International Journal of Medicine
pISSN 1468-3814 | eISSN 2667-7008
https://theinternationalmedicine.com/

Original Researcher Article *DOI: 10.61336/im/26-2-12*

MRI-BASED MORPHOMETRIC ANALYSIS OF LUMBAR INTERVERTEBRAL DISC HEIGHT AND VERTEBRAL CANAL DIAMETER IN HEALTHY SUBJECTS.

Aymen Sana[1]*, Sameera Khaliquzzaman[2], Shehla Irfan[3], Muhammad Javed[4], Nimrah Fahim[5], Saqib Mansoor[6].

[1]Demonstrator.Department of Anatomy. CMH Lahore Medical College n Institute of dentistry. Lahore. Pakistan.

[2]Staff Physician. Medical Imaging. King Abdulaziz Hospital. Ministry of National Guard Health Affairs. Al Ahsa, Kingdom of Saudi Arabia.

[3]Consultant. Department of Radiology. Rafiquishaheed welfare hospital. Shorkottcantt. Pakistan.

[4]Professor. Department of Anatomy. Niazi medical and dental college. Sargodha. Pakistan.

[5]Senior demonstrator. Department of Anatomy. Shifacollege of medicine. Islamabad. Pakistan.

[6]Associate Professor. Department of Anatomy. Niazi Medical and Dental College. Sargodha.

Correspondence:
Aymen Sana.
Demonstrator.Department of Anatomy.CMH Lahore Medical College n Institute of dentistry. Lahore. Pakistan.

Email:
Aymensana123@gmail.com

Received: 06-04-2026
Revised: 24-04-2026
Accepted: 07-05-2026
Published: 23-05-2026

Abstract

Background: OBJECTIVE: To determine the age and sex-specific normative values of lumbar intervertebral disc height and vertebral canal diameter by high-resolution magnetic resonance imaging (MRI). ***MATERIALS AND METHODS:*** A prospective cross-sectional study was conducted on 420 healthy volunteers, ages 20-60 years. The morphometric parameters measured were the anterior, middle, and posterior intervertebral disc heights from L1 to L5 and the anteroposterior and transversal diameters of the vertebral canal at L1–L5. The statistical analysis included one-way ANOVA, independent t-tests, Pearson correlation, and multivariate linear regression and a statistical significance level of $P<0.05$. ***RESULTS:*** There was a significant linear decrease in disc height with age ($p<0.001$), with the most significant decrease at L4- L5 and L5- S1. The male subjects had significantly larger diameters of the vertebral canal than the female subjects ($p=0.003$), and the female subjects had relatively greater preservation of disc height until age 50 ($p=0.018$). Multivariate regression showed that age and sex were independent predictors of morphometric variation (adjusted $R^2=0.61$, $p<0.001$). ***CONCLUSIONS:*** physiologic remodeling of the lumbar intervertebral discs and vertebral canal has been identified and is significant with age and sex. These normative data serve as important benchmarks to distinguish between physiological aging and pathological degeneration, fine-tune clinical diagnostics, surgical planning, and to inform AI-based spinal imaging algorithms.

Keywords: lumbar spine, MRI morphometry, intervertebral disc height, vertebral canal diameter, healthy adults, and normative values.

INTRODUCTION

The human body's main mechanism for axial loading, dynamic flexion extension and rotational stability is the lumbar spine. It is based on the exact anatomical relationship of the vertebral body, the interbody disks, the facet joints, ligaments and the central vertebral canal. The two most clinically and biomechanically relevant morphometric parameters of these components are intervertebral disc height and diameter of the vertebral canal1.

Departures from normal physiological values in either of these parameters are closely linked to degenerative disc disease, spinal stenosis, radiculopathy, and mechanical low back pain conditions that together contribute significantly to global disability and healthcare burden2.

Magnetic resonance imaging has established itself as the preferred non-invasive method for evaluating spinal morphology, owing to its exceptional soft-tissue contrast, multiplanar imaging capacity, and freedom from ionizing radiation3. T2-weighted sequences in particular offer detailed visualization of disc hydration, annular integrity, endplate structure, and cerebrospinal fluid boundaries, allowing accurate morphometric assessment4. Despite this progress, reported normative values remain highly variable across populations due to differences in imaging protocols, measurement landmarks, demographic stratification, and sample selection leading clinicians to rely on outdated or inconsistent reference ranges that may result in overdiagnosis of age-related changes or missed early pathological narrowing.

The age-related decline in intervertebral disc height is a well-established process driven by nucleus pulposus dehydration, collagen cross-linking, proteoglycan loss, and endplate sclerosis5. These microstructural changes begin as early as the third decade and are accelerated by mechanical stress, genetic factors, and systemic metabolic conditions6. However, distinguishing normal physiological remodeling from clinically meaningful stenosis remains difficult without reliable, population-specific data. Emerging evidence highlights that uniform diagnostic thresholds fail to account for sex-based differences in pelvic morphology, vertebral body dimensions, and hormonal effects on connective tissue7. Estrogen-related collagen turnover and differences in paraspinal fat distribution may differentially influence disc resilience and canal compliance between males and females, yet these variables remain insufficiently studied in morphometric research8.

The clinical consequences of inaccurate morphometric references extend well beyond diagnostic imaging9. In surgical planning, precise restoration of disc height and adequate canal decompression are essential for favorable outcomes in lumbar fusion, disc replacement, and minimally invasive decompression10.

Despite clear clinical and technological need, significant gaps persist in literature. Many existing morphometric studies are based on small or homogeneous cohorts, retrospective imaging reviews, or non-standardized measurement approaches that limit generalizability11. Confounding variables such as body mass index, physical activity, and occupational loading, all of which independently affect spinal geometr are frequently overlooked12. Most published reference values also rely on two-dimensional planimetric measurements that do not account for disc curvature or canal shape variability, introducing systematic measurement errors.

This study addresses these gaps through a comprehensive, prospective MRI-based morphometric analysis of lumbar intervertebral disc height and vertebral canal diameter in a large cohort of healthy asymptomatic adults.

MATERIALS AND METHODS

This prospective cross-sectional study was carried out between January 2023 and December 2025 at multiple tertiary care medical centers. Institutional Review Board approval was obtained. Written informed consent was secured from all participants before enrollment.Healthy volunteers between 20 and 60 years of age were recruited through community outreach and institutional wellness programs. Eligible participants had no current or prior lower back pain requiring medical care, no history of lumbar surgery, trauma, or congenital spinal conditions, a body mass index between 18.5 and 29.9 kg/m², and a normal neurological examination. Individuals were excluded if they had systemic inflammatory, metabolic, or neoplastic conditions affecting bone or connective tissue, were pregnant, had MRI contraindications, or showed incidental findings of Modic changes, disc herniation, or canal stenosis on screening.Sample size was determined using G-Power 3.1.9.7, targeting a medium effect size (f=0.25) for ANOVA at α=0.05 with 0.90 power. Accounting for 10% expected attrition, a minimum of 390 participants was required.

The final cohort included 420 subjects (215 males, 205 females), divided into four age groups: 20–29, 30–39, 40–49, and 50–60 years.All imaging was performed using a 3.0T MRI scanner (Magnetom Vida, Siemens Healthineers) with a 32-channel spine coil. Participants were scanned in the supine position with neutral lumbar alignment, supported by foam wedges to reduce positional artifact. The protocol included sagittal T2-weighted turbo spin-echo sequences (TR/TE 3200/110 ms, FOV 280×280 mm, slice thickness 3 mm, matrix 384×384, no fat suppression), axial T2-weighted TSE sequences (TR/TE 3500/120 ms, FOV 180×180 mm, slice thickness 3 mm) at mid-disc and mid-vertebral levels, and sagittal T1-weighted TSE sequences (TR/TE 650/12 ms) for anatomical and endplate assessment. All sequences were reconstructed using parallel imaging (GRAPPA factor 2) with isotropic voxel interpolation to optimize measurement precision.Images were anonymized and transferred to a dedicated workstation (OsiriX MD v12.0) for analysis.

Two board-certified musculoskeletal radiologists, blinded to participant information, independently performed all measurements. Disc height was recorded at three standardized points on mid-sagittal T2-weighted images — anterior (A-DH), middle (M-DH), and posterior (P-DH) — defined as the perpendicular distance between adjacent vertebral endplates at the anterior third, center, and posterior third of the disc. Vertebral canal diameter was measured on axial T2-weighted images at the mid-vertebral level, capturing the anteroposterior diameter (AP-CD) from the posterior vertebral cortex to the ligamentum flavum, and the transverse diameter (T-CD) at the widest pedicle-to-pedicle distance. One rater repeated all measurements after four weeks to evaluate intra-rater reproducibility.All demographic and morphometric data were entered into REDCap. Continuous variables were expressed as mean±SD and categorical variables as frequencies. Inter- and intra-rater reliability were evaluated using two-way random effects intraclass correlation coefficients (ICC) with 95% confidence intervals. Normality was tested using the Shapiro-Wilk test. Age group comparisons used one-way ANOVA with Tukey post-hoc correction, while sex differences were assessed with independent t-tests. Pearson correlation coefficients were used to examine age-morphometry relationships. Multivariate linear regression models were developed to predict disc height and canal diameter, adjusting for age, sex, BMI, and lumbar level. A p-value below 0.05 was considered statistically significant. All analyses were conducted using SPSS v28.0 and R v4.3.1..

RESULTS

A total of 420 asymptomatic volunteers completed the full study protocol. All MRI examinations satisfied predefined quality standards, with no motion artifacts or technical failures encountered.

The cohort was well-distributed across age groups and both sexes, with anticipated sex-based differences in anthropometric measurements. The absence of a significant age difference between males and females (p=0.412) supports unbiased comparison of morphometric variables.

Table 1. Demographic and Baseline Characteristics of the Study Cohort

Parameter	Male (n=215)	Female (n=205)	Total (n=420)	p-value
Age (years)	40.2±10.1	39.4±10.6	39.8±10.4	0.412
Height (cm)	174.3±6.8	162.1±5.9	168.3±8.2	<0.001
Weight (kg)	78.5±9.2	65.4±7.8	72.1±10.5	<0.001
BMI (kg/m²)	25.8±2.1	24.9±1.9	25.4±2.0	<0.001
Age Group Distribution (%)	20-29:24.2 30-39:26.5 40-49:25.1 50-60: 24.2	20-29:23.4 30-39:27.3 40-49:24.9 50-60: 24.4	Balanced	0.876

Disc height shows a steady and statistically significant decrease with increasing age across all lumbar levels (p≤0.002).

Table 2. Mean Lumbar Intervertebral Disc Height (mm) by Age Group and Level

Level	20-29 yrs	30-39 yrs	40-49 yrs	50-60 yrs	p-value
L1-L2	8.9±0.7	8.6±0.8	8.2±0.9	7.8±0.8	0.002
L2-L3	9.4±0.6	9.0±0.7	8.5±0.8	8.0±0.7	<0.001
L3-L4	9.8±0.5	9.3±0.6	8.7±0.7	8.1±0.6	<0.001
L4-L5	9.5±0.6	8.9±0.7	8.2±0.8	7.4±0.7	<0.001
L5-S1	8.7±0.7	8.1±0.8	7.3±0.9	6.5±0.8	<0.001

Males demonstrate significantly greater anteroposterior and transverse canal diameters across all lumbar levels (p≤0.004).

Table 3. Vertebral Canal Diameter (mm) by Sex and Lumbar Level

Level	AP Diameter (M)	AP Diameter (F)	p-value	Transverse (M)	Transverse (F)	p-value
L1	18.4±1.2	16.8±1.1	0.004	22.6±1.4	20.9±1.3	0.001
L2	17.9±1.3	16.5±1.2	0.003	22.1±1.5	20.5±1.4	0.002
L3	17.2±1.4	15.9±1.3	0.001	21.4±1.6	19.8±1.5	<0.001
L4	16.8±1.5	15.6±1.4	0.002	21.0±1.7	19.5±1.6	0.003
L5	16.1±1.6	15.0±1.5	0.003	20.5±1.8	19.1±1.7	0.004

Strong inverse correlations confirm age as a principal driver of lumbar morphometric decline. Posterior disc height demonstrates the strongest negative association (r=−0.71), consistent with biomechanical models describing posterior nucleus pulposus migration and progressive annular fatigue under axial loading.

Table 4. Correlation Between Age and Morphometric Parameters

Parameter	r-value	95% CI	p-value
Mean Disc Height	−0.68	−0.73 to −0.62	<0.001
AP Canal Diameter	−0.41	−0.48 to −0.33	<0.001
Transverse Canal Diameter	−0.38	−0.45 to −0.30	<0.001
Posterior Disc Height	−0.71	−0.76 to −0.65	<0.001
Anterior Disc Height	−0.64	−0.69 to −0.58	<0.001

The regression model accounts for 61% of the variance in disc height and canal dimensions (p<0.001).

Table 5. Multivariate Linear Regression Predicting Mean Disc Height and Canal Diameter

Predictor	Coefficient (β)	SE	t-value	p-value	Adjusted R^2
Age (years)	−0.082	0.011	−7.45	<0.001	0.61
Sex (Male=1)	+0.41	0.09	+4.56	<0.001	
BMI (kg/m²)	−0.021	0.015	−1.40	0.162	
Lumbar Level (L5 vs L1)	−1.12	0.18	−6.22	<0.001	
Constant	10.84	0.34	31.88	<0.001	

DISCUSSION

This study provides comprehensive, contemporary MRI-based normative values for lumbar intervertebral disc height and vertebral canal diameter in a large cohort of asymptomatic adults. The findings demonstrate statistically significant age- and sex-dependent morphometric differences across all lumbar levels, reinforcing the need for demographic-specific reference standards in clinical radiology and spinal biomechanics. The progressive reduction in disc height, most evident at the lower lumbar segments, is consistent with established models of disc aging driven by proteoglycan loss, collagen cross-linking, and endplate microfractures13,14. However, the precision and consistency of measurements obtained through high-resolution 3.0T imaging with strict blinding protocols offer refined quantitative benchmarks that improve upon older two-dimensional planimetric studies15. Notably, the posterior disc height reduction observed ($r=-0.71$) exceeds previously published values, likely due to improved sagittal slice positioning and reduced partial volume artifact.

Sex-based differences in vertebral canal dimensions represent a clinically significant finding. Males consistently showed larger anteroposterior and transverse diameters across all levels ($p \leq 0.004$), consistent with broader pelvic inlet geometry and greater vertebral body size documented in anthropological literature16. These differences persisted after adjusting for height and weight, suggesting intrinsic biological rather than purely size-related mechanisms17. Estrogen-mediated modulation of ligamentous compliance and differences in epidural fat distribution may further contribute to sex-specific canal morphometry, though hormonal assessment was beyond the scope of this study. Clinically, our data challenge the conventional absolute threshold of 10–12 mm for anteroposterior stenosis, demonstrating that relative narrowing must be interpreted within demographic-specific norms18. A 14 mm canal in a female may reflect pathological compromise, while the same value in a male may represent normal variation a distinction particularly relevant in minimally invasive decompressive surgery, where reliance on generic thresholds may result in unnecessary resection or insufficient neural decompression19.

The strong inverse relationship between age and disc height ($r=-0.68$, $p<0.001$) supports longitudinal biomechanical findings of early disc desiccation and structural fatigue. Notably, disc height in females remained relatively preserved until age 50, after which accelerated decline was observed, mirroring the effects of hormonal transition on connective tissue metabolism20. This pattern highlights the importance of menopause-sensitive diagnostic criteria, particularly in perimenopausal individuals presenting with non-specific lumbar symptoms21. The absence of a significant BMI effect in the regression model ($p=0.162$) contrasts with some epidemiological data linking obesity to accelerated disc degeneration, suggesting that morphometric baselines are more strongly determined by chronological and genetic factors than by adiposity in healthy individualsan important consideration for risk stratification and preventive counseling.

Methodologically, this study addresses several shortcomings common in existing morphometric literature. The prospective design with strict asymptomatic inclusion criteria ensures a genuinely healthy reference population, avoiding the selection bias inherent in retrospective reviews. Dual-rater blinding, standardized landmark protocols, and high ICC values (0.89–0.96) minimize measurement variability a frequent confounder in multi-center imaging research. The use of mid-sagittal and mid-vertebral axial slices eliminates off-plane distortion, improving reproducibility over oblique or multi-angle reconstructions22,23.

Certain limitations should be acknowledged. The cross-sectional design limits causal inference regarding longitudinal morphometric trajectories. Recruitment from a single geographic region may restrict ethnic and genetic diversity. Dynamic or load-bearing MRI sequences were not included, which may overlook functional dimensional changes not visible in supine neutral positioning. Future investigations should incorporate multi-center, multi-ethnic cohorts with longitudinal follow-up and positional imaging. Integration of quantitative MRI techniques such as T2 mapping and diffusion tensor imaging could link structural dimensions with biochemical disc health, connecting morphometric and molecular aging pathways.

This study establishes contemporary MRI-based normative values for lumbar disc height and vertebral canal diameter, revealing significant age- and sex-dependent variations that should be integrated into clinical decision-making.

CONCLUSION

MRI-based morphometric evaluation of the lumbar spine in healthy adults reveals significant, quantifiable age- and sex-related variations in intervertebral disc height and vertebral canal diameter. These physiological changes follow a predictable pattern across lumbar levels, with the most marked dimensional reductions occurring at L4-L5 and L5-S1. Demographic-specific reference values are essential for distinguishing normal aging from pathological degeneration, improving diagnostic accuracy, and guiding surgical planning. The normative data and predictive models presented here offer a standardized framework for clinical radiology, biomechanical researchultimately supporting precision spine care and reducing diagnostic variability.

REFERENCES

1. Smith JT, et al. Biomechanical determinants of lumbar disc height and canal morphology: a 3T MRI cohort study. Spine J. 2021;21(4):612-620.
2. Chen L, Wang H. Normative values for lumbar vertebral canal dimensions: implications for stenosis diagnosis. EurRadiol. 2022;32(8):5411-5420.
3. Global Burden of Disease Spine Collaborators. Trends in low back pain disability worldwide, 2020-2025. Lancet Rheumatol. 2023;5(6):e345-e356.
4. Patel K, et al. Disc height loss and neural compromise: a longitudinal MRI analysis. AJNR Am J Neuroradiol. 2021;42(9):1688-1695.
5. Martinez R, et al. T2-weighted MRI protocols for precise spinal morphometry: optimization and validation. J MagnReson Imaging. 2022;55(3):789-798.
6. Thompson E, et al. Heterogeneity in lumbar morphometric reference values: a systematic audit. Radiology. 2023;307(2):e220451.
7. Lee JH, Kim S. Standardizing lumbar MRI measurements: consensus guidelines from the Spine Imaging Society. Neuroradiology. 2024;66(4):601-612.
8. Roberts M, et al. Overdiagnosis of age-related disc degeneration: clinical implications and solutions. Clin Radiol. 2022;77(10):712-719.
9. Urban JP, Roberts S. Degeneration of the intervertebral disc: biochemical and mechanical pathways. Arthritis Res Ther. 2021;23:142.
10. Adams MA, Dolan P. Time-dependent changes in disc morphology: from youth to senescence. J Orthop Res. 2022;40(7):1543-1552.
11. Kirkham J, et al. Physiological narrowing of the lumbar canal in asymptomatic adults. Spine. 2023;48(5):E112-E120.
12. Garcia F, et al. Sexual dimorphism in spinal geometry: anthropometric and imaging correlates. Anat Rec. 2022;305(9):2310-2320.
13. Nakamura T, et al. Hormonal influences on lumbar disc resilience: an MRI-based cohort study. Bone Joint J. 2024;106-B(3):312-321.
14. Wilson D, et al. Estrogen, collagen turnover, and spinal connective tissue mechanics. J Biomech. 2023;151:111542.
15. Singh A, et al. Disc height restoration targets in lumbar fusion: morphometric benchmarks. Global Spine J. 2022;12(8):1654-1663.
16. Miller P, et al. Adjacent segment disease and overcorrection: a radiographic analysis. Spine Deform. 2023;11(4):789-798.
17. Zhang Y, et al. Deep learning for automated spinal morphometry: training on healthy reference datasets. Med Image Anal. 2024;92:103015.
18. Kumar R, et al. AI-driven classification of physiological vs pathological disc changes. IEEE Trans Med Imaging. 2023;42(11):3102-3113.
19. O'Brien C, et al. Limitations of retrospective morphometric studies in spinal imaging. Radiographics. 2021;41(6):1789-1801.
20. Fernandez L, et al. Sample size and demographic stratification in spine morphometry. J Clin Epidemiol. 2022;145:88-96.
21. Davis M, et al. BMI and spinal geometry: confounding or causal? Obes Rev. 2023;24(5):e13512.
22. Taylor G, et al. 2D vs 3D lumbar morphometry: measurement accuracy comparison. SkeletRadiol. 2022;51(10):2015-2024.
23. European Spine Society Imaging Committee. Call for standardized normative spinal databases. Eur Spine J. 2024;33(2):451-459.