

Original Research Article

MORPHOANATOMICAL CHANGES IN LUMBAR SPINAL CANAL IN CASES OF LUMBAR SPINAL CANAL STENOSIS IN POPULATION OF WESTERN RAJASTHAN

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ABSTRACT

Background: Lumbar spinal canal stenosis is an important cause of chronic low back pain, neurogenic claudication & functional disability. Degenerative changes in lumbar spine may alter the dimensions of the spinal canal, vertebral bodies, intervertebral discs & paraspinal muscles. As these morphometric parameters may vary with age, sex & ethnicity, region-specific reference data are required for accurate radiological assessment & clinical management. The objective is to estimate morphometric parameters of spinal canal of lumbar region in patients of lumbar canal stenosis (LCS) by assessment of radiological data (MRI), by measuring the anteroposterior diameter, transverse diameter of lumbar spinal canal, and height of intervertebral disc at L3-L4, L4-L5, & L5-S1, and determine its correlation with demographic factors like age & gender of the patients.

Materials and Methods: This cross-sectional descriptive study was performed on 384 patients aged 20–70 years with chronic low back pain & MRI-confirmed lumbar spinal canal stenosis. T2W-sagittal & T2W-axial scans were studied in DICOM format. Spinal canal width (transverse diameter) & spinal canal diameter (anteroposterior diameter), & intervertebral disc height were calculated at vertebral level L3-L4, L4-L5 & L5-S1.

Results: Among 384 subjects, 212 (55.2%) were males & 172 (44.8%) were females. The overall mean age was approximately 45.44 ± 14.62 years. Spinal canal width showed a significant age & gender-wise difference at L5-S1 ($p < 0.001$), while spinal canal diameter showed no significant difference at any lumbar level. Intervertebral disc height differed significantly at L3-L4 ($p = 0.026$).

Conclusion: Lumbar spinal canal morphometry varies according to age, gender & vertebral level. These findings provide useful population-specific morphometric data that may assist in radiological evaluation, early diagnosis & management of lumbar spinal canal stenosis in Western Rajasthan.

Keywords: Lumbar spinal canal stenosis; morphometry; magnetic resonance imaging; spinal canal dimensions; Western Rajasthan.

INTRODUCTION

The lower back extends from lowest rib to upper part of the buttocks & is supported by five lumbar vertebrae (L1-L5). These vertebrae have large, kidney-shaped bodies anteriorly & vertebral arch enclosing the spinal canal posteriorly. The lumbar spinal canal is triangular or trefoil-shaped.^[1] The vertebral column undergoes continuous remodeling

& degeneration throughout life. These changes are influenced by intrinsic factors, such as genetics, metabolism, nutrition, & hormones, & extrinsic factors, such as mechanical loading, posture, occupation, lifestyle, & physical activity.^[2] Age-related degeneration commonly begins in the intervertebral disc, where loss of water-binding proteoglycans causes dehydration & reduced elasticity of nucleus pulposus.^[3,4] Lumbar spinal

canal stenosis (LSCS) is the narrowing of the spinal canal, lateral recesses, or neural foramina, resulting in compression of neural & vascular structures. LSCS usually develops gradually & commonly presents as neurogenic claudication, including pain, numbness, tingling, weakness, cramping, or heaviness in the buttocks & lower limbs. Symptoms worsen during walking, prolonged standing, or lumbar extension & improve with sitting, squatting, or forward bending.^[5] Nerve-root compression may cause unilateral or bilateral radicular symptoms, sensory impairment, motor weakness, & reduced deep tendon reflexes. The L5 nerve root is most commonly affected, followed by L4 & L3.^[6] Chronic low back pain persists for more than 12 weeks, & LSCS is an important structural cause among older adults.^[7,8] The diagnosis of LSCS has been preferably done by Magnetic resonance imaging (MRI) as it is non-invasive investigation & clearly demonstrates spinal canal dimensions, intervertebral discs, facet joints, neural structures, & paraspinal muscles.^[9] However, detailed MRI-based morphometric data on LSCS remains limited in North Indian population, particularly in Western Rajasthan. Therefore, the present study aims to evaluate the key morphometric parameters of the lumbar spinal canal in male & female patients with chronic low back pain & determine their relationship with age. These findings aims to improve diagnostic accuracy, treatment planning, & patient care & may also be useful for anatomists, radiologists, neurologists, spine surgeons, forensic experts, & other healthcare professionals.

Aim & Objectives: The study aimed to evaluate morphoanatomical changes in the lumbar spinal canal & intervertebral disc of lumbar regions among patients with LSCS from Western Rajasthan. The objectives were to measure spinal canal width, spinal canal diameter and intervertebral disc height at L3–L4, L4–L5 & L5–S1; & compare these parameters by lumbar vertebral level, age group & gender.

MATERIALS AND METHODS

The present study was an institution-based, observational, descriptive, cross-sectional, MRI based study, conducted in Department of Anatomy in collaboration with Department of Radiodiagnosis, Sardar Patel Medical College & Associated Group of Hospitals, Bikaner, Rajasthan, India, for a period of one year, from June 2024 to June 2025. By using Andrew Fisher formula for estimation of sample size at 95% confidence level & error margin as 5%, the calculated sample size was 384.

Human adult aged 20-70 years from Western Rajasthan who underwent lumbar spine MRI & were diagnosed clinically &/or radiologically as cases of lumbar spinal canal stenosis were included in the study. Patients commonly presented with chronic low back pain, leg pain, neurogenic claudication or pain aggravated by walking & relieved by rest or forward flexion. Only MRI scans in DICOM format, fulfilling

the anatomical & image-quality requirements were included for final morphoanatomical assessment. Intra-observer reliability was assessed, considering the measurement consistency.

Patients with history of lumbar spine surgery, recent spinal intervention, & pathology of spinal cord, vertebral column, major disc herniation, congenital vertebral malformations, orthopedic disorders, peripheral neuropathy, pregnant females & those with poor quality or incomplete scans were excluded from the study.

Ethical clearance was taken from Institutional Ethics Committee (Ethical & research board approval number: F.29 (Acad) SPMC/2023/2274). All study participants were informed about the objective of the study, nature of data collection, potential academic benefits & confidentiality measures in their native language. Written informed consent was obtained, prior to inclusion. The standard guidelines to ensure confidentiality of patient's information was followed. Therefore, the MRI data were tabulated & analysed in pseudonymised format wherein the patient's identifiers were replaced with unique study codes while maintaining the ability for data linkage. Relevant demographic details such as age, gender, & residence of included subjects were recorded.

MRI Acquisition Protocol: All the patients underwent lumbar MRI examinations using a 3.0 Tesla MRI scanner available at the institution, i.e. Philips Ingenia Elition 3.0T X, following the standard lumbar spine MRI protocol.^[10] The patients were placed in supine position with neutral lumbar alignment in order to minimize positional measurement errors. We obtained both T1 (longitudinal relaxation time) & T2 (transverse relaxation time) weighted fast spin echo (FSE) images in axial as well as sagittal planes to achieve optimum image contrast & resolution. Repetition time (TR) & echo time (TE) were adjusted for the axial & sagittal images accordingly. The image sequences were namely, T1W-FSE Sagittal, T1W-FSE axial, T2W-FSE Sagittal & T2W-FSE axial. All images were acquired in Digital Imaging & Communications in Medicine (DICOM) format & analyzed using an open access RadiAnt DICOM Viewer software 2025.2 64 bit version. This software was used for image viewing, level confirmation, & linear measurement.

For morphometric analysis, T2W sagittal & T2W axial images were primarily used due to better soft tissue contrast & clearer delineation of intervertebral discs & spinal canal [Figure 1].

We adjusted the slice thickness at 4 mm & interslice thickness at 1 mm. For sagittal T2-weighted images, repetition time (TR) & echo time (TE) were in range of approximately 2100-2200 ms & 110-120 ms, respectively, whereas for axial images, TR/TE were approximately 4000-4200 ms /110-120 ms, & field of view (FOV) was 280 - 320 mm.

In MRI, lumbar vertebrae from L1 to L5 were identified on sagittal & axial MRI images by using established anatomical landmarks, intervertebral disc

numbering & cross-referencing between planes. In sagittal view, sacrum & iliac crest were primary bony landmarks. The L5 vertebral body was identified immediately above the sacrum (S1), & L4 vertebral level in corresponding to the level of iliac crest. Counting was then performed upward from these fixed landmarks to number L1-L5 sequentially. Additional anatomical orientation was obtained from the termination level of the conus medullaris typically at L1 [Figure 1]. For morphometry, we obtained measurements at L3-L4, L4-L5 & L5-S1 levels.

T2W-TSE axial slices was used for assessment of superior end plate of the succeeding vertebra (L4, L5 & S1) for linear measurements of Spinal canal width (SCW) & spinal canal diameter (SCD) [Figure 2-4]. Axial images were cross-referenced with sagittal images to ensure accurate level identification before measurement [Figure 2-4]. This method aligns with standard spine MRI interpretation practices [10, 11]. T2W-TSE Mid-sagittal images were used for measurement of intervertebral disc height [9] [Figure 5]. All linear measurements were measured in centimetres (cm) by using digital calliper & recorded in predesigned Excel sheets.

Spinal canal width is the maximum transverse distance measured as between the medial borders of the right & left pedicles of lumbar vertebra [12] [Figure 2-4]. Spinal canal diameter is anteroposterior diameter, measured from the midpoint of the posterior surface of the vertebral body to the midpoint of the inner bony surface of the posterior vertebral

arch, where both lamina meet^[12] [Figure 2-4]. Intervertebral disc height (IVDH) was measured using a standardized morphometric technique described by Wolfgang Frobin et al, [13] in Clinical Biomechanics. Mid-sagittal MRI images of the lumbar spine with clearly visualized superior & inferior vertebral endplates were selected for analysis. For each vertebral motion segment, the anterior, middle, & posterior points of intervertebral disc space were identified between inferior endplate of superior vertebra & superior endplate of inferior vertebra. Disc height was measured as the perpendicular distance between the adjacent endplates at midpoints. Accordingly, middle disc height was obtained^[13] [Figure 5].

RESULTS

The morphometric analysis was done on 384 samples (male = 212, female = 172) of age ranged from 20-70 years. They were further classified into 3 groups as: group A (20-36 years), group B (37-52 years), & group C (53-70 years) as shown in Table 1.

For each group, mean & standard deviation of lumbar morphometric parameters (in cm) were calculated: Spinal canal width (SCW), spinal canal diameter (SCD), intervertebral disc height (IVDH). The following tables present the vertebral level-wise, gender-wise & age-group-wise distribution of lumbar morphometric measurements. The values of each group were expressed as mean $\pm$ standard deviation.

Table 1: Gender distribution

Group	Age range	L3-L4		L4-L5		L5-S1	
		Male	Female	Male	Female	Male	Female
A	20-36	81	45	81	45	81	45
B	37-52	63	66	63	66	63	66
C	53-70	68	61	68	61	68	61
Total		212	172	212	172	212	172
p-value (ANOVA)		0.036*		0.036*		0.036*	

Table 1 shows that the gender distribution was the same at all three lumbar levels. Group A (20-36-year) included 81 males & 45 females, group B (37-52-year) included 63 males & 66 females, & group C (53-70 year) included 68 males & 61 females. Overall, there were 212 males & 172 females at each

level, & the age-group & gender distribution was statistically significant ($p=0.036$).

Males constituted 212 (55.2%) & females constituted 172 (44.8%) of the 384 observations at each lumbar level. The gender distribution was identical at L3-L4, L4-L5 & L5-S1, & no statistically significant difference was observed ($p=1.000$).

Table 2: Comparison of mean Spinal Canal Width (SCW) according to age & gender at L3-L4, L4-L5 & L5-S1 vertebral Levels

Lumbar Level	20–36 Years				37–52 Years				53–70 Years				p-value
	Male		Female		Male		Female		Male		Female		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
L3–L4	1.57	0.24	1.64	0.20	1.57	0.27	1.57	0.38	1.59	0.23	1.52	0.28	0.381
L4–L5	1.62	0.24	1.60	0.25	1.54	0.31	1.51	0.21	1.75	0.17	1.53	0.26	0.481
L5–S1	1.67	0.29	1.72	0.32	1.53	0.30	1.49	0.24	1.57	0.30	1.48	0.31	<0.001*

The mean spinal canal width (SCW) at L3-L4 level ranged from 1.52 ± 0.28 to 1.64 ± 0.20 across the different age & gender groups. Females aged 20-36 years exhibited the highest mean SCW (1.64 ± 0.20), whereas females aged 53-70 years had the lowest mean value (1.52 ± 0.28). The differences among the

study groups were not statistically significant ($p = 0.381$).

At the L4-L5 level, the mean SCW varied from 1.51 ± 0.21 to 1.75 ± 0.17 . The greatest mean SCW was recorded in males aged 53-70 years (1.75 ± 0.17), while the lowest value was observed in females aged 37-52 years (1.51 ± 0.21). Despite these variations,

no statistically significant differences were identified between the age & gender groups ($p = 0.481$). At the L5–S1 level, the mean SCW ranged between 1.48 ± 0.31 & 1.72 ± 0.32 . Females in the 20–36-year age group demonstrated the highest mean SCW (1.72 ± 0.32), whereas the lowest mean value was observed among females aged 53–70 years (1.48 ± 0.31).

Unlike the upper lumbar levels, the differences at L5–S1 were statistically significant ($p < 0.001$). Overall, age- & gender-related variations in SCW were not statistically significant at L3–L4 & L4–L5 levels. However, a statistically significant difference was observed at L5–S1 level, suggesting that SCW at this level varies across age & gender groups included in study.

Table 3: Comparison of mean Spinal Canal diameter (SCD) according to age & gender at L3–L4, L4–L5 & L5–S1 vertebral Levels

Lumbar Level	20–36 Years				37–52 Years				53–70 Years				p-value
	Male		Female		Male		Female		Male		Female		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
L3–L4	1.36	0.22	1.48	0.22	1.31	0.24	1.35	0.25	1.48	1.43	1.28	0.21	0.400
L4–L5	1.29	0.23	1.36	0.25	1.24	0.28	1.26	0.20	1.46	1.65	1.25	0.25	0.492
L5–S1	1.27	0.25	1.33	0.26	1.24	0.27	1.23	0.23	1.24	0.24	1.27	0.30	0.420

The mean spinal canal diameter (SCD) at L3–L4 level ranged from 1.28 ± 0.21 to 1.48 ± 0.22 across age & sex groups. Females aged 20–36 years & males aged 53–70 years exhibited highest mean SCD (1.48), whereas the lowest mean value was observed in females aged 53–70 years (1.28 ± 0.21). However, differences among the study groups were not statistically significant ($p = 0.400$). At L4–L5 level, mean SCD varied from 1.24 ± 0.28 to 1.46. The highest mean value was recorded in males aged 53–70 years (1.46), while lowest mean value was observed in males aged 37–52 years (1.24

± 0.28). No statistically significant differences were identified among the age & sex groups ($p = 0.492$). At L5–S1 level, mean SCD ranged between 1.23 ± 0.23 & 1.33 ± 0.26 . Females aged 20–36 years demonstrated highest mean SCD (1.33 ± 0.26), whereas females aged 37–52 years had lowest mean value (1.23 ± 0.23). The differences among the age & sex groups were not statistically significant ($p = 0.420$). Overall, no statistically significant age- or sex-related differences in spinal canal diameter were observed at the L3–L4, L4–L5, or L5–S1 levels in the study population.

Table 4: Comparison of mean Inter vertebral disc height (IVDH) according to age & gender at L3–L4, L4–L5 & L5–S1 vertebral Levels

Lumbar Level	20–36 Years				37–52 Years				53–70 Years				p-value
	Male		Female		Male		Female		Male		Female		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
L3–L4	0.98	0.16	0.96	0.15	1.04	0.17	0.99	0.19	1.05	0.21	0.99	0.15	0.026*
L4–L5	1.08	0.19	1.25	1.36	1.07	0.21	0.98	0.17	1.02	0.25	0.99	0.20	0.096
L5–S1	1.00	0.17	0.97	0.21	1.00	0.22	0.93	0.19	1.03	0.22	1.05	0.62	0.299

The mean intervertebral disc height (IVDH) at the L3–L4 level ranged from 0.96 ± 0.15 to 1.05 ± 0.21 across the age & sex groups. The highest mean IVDH was observed in males aged 53–70 years (1.05 ± 0.21), whereas the lowest mean value was recorded in females aged 20–36 years (0.96 ± 0.15). The differences among the study groups were statistically significant ($p = 0.026$). At the L4–L5 level, the mean IVDH varied between 0.98 ± 0.17 & 1.25 ± 1.36 . Females aged 20–36 years demonstrated the highest mean IVDH (1.25 ± 1.36), while the lowest mean value was observed in females aged 37–52 years (0.98 ± 0.17). However, the differences among the age & sex groups were not statistically significant ($p = 0.096$). At the L5–S1 level, the mean IVDH ranged from 0.93 ± 0.19 to 1.05 ± 0.62 . The highest mean value was recorded in females aged 53–70 years (1.05 ± 0.62), whereas the lowest mean value was observed in females aged 37–52 years (0.93 ± 0.19). No statistically significant differences were identified among the study groups ($p = 0.299$). Overall, a statistically significant age- & sex-related difference in intervertebral disc height was observed

only at the L3–L4 level. In contrast, no significant differences were found at the L4–L5 & L5–S1 levels.

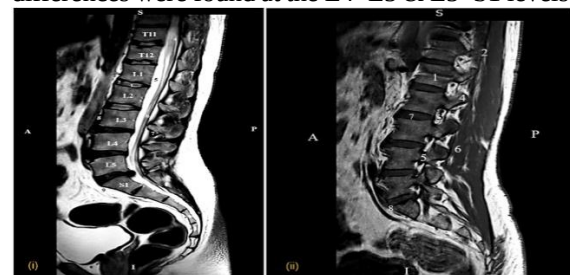


Figure 1 (i): Mid-sagittal T2W-TSE MR image of lumbar spine of 27 year old male showing 1: Intervertebral disc (nucleus pulposus), 2: annulus fibrosus, 3: Basivertebral vein, 4: Conus medullaris, 5: Cerebro-spinal fluid, 6: Cauda equina, 7: epidural space filled with epidural fat, 8: Anterior Longitudinal ligament, 9: Sacral promontory. A: Anterior, P: Posterior, S: Superior, I: Inferior. **Figure 1 (ii):** Para-sagittal T2W-TSE MR image of lumbar spine of 27 year old male showing 1: Body of lumbar vertebra, 2: Supraspinous ligament, 3: Spinal nerves emerging from intervertebral foramen, 4: Spinous process, 5: Pedicle, 6: Erector spinae muscle, 7: Intervertebral disc, 8: Sacral Promontory. A: Anterior, P: Posterior, S: Superior, I: Inferior.

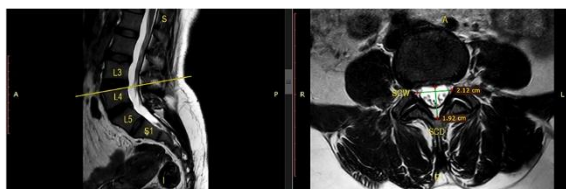


Figure 2: (i)Mid-sagittal & (ii) axial T2W-TSE MR Image of lumbar spine at superior end plate of L4 vertebral body in 29 year old female showing measurement of spinal canal width & spinal canal diameter. A: Anterior, P: Posterior, R: Right, L: Left, S: Superior, I: Inferior, L3-S1 vertebral level.

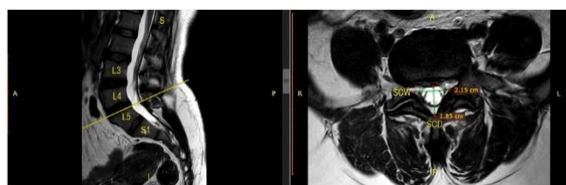


Figure 3: (i)Mid-sagittal & (ii) axial T2W-TSE MR Image of lumbar spine at superior end plate of L5 vertebral body in 29 year old female showing measurement of spinal canal width & spinal canal diameter. A: Anterior, P: Posterior, R: Right, L: Left, S: Superior, I: Inferior, L3-S1 vertebral level.



Figure 4: (i)Mid-sagittal & (ii) axial T2W-TSE MR Image of lumbar spine at superior end plate of S1 vertebral body in 29 year old female showing measurement of spinal canal width & spinal canal diameter. A: Anterior, P: Posterior, R: Right, L: Left, S: Superior, I: Inferior, L3-S1 vertebral level.

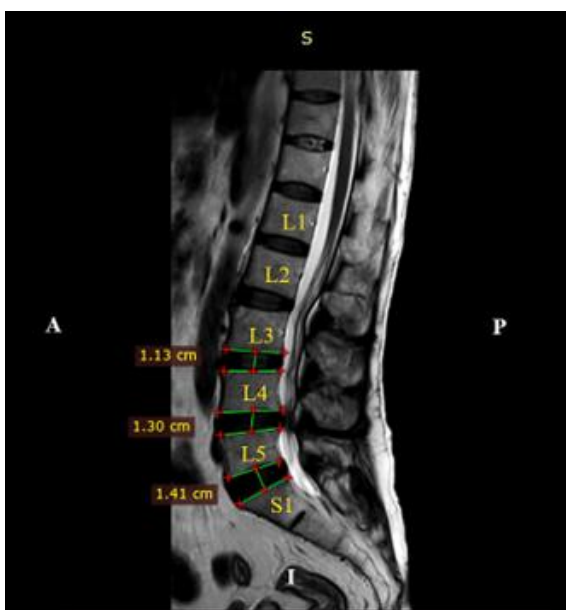


Figure 5: Mid-sagittal T2W-TSE MR image of lumbar spine of 52 year old male showing measurement of intervertebral disc height at vertebral level L3-L4, L4-L5, & L5-S1. A: Anterior, P: Posterior, S: Superior, I: Inferior.

DISCUSSION

The present MRI-based study evaluated 384 subjects from Western Rajasthan, including 212 males & 172 females aged 20–70 years. The participants were divided into three age groups: 20–36 years, 37–52 years & 53–70 years. Measurements were obtained at L3–L4, L4–L5 & L5–S1. The parameters included spinal canal width, spinal canal diameter, & intervertebral disc height. This broad assessment is important to understand the lumbar spinal stenosis by measuring the bony canal.

SPINAL CANAL WIDTH: In present study, mean spinal canal width at L3–L4 ranged from 1.52 ± 0.28 cm in females aged 53–70 years to 1.64 ± 0.20 cm in females aged 20–36 years ($p = 0.381$). At L4–L5, the values ranged from 1.51 ± 0.21 cm in females aged 37–52 years to 1.75 ± 0.17 cm in males aged 53–70 years ($p = 0.481$). No statistically significant differences were observed at both of these levels. In contrast, at L5–S1, SCW ranged from 1.48 ± 0.31 cm in females aged 53–70 years to 1.72 ± 0.32 cm in females aged 20–36 years, & the difference was statistically significant ($p < 0.001$). The significant finding at L5–S1 suggests that the lower lumbar canal is more sensitive to combined age- & sex-related variation than L3–L4 & L4–L5. The lower value in older females may be related to smaller skeletal dimensions, degenerative remodeling & reduced reserve around the neural structures.

The relatively stable SCW observed at the L3–L4 & L4–L5 levels is in agreement with previous morphometric studies, which have shown that bony lumbar canal dimensions shows minimal variation during adulthood. Nandi et al. (2022),^[14] found significantly smaller canal dimensions in symptomatic individuals than in asymptomatic controls but observed no significant association between age & canal diameter, indicating that congenital canal dimensions may influence susceptibility to lumbar spinal canal stenosis more than chronological aging. Collectively, these findings support the absence of significant age-related differences in SCW at the L3–L4 & L4–L5 levels observed in the present study.

Unlike the upper lumbar levels, SCW at L5–S1 showed a significant difference among the study groups. Elrakhaw et al. (2010),^[15] also reported substantial individual variation in lumbar vertebral canal morphology & emphasized that developmental anatomy contributes significantly to canal dimensions & susceptibility to lumbar spinal canal stenosis. They found that the canal was wider than it was deep, that the canal narrowed around L3, & that the ratio of vertebral foramen width to vertebral body width was approximately 0.6 at most levels but about 0.5 at L3 & L5. These numerical ratios support the concept that canal width does not remain constant across the lumbar region. The present study similarly found meaningful lower-lumbar variation, especially at L5–S1 ($p < 0.001$). Differences in absolute values

are expected because Elrakhawy et al.^[15] studied an Egyptian population using radiographs & dry bones, while the present study evaluated living subjects from Western Rajasthan by MRI.

Although males generally possess larger vertebral dimensions than females, the present study demonstrated no significant sex-related differences in SCW at the L3–L4 & L4–L5 levels. Similar observations were reported by Yadav et al. (2020),^[16] that described only modest sex-related differences in lumbar canal dimensions despite significant differences in vertebral body measurements. These findings suggest that vertebral canal width is relatively conserved between genders & is less influenced by overall skeletal size than vertebral body morphology.

Overall, the present findings indicate that spinal canal width remains relatively stable across age groups at the L3–L4 & L4–L5 levels, while the significant variation observed at L5–S1 suggests that regional anatomical characteristics may influence canal morphology. These observations further support the concept that lumbar spinal canal stenosis is a multifactorial disorder & that isolated assessment of spinal canal width is insufficient for determining disease severity.

Spinal canal diameter: In the present study, spinal canal diameter (SCD) demonstrated minimal variation across age groups & between sexes. At the L3–L4 level, mean spinal canal diameter ranged from 1.28 ± 0.21 cm in females aged 53–70 years to 1.48 ± 0.22 cm in females aged 20–36 years; the reported value in 53–70 males was 1.48 ± 1.43 cm. The overall difference was not significant ($p = 0.400$). At L4–L5, the diameter ranged from 1.24 ± 0.28 cm in males aged 37–52 years to 1.46 ± 1.65 cm in males aged 53–70 years ($p = 0.492$). At L5–S1, values ranged from 1.23 ± 0.23 cm in females aged 37–52 years to 1.33 ± 0.26 cm in females aged 20–36 years ($p = 0.420$). No significant differences were observed at the L4–L5 & L5–S1 levels, despite slight variations in the mean values. Thus, although the mean diameter generally tended to be smaller at lower levels, chronological age & sex did not independently produce a consistent statistically significant pattern.

The present findings are comparable with those reported by Sethi et al (2018),^[17] who demonstrated that anteroposterior diameter of the lumbar spinal canal reduced in symptomatic subjects, particularly at L4 & L5, but did not find a significant association between age & SCD in either age group. This is closely comparable to the present finding, where spinal canal diameter did not differ significantly across age & sex groups at L3–L4 ($p = 0.400$), L4–L5 ($p = 0.492$) or L5–S1 ($p = 0.420$). Both studies suggest that canal diameter is influenced by factors other than age alone, including inherited canal size, degenerative soft-tissue encroachment & individual anatomical variation.

Likewise, Nandi et al. (2022),^[14] reported that mean midsagittal anteroposterior canal diameter progressively decreased from L1–L2 to L5–S1 & was

significantly smaller at all levels in symptomatic individuals. They also found no significant relationship between age & symptom occurrence. The present study similarly shows lower mean values at the caudal levels but no significant age–sex group difference. Collectively, these studies support the absence of significant age-related variation in SCD observed in the present study.

The lack of significant sex-related differences in SCD observed in the present study is also consistent with previous morphometric investigations. Although males generally possess larger vertebral body dimensions than females, lumbar spinal canal dimensions exhibit comparatively little sexual dimorphism because the vertebral canal must accommodate neural structures of similar size in both sexes. Yadav et al. (2020),^[16] similarly reported only minor sex-related differences in lumbar canal dimensions despite significant differences in vertebral body measurements, suggesting that spinal canal diameter is relatively conserved irrespective of sex.

The present findings also support the observations of Anasuya et al. (2015),^[18] who emphasized that spinal canal diameter alone cannot reliably differentiate symptomatic from asymptomatic individuals. They demonstrated that some individuals with morphometrically narrow canals remain asymptomatic, whereas others develop clinical manifestations despite canal dimensions within the accepted normal range.

Similarly, Yuan et al. (2016),^[19] reported that functional narrowing of the spinal canal is influenced not only by the bony canal diameter but also by secondary degenerative changes such as ligamentum flavum hypertrophy, facet joint hypertrophy, intervertebral disc bulging, & osteophyte formation. Unlike spinal canal width, spinal canal diameter did not demonstrate a statistically significant difference at any lumbar level in the present study. Therefore, the severity of lumbar spinal canal stenosis is unlikely to be explained solely by static osseous canal dimensions & should instead be interpreted in conjunction with degenerative soft tissue changes & clinical presentation.

Overall, the present study indicates that spinal canal diameter remains relatively stable across different age groups & between sexes, supporting previous morphometric studies that describe lumbar canal dimensions as predominantly developmentally determined. These findings reinforce the importance of comprehensive MRI evaluation incorporating both osseous morphometry & degenerative soft tissue changes for accurate assessment of lumbar spinal canal stenosis.

IVDH: In the present study, intervertebral disc height (IVDH) demonstrated variable measurements across lumbar levels. At L3–L4, intervertebral disc height ranged from 0.96 ± 0.15 cm in females aged 20–36 years to 1.05 ± 0.21 cm in males aged 53–70 years, & the group difference was significant ($p = 0.026$). At L4–L5, values ranged from 0.98 ± 0.17 cm in

females aged 37–52 years to 1.25 ± 1.36 cm in females aged 20–36 years, but the difference was not significant ($p = 0.096$). At L5–S1, values ranged from 0.93 ± 0.19 cm in females aged 37–52 years to 1.05 ± 0.62 cm in females aged 53–70 years, with no significant difference ($p = 0.299$). Therefore, disc height did not show a simple progressive decline with age. These findings indicate that age- & sex-related differences in disc height were more evident at the upper lumbar level than at the lower lumbar segments in the present study.

The significant variation in IVDH at the L3–L4 level is consistent with the observations of Boissière et al. (2016),^[20] who reported that lumbar disc height varies with age & spinal level & reflects progressive structural changes within the intervertebral disc. They demonstrated that age-related alterations in disc morphology are influenced by degeneration of the nucleus pulposus, reduction in proteoglycan content, & decreased water retention, resulting in changes in disc dimensions. Similarly, Urrutia et al.,^[21] observed that lumbar disc height is associated with both age & degenerative changes, although the magnitude of these changes differs among lumbar levels. These findings support the significant variation in L3–L4 disc height observed in the present study.

Despite being the levels most frequently affected by degenerative lumbar disease, L4–L5 & L5–S1 did not demonstrate statistically significant differences in disc height in the present study. This observation may indicate that disc height alone does not fully reflect the severity of degenerative changes. Degeneration is a complex process involving alterations in disc composition, annular integrity, end-plate morphology, & hydration, which may precede or occur independently of measurable reductions in disc height.

Sex-related differences in IVDH were minimal throughout the study population. Although slight differences in mean values were observed between males & females, these variations were not consistent across lumbar levels, suggesting that disc height is influenced more by individual degenerative changes & mechanical loading than by sex alone. This observation is in accordance with previous morphometric studies, which have reported only modest sex-related variation in lumbar disc height after skeletal maturity.

Overall, the present study demonstrates that significant variation in intervertebral disc height was observed only at the L3–L4 level, whereas measurements at L4–L5 & L5–S1 remained relatively comparable across age & sex groups. These findings suggest that linear disc height measurements should be interpreted alongside qualitative MRI features to accurately assess the extent of lumbar degenerative changes.

CONCLUSION

The present study demonstrates that the lumbar spinal canal and intervertebral disc exhibit distinct level-,

age- & sex-related morphoanatomical variations in patients with lumbar spinal canal stenosis from Western Rajasthan. Spinal canal width showed a significant difference only at L5–S1, while spinal canal diameter remained statistically comparable across age & sex groups at all three studied levels. Intervertebral disc height differed significantly only at L3–L4. Therefore, MRI assessment of lumbar spinal canal stenosis should include systematic, bilateral & multilevel evaluation of the multifidus, erector spinae & psoas major muscles along with spinal canal & disc measurements. Such a comprehensive morphometric approach may improve anatomical characterization of lumbar spinal canal stenosis in the Western Rajasthan population; however, clinical & functional correlations are required before these measurements can be used independently for determining disease severity or patient outcome.

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