the participants. This high proportion should be viewed in the context of the symptomatic, referral-based population and should not be extrapolated to the community. The Pfirrmann system was created to standardize the MRI evaluation of lumbar disc degeneration.¹⁴ Good to excellent inter- and intra-observer agreement has been shown in some settings through independent studies. The Pfirrmann classification was used by Urrutia et al.,²³ and excellent inter-observer agreement (weighted kappa = 0.83)

and intra-observer agreement (weighted kappa = 0.89) was reported. But there can be differences in agreement between readers and assessment methods. Measurement technique and observer-related factors can also affect disc-height measurements.²¹ Importantly, MRI-detected degeneration does not necessarily mean that it is causing pain: degenerative findings are common in asymptomatic adults and are more common with age, but some imaging findings are more common in adults with low back pain.^{8, 9, 24}

MRI can be used to assess the structural findings of the lumbar spine and identify the LDD in patients with normal radiographs, even in asymptomatic patients. A 7-year follow-up study of asymptomatic people showed that baseline MRI results were not predictive of the onset or persistence of low back pain, highlighting the need for clinical correlation when evaluating imaging abnormalities.²⁵ Modic changes and anterolisthesis were the most strongly associated with low back pain (odds ratio >4) in a group of 40-year-old adults, and most degenerative disc abnormalities were only moderately associated.²⁶ Watanabe et al. conducted a cross-sectional community study of 382 adults and did not find any significant differences in the prevalence of low back pain, pain intensity, disability, or health-related quality of life among the age-appropriate and age-inappropriate disc degeneration groups.²⁷ These findings support our observation that MRI may demonstrate degenerative changes that are not necessarily associated with clinical symptoms. Therefore, the degenerative changes identified on MRI should be interpreted in conjunction with the patient's clinical findings rather than considered as a direct cause of low back pain.

The high prevalence of nerve-root compression (70.8%) and lateral recess compression (67.5%) in this cohort, in addition to the presence of radiculopathy in 78.3%, further illustrates that there were significant neural and degenerative abnormalities in this population. These MRI findings are not usually described by plain radiography, further emphasizing the complementary diagnostic information provided by MRI.¹³ However, digital radiography is still useful as a readily available first imaging test, as it is relatively inexpensive, quickly obtained, and can show significant structural changes.¹⁰ It should therefore be used in the clinical context and not as a replacement for MRI if further detailed evaluation is warranted.

Limitations

There are a number of limitations to be taken into account. The study was conducted in one tertiary care center and purposive sampling was used, which restricted the generalizability of the study. The results are not representative of the prevalence of lumbar disc degeneration in the general population because the participants were symptomatic and referred for both examinations. There was a range of 0 to 65 days with a mean gap of 19.84 ± 12.60 days between radiography and MRI, which may have caused some temporal discordance. MRI was the imaging reference standard, however MRI-detected degeneration does not prove pain causation [8]. Radiographic measurements were not evaluated for interobserver and intraobserver reliability. Lastly, the posterior disc-height cutoff was internally derived and needs external validation prior to routine clinical use.

CONCLUSION

This study shows that digital radiography has good diagnostic performance for lumbar disc degeneration confirmed by MRI, with a sensitivity of 78.41%, specificity of 87.50%, overall accuracy of 80.68%, and an AUC of 0.830. Posterior disc height was the most discriminatory quantitative parameter (AUC 0.850) at a cutoff of ≤ 8.25 mm, suggesting that it may be a simple and reproducible radiographic marker of disc degeneration. The

results support the use of digital radiography as a reliable, easily accessible, first-line diagnostic tool for the assessment of existing lumbar disc degeneration. MRI is still important, however, when clinical suspicion remains despite normal radiographs, as a normal radiograph did not rule out MRI-confirmed pathology in 15.8% of participants. Digital radiography and MRI should therefore be considered complementary imaging modalities and external validation of the posterior disc-height cutoff in larger, multi-center cohorts is recommended.

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Competing Interests

The author declares no competing interests.

Ethics Approval and Consent

This study received institutional ethical approval. Written informed consent was obtained from all participants. The study was not registered in a diagnostic accuracy or clinical trial registry.

Data Availability

The datasets generated during this study are available from the author upon reasonable request.

Author Contributions

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Methodology: Muhammad Umair Hassan, Abdul Sammad Ali Khan Shirwany

Collection: Muhammad Umair Hassan

Analysis: Abdul Sammad Ali Khan Shirwan, Sumaira Noor Malik, Sehrish Khakwani

Writing –Original Draft: Muhammad Umair Hassan

Writing –Review & Editing: Abdul Sammad Ali Khan Shirwany, Sumaira Noor Malik, Sehrish Khakwani

All authors take full responsibility for the research and are accountable for all aspects of the work, including the study design, data collection, analysis and interpretation of the findings, manuscript preparation, and the accuracy and integrity of the research.

Use of Artificial Intelligence

ChatGPT was used solely for language editing, grammar correction, and improvement of the clarity and readability of the manuscript. The authors reviewed and approved the final content and take full responsibility for the accuracy, originality, and integrity of the work.

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