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Prevalence and Morphology of L5 Sacralization: A Retrospective Radiological Study

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ABSTRACT

Background: Lumbosacral transitional vertebrae (LSTV), specifically sacralization of the fifth lumbar vertebra (L5), affect load transmission at the lumbosacral junction. This altered L5–S1 articulation can impact spinal biomechanics, potentially accelerating degenerative changes and increasing the risk of low back pain (LBP). Reported prevalence ranges from 3% to 36%, varying by population and methodology, yet data on the link between sacralization, degeneration, and pain in the Indian population are limited. This study assessed the incidence, distribution, and clinical associations of sacralization using radiographic & imaging data.

Methods: A retrospective observational study reviewed 500 lumbosacral imaging samples (X-ray, CT, MRI) obtained between January and March 2025, of which 489 met the inclusion criteria. LSTV were classified by Castellvi's criteria as complete or incomplete sacralization. Associations between sacralization, degenerative changes, and LBP were analysed using Fisher's Exact test and one-way ANOVA.

Results: Sacralization prevalence was 4.9% (n = 24; 1.8% complete, 3.1% incomplete), all bilateral. A significant association was found between sacralization and LBP (p = .025), whereas sacralization type and degenerative changes were not associated (p = .519); degenerative changes were strongly linked with LBP (p = .001). Mean pain duration was significantly higher in complete sacralization (6.89 ± 8.49 months) than in incomplete or absent cases (p = .015).

Conclusion: Sacralization of L5, though relatively uncommon, demonstrates a significant relationship with LBP, emphasising the need for early identification and biomechanical evaluation in clinical practice. Further longitudinal and biomechanical analyses are warranted to elucidate causal mechanisms..

Key-words: Castellvi classification; Degenerative changes; Low back pain; Lumbosacral transitional vertebrae; Sacralization; Spinal biomechanics

INTRODUCTION

The lumbosacral junction occupies a critical biomechanical role in the transmission of loads from the lumbar spine to the pelvis and lower extremities, and anatomical variations in this region may carry significant clinical implications.

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One such variation is the sacralization of the fifth lumbar vertebra (L5), defined as a developmental fusion of L5 with the first sacral segment (S1) [1]. The prevalence of sacralization has been reported to range widely. Dry-bone studies in Indian populations have found incidence values of 6.25% [1] and 17.7% in a sample of 79 sacra [2]. In a surgical series of patients with degenerative spondylolisthesis at L4–L5, sacralization was present in 37 of 102 patients (36.3%) [3]. These data illustrate that the incidence of sacralization in different populations may span from approximately 6% to over 30% depending on sampling, imaging modality, and definition [4,5]. Given

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this wide variability, establishing robust epidemiological data in defined clinical settings remains a priority.

Sacralization of L5 is one form of a broader category of lumbosacral transitional vertebrae (LSTV), which also includes lumbarization of S1, where the first sacral vertebra becomes functionally or anatomically similar to a lumbar segment [6]. For sacralization, the anatomical changes may include bony fusion of the L5 transverse process(es) to the sacral ala, partial articulation (pseudo-joint) between L5 and the sacrum, or even complete sacral assimilation of L5 [7]. These variants may occur unilaterally or bilaterally and are often classified using the Castellvi classification. The presence of sacralization reduces mobility at the L5–S1 segment, thereby altering the biomechanics of the lumbosacral junction [8].

From a biomechanical perspective, fusion of L5 to S1 effectively converts what would normally be a mobile motion segment into a block structure, shifting load and motion demands cephalad to the level above, namely L4–L5. Prior biomechanical work has reported that approximately 70–75% of flexion–extension in the lumbar region occurs at L5–S1 under normal anatomy [8], implying that sacralization can result in disproportionate stress on the L4–L5 disc and facet joints. Altered load distribution may lead to increased shear forces and abnormal kinematics, contributing to adjacent-segment degeneration (ASD) and potential spinal instability [3,9].

Recent advances in magnetic resonance imaging and morphological analysis have deepened understanding of the biomechanical impact of sacralization and other lumbosacral transitional variants. Griffith *et al.* demonstrated, through quantitative MRI of 240 individuals, that those with transitional vertebrae exhibited significantly larger vertebral body areas and higher grades of disc and facet degeneration across all lumbar levels compared with controls ($p < 0.001$) [10]. Verhaegen *et al*., in a mixed cohort of 360 healthy and symptomatic participants, reported that transitional anomalies were present in 28.1% of subjects and correlated with increased pelvic incidence and reduced lumbar lordosis [11]. Fang *et al*. used an axial-loading MRI device in 52 patients and observed dynamic narrowing of the spinal canal and altered nerve root displacement under load [12]. Çankal *et al.* showed significant atrophy of the multifidus and psoas muscles in individuals with sacralization, suggesting chronic functional compensation [13]. Zhang *et al.* identified a 17.5% prevalence of sacralization among adolescents with lumbar disc herniation, proposing aberrant mechanical stress as a contributory mechanism [14]. Together these data delineate the continuum between morphological adaptation, altered muscle dynamics, and degeneration that characterises the clinical spectrum of sacralization-related disorders.

Clinically, sacralization has been implicated in a number of pathological spinal conditions. Yao *et al.* demonstrated that among patients with L4 spondylolysis, those with sacralization had significantly greater vertebral slippage and disc degeneration at L4–L5 than patients without sacralisation [3]. In a surgical cohort of lumbosacral fusion patients, the incidence of degenerative spondylolisthesis and lumbar canal stenosis was higher in those with LSTV (20.3% and 11.3%, respectively) than in non-LSTV cases (9.7% and 5.2%) [9]. Changes in the iliolumbar ligament complex, which stabilises the lumbosacral region, occur on the side of the transitional vertebra, suggesting a congenital basis for altered biomechanics [15]. These findings imply that sacralization may not simply be an incidental anatomical variant but may carry meaningful clinical consequences.

Reliable identification of sacralization is particularly important for orthopaedic and radiological assessment. Mis-numbering of vertebrae, failure to recognise a transitional segment and poor awareness of the biomechanical implications may lead to sub-optimal diagnosis, inappropriate surgical level selection, and unfavourable operative outcomes [16]. Given the potential for adjacent-segment degeneration, radiculopathy, altered gait mechanics, or chronic low back pain, a more refined understanding of incidence, classification, and association with degenerative changes is warranted.

To the best of our knowledge, while prior studies have reported prevalence and associations, few investigations have combined classification of sacralization, radiological assessment of degenerative changes, and correlation with clinical low back pain in a single, defined hospital-based population. Accordingly, this study aims to evaluate the incidence of sacralization of the fifth lumbar vertebra in patients undergoing lumbar spine imaging, to classify sacralization based on radiologic findings, to assess its association with low back pain and degenerative spinal changes, and to compare findings with the existing literature.

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MATERIALS AND METHODS

Study Design- This research employed a retrospective observational design to determine the incidence and clinical correlates of sacralization of the fifth lumbar vertebra (L5). The study used existing radiological and clinical records of patients who underwent lumbar spine imaging at the Department of Radiodiagnosis, Dr B R Ambedkar Medical College and Hospital over a defined three-month period (January–March 2025). The retrospective design enabled analysis of a large dataset representing varied clinical presentations without influencing patient management.

Study Setting and Data Source- Data were obtained from the institutional Picture Archiving and Communication System (PACS) and corresponding medical records. Radiographs, computed tomography (CT) scans, and magnetic resonance imaging (MRI) reports of the lumbosacral region were screened. Clinical records were reviewed for documented complaints of low back pain, neurological symptoms, and degenerative spinal disorders. Demographic information, including age and sex, was extracted from hospital records to enable subgroup analyses.

Sample Size Determination- The required sample size was estimated using the formula $n = Z^2 \times p \times (1 - p) / d^2$, where Z = 1.96 (for a 95% confidence interval), p = 0.42 [2], and d = 0.05 (precision). Substituting these values yielded a minimum sample size of 374. To enhance statistical power and accommodate potential exclusions, a total of 500 radiological records were reviewed. This sample size provided an acceptable confidence level for estimating prevalence and enabled subgroup comparisons of degenerative features.

Inclusion Criteria- Patients aged 18 years and above; availability of lumbar spine radiographs (anteroposterior and lateral views) with complete visualisation of the lumbosacral junction; and imaging performed within the study period and archived in the PACS system.

Exclusion Criteria- History of prior spinal surgery (laminectomy, fusion, instrumentation); presence of other congenital vertebral anomalies such as lumbarization, spina bifida occulta, hemivertebra, or butterfly vertebra; and inadequate or obscured imaging precluding reliable assessment of the L5–S1 articulation.

Data Collection Procedure- All radiographs and cross-sectional images were independently reviewed by two radiologists with more than five years of musculoskeletal imaging experience; discrepancies were resolved by consensus. The following parameters were recorded: presence or absence of sacralization; laterality (unilateral or bilateral); type and degree of fusion (complete or partial); associated degenerative changes at L4–L5 and L5–S1 (disc space narrowing, osteophytes, endplate sclerosis, or facet arthropathy); and clinical evidence of low back pain, radiculopathy, or gait alteration from patient records. Each image was anonymised prior to review to maintain confidentiality, and findings were documented in a structured proforma to ensure uniformity of data extraction.

Variables and Operational Definitions- Sacralization of L5 was defined as partial or complete fusion or articulation of the transverse process of L5 with the sacral ala. Low back pain (LBP) was defined as a documented complaint persisting for more than 12 weeks, localised between the costal margin and gluteal folds. Degenerative change was defined as radiologically evident disc space narrowing, osteophyte formation, endplate sclerosis, or facet arthropathy at the L4–L5 and/or L5–S1 levels. Age and sex were recorded as demographic variables to explore associations with prevalence and degenerative findings.

Radiological Classification- The Castellvi classification system was used to categorise sacralization: Type I, dysplastic transverse process (>19 mm) without bony union; Type II, pseudo-articulation between transverse process and sacrum (IIa unilateral, IIb bilateral); Type III, complete bony fusion (IIIa unilateral, IIIb bilateral); and Type IV, mixed (fusion on one side, pseudo-articulation on the other). For each case, the type and laterality were recorded, together with associated findings including disc degeneration and spondylolisthesis.

Statistical Analysis- All data were analyzed using IBM SPSS Statistics v29.0. Descriptive statistics summarized demographic and imaging variables. Categorical data (gender, imaging type, sacralization status) were expressed as frequency and percentage, while continuous variables (age, pain duration) were presented as mean ± SD. Associations between sacralization and

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low back pain, and between related categorical variables, were tested using Fisher's Exact test due to small expected cell counts. One-way ANOVA was used to compare mean pain duration across sacralization types, with post hoc analysis where applicable. A p-value < 0.05 was considered statistically significant.

Ethical Considerations- Institutional Ethics Committee approval was obtained prior to commencement (Approval No.EC-582). As this was a retrospective study using anonymised imaging and medical records, the requirement for individual informed consent was waived. All procedures conformed to the ethical principles of the Declaration of Helsinki (2013 revision) and institutional data-protection policies.

RESULTS

Table 1 presents the demographic and imaging characteristics of the study population (N = 489). The majority of participants belonged to the 31–45 years age group (56.6%), followed by 18–30 years (22.9%), 46–60 years (19.4%), and >60 years (1.0%). The sample was predominantly male (60.9%), while females comprised 39.1%. Regarding imaging modality, X-ray was the most frequently used technique (70.1%), followed by CT (18.6%) and MRI (11.2%).

Table 1: Demographic profile and incidence of sacralization (N = 489)

Variable	Category	Frequency (n)	Percentage (%)
Age group (years)	18–30	112	22.9
	31–45	277	56.6
	46–60	95	19.4
	>60	5	1.0
Gender	Male	298	60.9
	Female	191	39.1
Imaging type	X-ray	343	70.1
	CT	91	18.6
	MRI	55	11.2
Sacralization status	Present	24	4.9
	Absent	465	95.1
Type among sacralized cases	Complete	9	1.8
	Incomplete	15	3.1
	Not applicable	465	95.1

Among the 24 sacralized cases, all instances were bilateral (4.9% of the total sample) with no unilateral cases; by completeness, there were 9 complete and 15 partial fusions (Table 2).

Table 2: Laterality and completeness of fusion in sacralized cases (n = 24)

Parameter	Category	Frequency (n)	Percentage (%)
Laterality	Bilateral	24	4.9
	Unilateral	0	0.0
	Not applicable	465	95.1
Completeness	Complete	9	1.8
	Partial	15	3.1
	Not applicable	465	95.1

Table 3 summarizes the distribution of sacralization, low back pain (LBP), and degenerative changes in 489 cases. Sacralization was present in 9 cases, absent in 15, and not observed in 465 cases. LBP was present in 4, 7, and 103 cases respectively, while degeneration was observed in 2 cases of complete sacralization, 4 incomplete, and 81 with no sacralization; corresponding non-degeneration counts were 7, 11, and 384.

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Overall, LBP was present in 114 cases and absent in 375, while degeneration was present in 87 and absent in 402. Fisher's Exact test showed a significant association between sacralization and LBP (p = 0.025), no significant association with degeneration (p = 0.519), and a highly significant association between LBP and degeneration (p = 0.001).

Table 3: Association between sacralization, LBP and degenerative changes

Sacralization	LBP present (n)	LBP absent (n)	Total
Present	4	5	9
Absent	7	8	15
None	103	362	465
Total	114	375	489
Degeneration	Degeneration present (n)	Degeneration absent (n)	
Complete	2	7	9
Incomplete	4	11	15
None	81	384	465
Present	50	64	114
Absent	37	338	375
Total	87	402	489

Note: *Fisher's Exact test: LBP = 6.907 (p = .025); Degeneration = 1.457 (p = .519), two-sided; LBP vs Degeneration = 59.984 (p = .001), two-sided.*

Table 4 details the types of degenerative change (disc degeneration, facet arthropathy, spondylolisthesis) and their severity. A significant association was noted (Fisher's Exact p = .001), with disc degeneration and facet arthropathy showing the highest frequencies across the mild-to-severe categories.

Table 4: Type and severity of degenerative changes (N = 489)

Type of change	Mild	Moderate	Severe	None	Total
Disc degeneration	10	12	6	0	28
Facet arthropathy	23	28	4	0	55
Spondylolisthesis	1	2	1	0	4
None	0	0	0	402	402
Total	34	42	11	402	489

Note: Fisher's Exact test = 449.958; p = .001 (two-sided).

Table 5 provides a demographic breakdown of the 24 patients with sacralization: 8 cases in the 18–30 group, 9 in the 31–45 group, and 7 in the 46–60 group, with none above 60 years, and a male predominance (70.8%).

Table 5: Demographic profile of patients with sacralization (n = 24)

Variable	Category	n	%
Age group (years)	18–30	8	33.3
	31–45	9	37.5
	46–60	7	29.2
	>60	0	0.0
Gender	Male	17	70.8
	Female	7	29.2

Note: Mean age of the sacralized subgroup = 37.79 ± 9.52 years (SD).

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Table 6 compares the mean duration of pain across sacralization types. A statistically significant difference was found (one-way ANOVA, p = .015), with the longest mean duration in complete sacralization (6.89 ± 8.49 months), followed by incomplete (5.40 ± 6.64 months) and absent (2.61 ± 5.53 months) cases.

Table 6: Comparison of pain duration across sacralization types (one-way ANOVA)

Sacralization type	n	Mean ± SD (months)	Minimum	Maximum
Complete	9	6.89 ± 8.49	0	21
Incomplete	15	5.40 ± 6.64	0	18
None	465	2.61 ± 5.53	0	27

Note: One-way ANOVA, F = 4.225; p = .015. SD = standard deviation (months).

DISCUSSION

In this retrospective series of 489 eligible lumbar imaging studies, the overall sacralization incidence was 4.9% (n = 24), all bilateral; complete sacralization accounted for 1.8% (n = 9) and incomplete/partial sacralization for 3.1% (n = 15). Sacralization was more common in males (70.8% of sacralized cases) and concentrated in the 18–45-year age range (71% of sacralized cases). Individuals with sacralization had a longer mean pain duration and a higher probability of presenting with low back pain (Fisher's Exact p = .025). Degenerative changes were present in 87 cases overall and were strongly associated with low back pain (p = .001), whereas the association between sacralization subtype and degenerative changes was not statistically significant (p = .519). Disc degeneration and facet arthropathy predominated among degenerative findings.

The observed 4.9% incidence lies at the lower bound of prevalence estimates reported in hospital-based radiographic series but is consistent with population studies that use strict radiographic criteria [17,18]. Whole-spine MRI and large CT series typically report transitional vertebrae rates ranging from ~3% to >20% depending on case mix and modality [9,17,19]. The greater frequency of complete bilateral sacralization than unilateral forms aligns with other radiographic cohorts that emphasise bilateral patterns when strict bony-fusion criteria are applied [20,21]. The male predominance in the sacralized subgroup echoes findings in several cadaveric and clinical series [2,18], although regional cohorts sometimes show sex neutrality [22], indicating population heterogeneity.

Most studies were plain radiographs (70.1%), with fewer CT and MRI studies. This distribution can underestimate complex LSTV morphology compared with CT [9,17]. Whole-spine and cross-sectional imaging allow more reliable vertebral numbering and detect numerical variants that plain lumbar films miss [17,23]. Thus, the lower incidence observed here may partly reflect modality and retrospective sampling.

The statistically significant association between sacralization and low back pain, and the longer pain duration among sacralized patients, are consistent with multiple clinical series and case–control studies reporting increased LBP prevalence, particularly for Castellvi types II and IV [20,22,24]. Several population and surgical series also show that patients with symptomatic Bertolotti syndrome present with chronic pain and longer symptom duration than non-LSTV patients [9,11]. Mechanistically, positional and load-dependent MRI studies demonstrate that LSTV alters canal geometry and neural-element displacement under axial load and provocative manoeuvres, providing a plausible substrate for persistent symptoms [12,25].

Degeneration clustered at L4–L5 and involved both disc and facet joints, a pattern widely reported in imaging and surgical series [4,10,26]. Finite-element and in vivo kinematic studies demonstrate that bony fusion at L5–S1 transfers motion and stress cephalad, increasing intradiscal pressure and facet loading at the adjacent superior level [8]. Large imaging cohorts likewise report higher rates of disc degeneration and facet arthropathy in LSTV patients across multiple lumbar levels [10,19,26]. The non-significant direct association between sacralization subtype and degeneration may reflect the limited number of sacralized cases (n = 24) and the cross-sectional nature of imaging: although sacralization predisposes to adjacent degeneration mechanistically, the onset and severity of degeneration are also influenced by age, activity, and body habitus [18,20,27].

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Muscle morphology and spinopelvic parameters modify the clinical expression of LSTV. Recent studies show multifidus and psoas atrophy and altered paraspinal muscle cross-sectional area in sacralized individuals, suggesting adaptive or disuse changes that may amplify pain and instability [13]. Spinopelvic mismatch, in which increased pelvic incidence and reduced lordosis occur, has been associated with LSTV in cohort studies and may mediate the load transfer that accelerates degeneration [11,21].

These results support the clinical relevance of L5 sacralization for pain and chronicity but caution against assuming a deterministic relationship with degeneration—an interpretation shared by larger series that emphasise multifactorial causation [22,24,26]. The practical implication is that clinicians should actively search for LSTV when planning interventions (e.g., injections, endoscopic discectomy, fusion), because mis-numbering and unrecognised transitional anatomy can lead to diagnostic and operative errors [16,23,28].

LIMITATIONS

Key limitations include the retrospective design, the predominance of radiographs over cross-sectional imaging, and the small sacralized subgroup, which limited power for subtype-specific analyses. Prospective studies using whole-spine CT/MRI with standardised Castellvi or refined classification schemas and longitudinal follow-up are required to determine causality and the temporal progression of adjacent degeneration. Biomechanical (finite-element) and dynamic-loading MRI studies would clarify load redistribution in vivo and its relation to clinical outcomes.

CONCLUSIONS

In this hospital-based sample, sacralization of L5 was present in 4.9% of cases and was associated with longer pain duration and a higher likelihood of low back pain. Degenerative changes correlated with pain, but not specifically with sacralization subtype. These findings suggest that sacralization is a clinically relevant anatomical variant that may influence spinal biomechanics and symptom chronicity, highlighting its importance in diagnosis, prognostication, and procedural planning. Future research should use multimodal longitudinal designs to clarify causal pathways between lumbosacral transitional vertebrae, biomechanical loading, degenerative cascades, and chronic low back pain. Imaging techniques as weight-bearing MRI or axial-loaded CT, along with three-dimensional motion analysis and finite-element modelling, improve understanding of altered spinopelvic kinematics. Large multicentric studies incorporating genetic, postural, and occupational factors are needed to establish normative baselines, while correlating imaging morphology with pain scores and neurophysiological data may enable a comprehensive clinical–biomechanical framework for personalised management of lumbosacral anomalies.

CONTRIBUTION OF AUTHORS

Research concept- Anil Kumar SV
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Supervision- Anil Kumar SV
Materials- Anil Kumar SV
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