A radiological parametric comparison of low-grade lytic spondylolisthesis to degenerative spondylolisthesis – A retrospective approach to establish its dysplastic origin

ABSTRACT

Objectives: This study aims to compare low-grade lytic spondylolisthesis (LS) and degenerative spondylolisthesis (DS) radiologically. In addition, it seeks to identify underlying similarities between LS and DS.

Methods: This study included patients with low-grade single-level spondylolisthesis at L4–L5 or L5–S1. They were categorized into LS and DS. Radiological features, including pedicle height, width, transverse, and sagittal angle, as well as anterior vertebral heights (AVH) and posterior vertebral heights (PVH), were measured using T1-weighted magnetic resonance imaging.

Results: The study involved 88 patients: 46 in the DS group and 42 in the LS group. In the LS group, the AVH was significantly higher than the posterior height at L4 and L5 (L4 PVH/AVH ratio 0.93 in LS vs. 0.96 in DS; L5 PVH/AVH ratio 0.84 in LS vs. 0.92 in DS), and pedicles were more medially oriented (L4: 19.62° in LS vs. 17.7° in DS; L5: 28.92° in LS vs. 26.47° in DS). In addition, at L5, the pedicle height (10.67 mm in LS vs. 11.48 mm in DS) and width (13.56 mm in LS vs. 14.37 mm in DS) were smaller compared to the DS group.

Conclusions: Low-grade LS shows distinct radiological vertebral and pedicle anatomy compared to DS. Short and thin pedicles and wedge-shaped vertebrae in LS resemble DS, indicating its dysplastic origin.

Keywords: Dysplasia, lumbar vertebra, pedicle, spondylolisthesis

INTRODUCTION

Spondylolisthesis is the translation of one vertebra over the subjacent vertebra and is more commonly observed in women. The two more prevalent types are degenerative spondylolisthesis (DS) and lytic spondylolisthesis (LS). DS typically involves a slip of L4 over L5, while LS is commonly seen as L5 slip over S1.[1]

The LS is characterized by the pars interarticularis defect. The cause of LS has been the subject of debate. Two main theories, traumatic and congenital, are associated with LS. The traumatic theory suggests recent injuries, especially in athletes, may lead to isthmic lyses, while the congenital theory proposes that spondylolysis results from normal mechanical forces acting on a weakened isthmus, with higher occurrence in certain ethnic groups and families.[2]

In 1976, Wiltse *et al*.[3] classified spondylolisthesis into five categories. Wiltse type II isthmic was further divided into three subtypes: lytic, elongated but intact pars, and acute pars fracture, including both developmental and acquired conditions under the same type. To address this

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classification issue, in 1997, Marchetti-Bartolozzi[4] classified spondylolisthesis either as developmental or acquired. In his work, he deliberately avoids using the term "isthmic" and instead highlights the differentiation between developmental dysplastic slips and acquired stress fractures of the isthmus.[5] This classification offers surgeons valuable insights into the causality of spondylolisthesis and guiding them in understanding the prognosis of the condition and treatment.

Spondylolisthesis is graded according to Meyerding's classification. Grades I and II are classified as low grade, and a majority of patients who undergo fusion surgery for spondylolisthesis fall into this category. Spondylolisthesis grades III, IV, and V are classified as high grade. High-grade spondylolisthesis is commonly linked to dysplastic origins, with traumatic and pathologic causes being rare.[6]

In DS, imaging features include endplate lesions, facet joint hypertrophy, sclerosis, and disc space narrowing. On the other hand, LS exhibits a break in the pars interarticularis, which appears as the "Scotty dog with collar" in an oblique radiograph, and a "wide canal sign" on magnetic resonance imaging (MRI).[7] In the dysplastic type, due to dysplasia of the disc, facet, vertebral body, and endplate, there is an asymmetry in the vertebral body and posterior elements. Pedicle elongation and trapezoidal-shaped vertebral body are the anatomical attributes of dysplastic spondylolisthesis.[8]

Patients with failed conservative management or neurological deficits need surgical interventions. Fusion using pedicle screw fixation is a commonly performed procedure that requires a proper insight into vertebral anatomy. Therefore, the radiological evaluation of vertebrae and pedicles is of utmost significance as an element of preoperative workup.

A comprehensive understanding of pedicle diameter, pedicle angulation, and vertebral morphology is very essential. Analyzing the dissimilarities in these parameters between DS and LS helps surgeons decide on the appropriate screw size, the direction of insertion, and the extent of exposure.

Despite all the advanced research on vertebral morphology,[9,10] there exists a disparity in recognizing the etiology of low-grade LS with the help of radiological parameters.

The objective of this study is to measure the vertebral and pedicle dimensions, such as pedicle height and width, transverse pedicle angle (TPA), and sagittal pedicle angles (SPAs), along with vertebral anterior and posterior heights, in patients with LS and DS and compare them. Our study also aims to find the dysplastic origin of low-grade LS by drawing radiological similarities of low-grade LS with dysplastic spondylolisthesis.

We propose that the vertebral morphometry of low-grade LS is different from that of low-grade DS, and certain radiological features are similar to dysplastic spondylolisthesis.

METHODS

Study design

In accordance with the Ethical Principles for Medical Research, the radiological retrospective study was conducted. Being a retrospective radiological study, Ethical Board Clearance was not necessary and considering the nature of our study, informed consent from patients was not required.

Assigning of patients was done based on the presence of pars interarticularis defect in the X-ray, which was reconfirmed using MRI or computed tomography (CT) imaging. The patients with defects were grouped under LS, whereas those without defects were grouped under degenerative. L4 on L5 and L5 on S1 slips being the most common were considered in our study. To eliminate potential confounding factors, multiple-level listhesis were excluded.

Inclusion criteria

Patients

1. Who had achieved skeletal maturity
2. With Meyerding grade I or grade II spondylolisthesis at a single level
3. Underwent surgery at our institute between April 2021 and July 2023
4. MRI scan done within 1 year before surgery.

Exclusion criteria

Patients

1. With a history of significant trauma, previous spine surgeries, infections, coronal, and sagittal plane deformities
2. With MRI scans performed outside our institute.

Measurements

Radiographic measurements were conducted using Insta PACS-Meddiff Technologies software, skillfully executed by a trained spine fellow. The study involved measuring the pedicle height (sagittal pedicle diameter [SPD]), pedicle width (transverse pedicle diameter [TPD]), anterior vertebral heights and posterior vertebral heights (AVH and PVH), TPA for assessing medialization of the pedicle, and SPA for evaluating caudal angulation of the pedicle in the L4 and L5 spinal segments of each patient. To maintain uniformity, all pedicle measurements were conducted specifically on the left pedicle. The definitions and measurements are briefly summarized.

Vertebral height

The upper and lower cortices of the vertebra are identified, and the distance between them is measured both anteriorly and posteriorly in a midsagittal section to assess the AVH and PVH [Figure 1].[11]

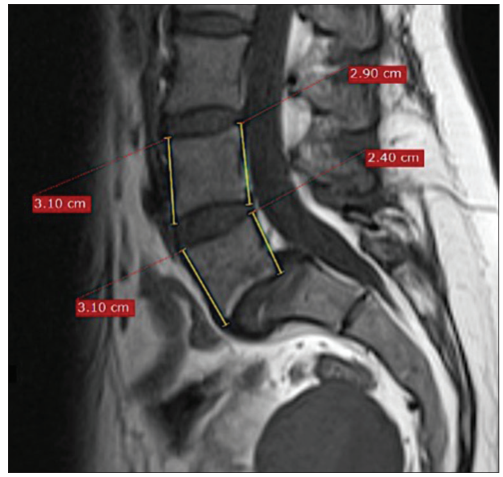

Figure 1: Anterior and posterior vertebral height at L4 and L5 vertebrae

Pedicle diameter

Pedicle diameter is measured in both axial and sagittal sections. At mid-pedicle width, the pedicle height (SPD) is measured as the distance between the superior and inferior cortices of the isthmus in the parasagittal section. On the other hand, at mid-pedicle height, the pedicle width (TPD) is measured as the distance between the medial and lateral cortices of the isthmus in the axial section [Figures 2 and 3].[12]

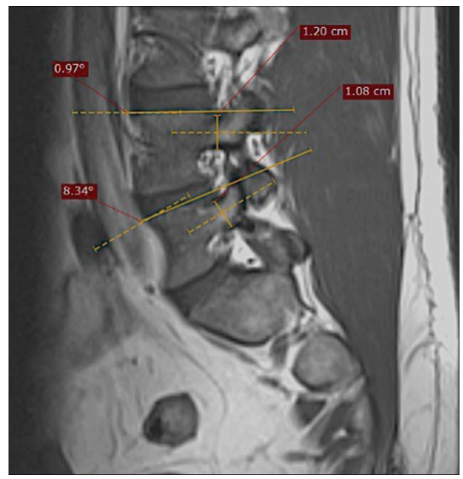

Figure 2: Sagittal pedicle diameter and sagittal pedicle angle at L4 and L5 vertebrae

Pedicle angle

Similarly, the pedicle angles are also measured in both parasagittal and axial sections. The SPA is the angle created between the axis of the pedicle and the superior border of the vertebral body. It is considered that the axis of the pedicle is perpendicular to the vertical height of the isthmus. The TPA is the angle formed between the bisector of the vertebra and the transverse isthmus [Figures 2 and 3].[12]

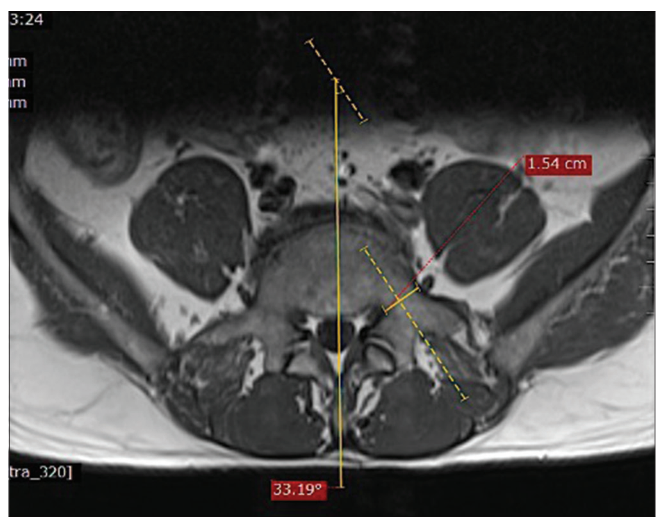

Figure 3: Transverse pedicle diameter and Transverse pedicle angle measured in L5 vertebra

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics software, Version 24, developed by International Business Machines Corporation (IBM), headquartered in Armonk, New York, United States. To test for significant differences between the two groups, we employed the parametric *t*-test in normally distributed and equal-variance data. On the other hand, when dealing with nonnormally distributed data or data that violated the assumption of equal variances, we utilized the nonparametric Mann–Whitney *U*-test. $P \leq 0.05$ was considered statistically significant, indicating a meaningful difference between the compared groups.

In addition, we used the Pearson correlation test to define the correlation between two continuous variables. An r value closer to -1 is considered a negative correlation, while an r value closer to $+1$ is indicative of a positive correlation. An r value closer to 0 suggests no correlation.

RESULTS

In this study, 88 patients were analyzed, comprising 46 individuals with DS and 42 individuals with LS. The patient demographics are provided in Table 1. Patients diagnosed with LS exhibited a significantly lower average age compared to those with DS (48.29 years vs. 63.22 years; $P < 0.001$). Gender did not show any statistically significant differences ($P = 0.771$) between the groups. In terms of prevalence, DS was more commonly observed at the L4–L5 level (39 patients, 84.78%) in comparison to LS (19 patients, 45.28%). Conversely, LS showed a higher occurrence at the L5–S1 level (23 patients, 54.77%) than DS (7 patients, 15.22%), ($P < 0.001$). Among patients with spondylolisthesis, there was a higher prevalence of Grade 2 spondylolisthesis in those diagnosed with LS (47.6% in LS) compared to DS (10.9% in DS) ($P < 0.001$).

Table 2 provides a comprehensive overview of all the measurements. LS group had a reduced pedicle height at the L5 vertebra (10.67 mm vs. 11.48 mm [$P = 0.01$]). In addition, LS patients also demonstrated a smaller pedicle width at the L5 level (13.55 mm vs. 14.37 mm [$P = 0.03$]). No significant differences were observed in terms of pedicle height and width between the two groups at the L4 level.

Table 1: Demographic data

	DS	LS
Age (years), mean±SD	63.22±8.67	48.29±10.60
Gender, *n* (%)		
Male	14 (30.43)	14 (33.33)
Female	32 (69.57)	28 (66.67)
Listhesis level, *n* (%)		
L4/L5	39 (84.78)	19 (45.23)
L5/S1	7 (15.22)	23 (54.77)

SD: Standard deviation; DS - Degenerative spondylolisthesis; LS - Lytic spondylolisthesis

The pedicles at the L4 level showed a higher degree of medialization in LS patients in comparison to DS patients (TPA: 19.6° vs. 17.6° [$P = 0.02$]). Among men, LS patients displayed a more pronounced medialization of the pedicles at the L5 level compared to DS patients (TPA: 29.85° vs. 24.26° [$P = 0.02$]). There was no significant distinction found in the caudal angulation of the pedicle between the two groups.

PVH and AVH are converted into a ratio, and the average for both groups is calculated and tabulated in Table 3. It is observed that in the lytic group, at both L4 ($P = 0.04$) and L5 ($P = 0.003$) levels, the ratio is significantly smaller than in the degenerative group.

The Pearson correlation test helped us determine the relationship between age and the PVH/AVH ratio. Since there was a significant difference in the average age between the lytic group (48.29 years) and the degenerative group (63.22 years), we investigated whether there is a correlation between age and the ratio. However, our findings indicated no correlation between age and the ratio [Table 4].

The comparison of the smallest pedicle diameter between the groups is tabulated in Table 5.

Table 2: Comparative Analysis of Pedicle Height (SPD), Pedicle Width (TPD), Spinous Process Angle (SPA), Transverse Process Angle (TPA), Anterior Vertebral Height (AVH), and Posterior Vertebral Height (PVH).

	Degenerative spondylolisthesis		Lytic spondylolisthesis		*P*
	Mean±SD				
	Female	Male	Female	Male	
Pedicle height (SPD)					
L4	11.53±0.98	12.24±1.41	11.07±1.21	12.14±0.99	0.211
L5	11.33±1.17	11.81±1.22	10.47±1.69	11.06±1.57	0.010
Pedicle width (TPD)					
L4	10.96±1.28	11.55±1.09	10.62±1.31	11.53±1.50	0.443
L5	14.01±1.61	15.20±1.21	13.29±2.18	14.09±1.30	0.035
SPA					
L4	-3.52±-2.83	-3.07±-3.03	-2.73±-2.02	-4.62±-4.89	0.900
L5	-7.57±-5.29	-5.02±-3.08	-9.20±-6.75	-7.02±-5.19	0.300
TPA					
L4	17.61±4.31	17.90±3.42	18.75±3.35	21.38±4.81	0.028
L5	27.44±6.08	24.26±4.59	28.45±5.73	29.85±7.43	0.061
AVH					
L4	27.41±2.29	28.14±2.33	27.57±2.52	28.63±2.65	0.580
L5	27.04±2.51	27.48±3.28	27.52±3.20	28.47±3.07	0.296
PVH					
L4	26.04±2.32	27.44±1.89	25.56±2.32	26.52±2.39	0.241
L5	24.57±1.75	25.86±2.03	23.45±2.83	23.22±1.20	0.008

SPD: Sagittal Pedicle Diameter, TPD: Transverse Pedicle Diameter, TPA: Transverse Pedicle Angle, SPA: Sagittal Pedicle Angle, AVH: Anterior Vertebral Height, PVH: Posterior Vertebral Height. Distance is measured in mm, whereas angle in degree

Table 3: Posterior vertebral height/anterior vertebral height

	DS	LS
L4/L5		
L4	0.96±0.07	0.91±0.06
L5	0.93±0.08	0.93±0.12
L5/S1		
L4	0.96±0.07	0.93±0.06
L5	0.83±0.10	0.76±0.14

DS - Degenerative spondylolisthesis; LS - Lytic spondylolisthesis

Table 4: Pearson correlation with age

	Pearson correlation with age (*r*)
Pedicle height (SPD)	
L4	0.088
L5	0.134
Pedicle width (TPD)	
L4	0.028
L5	0.024
TPA	
L4	−0.232
L5	−208
SPA	
L4	−0.071
L5	0.028
PVH/AVH	
L4	0.037
L5	0.183

SPD - Sagittal pedicle diameter; TPD - Transverse pedicle diameter; TPA - Transverse pedicle angle; SPA - Sagittal pedicle angle; AVH - Anterior vertebral height; PVH - Posterior vertebral height

Table 5: Smallest pedicle diameter

	LS	DS
SPD (mm)		
L4	8.2	10
L5	5.2	8.6
TPD (mm)		
L4	8.0	8.2
L5	6.5	10.3

SPD - Sagittal pedicle diameter; TPD - Transverse pedicle diameter; DS - Degenerative spondylolisthesis; LS - Lytic spondylolisthesis

DISCUSSION

When addressing symptomatic spondylolisthesis, instrumentation and fusion with pedicle screws are commonly employed as the preferred treatment option.[13] A comprehensive understanding of anatomical landmarks of the vertebra is crucial to ensure high insertional accuracy and low screw-related complications such as dural tears, vascular, visceral, and neural damage.

In the study, we observed that individuals with low-grade LS had a lower PVH/AVH ratio, indicating a wedge-shaped vertebral body. We also noted a greater medial orientation of the pedicles at both the L4 and L5 levels in men and at the L4 level in women. In addition, the pedicles at the L5 level were smaller in size in both the sagittal and transverse planes, illustrating the dissimilarities between the two groups.

In an analysis performed by Rosenberg[14] on DS, with a sample size of 200 patients, at L5, an average anterior height was larger than the posterior height by 2 mm. In the case of 61 patients diagnosed with isthmic spondylolisthesis, the anterior height of L5 was found to be, on average, 12 mm higher than the posterior height.

Goyal *et al*.,[15] conducted a study on 143 patients, revealing that individuals with isthmic spondylolisthesis exhibited significantly smaller pedicle height ($P < 0.001$) and width ($P = 0.001$) in comparison to patients with DS. In the isthmic spondylolisthesis group, the pedicles at the L4 ($P < 0.001$) and L5 ($P < 0.001$) levels exhibited a greater caudal angulation. The observed angulation of the pedicles in isthmic spondylolisthesis is unrelated to slip angle or lumbar lordosis and is likely due to increased wedging of the L4 and L5 vertebral bodies. Furthermore, when patients undergo surgery in a prone position, this angulation can be intensified, posing greater difficulties in achieving precise pedicle screw placement. This awareness is especially crucial for procedures performed at the lumbosacral junction.

In a study conducted by Choi *et al*.,[16] a comparison of CT scans between unaffected individuals and patients with isthmic spondylolisthesis revealed that the latter group had narrower and shorter pedicles. It was also observed that the pedicles at the L4 and L5 levels were more horizontally oriented in isthmic spondylolisthesis. Likewise, Matthews *et al*. observed that in isthmic spondylolisthesis, the L5 pedicles showed elongation and the vertebral body had smaller height and width. The degree of slip is related to the difference between the length of the posterior compartment of the pedicle and the height of the vertebral body. These anatomical variances may contribute to the adaptive response of isthmic spondylolisthesis.[17]

Cho and Kim[18] conducted a study on low-grade spondylolisthesis occurring at L4–L5 or L5–S1 levels among 135 individuals. The study found that the SPD/TPD ratio was substantially smaller at the involved vertebra in the lytic group than in the degenerative group. Furthermore, in L5–S1 LS, the L5 vertebra had a low PVH/AVH ratio ($P < 0.001$), displaying a resemblance to dysplastic spondylolisthesis.

Due to the imbalance between bone formation and bone resorption at the metabolic level, dysplastic spondylolisthesis is characterized by the identification of vertebrae with wedge or trapezoidal shapes, which is more evidently seen in the L5 vertebra of L5–S1 LS.[19,20] Smaller pedicle diameter[18] and wedge-shaped vertebral bodies denote the dysplastic nature of the LS population.

In our study, the smallest pedicle height and width observed in LS were 5.2 mm and 6.2 mm, respectively. When facing challenges caused by dysmorphic and narrow pedicles, particularly in cases of L5–S1 spondylolisthesis, it is advisable to contemplate instrumentation and fusion up to the L4 level.[21] This strategy ensures increased stability during the surgical procedure.

Some other situations that may be encountered during surgery in dysplastic spondylolisthesis, include the following:

1. The dome-shaped sacral superior endplates may create hardships in positioning the interbody cage.[22] Sufficient preoperative preparation should additionally encompass a careful evaluation of the placement and arrangement of the cage
2. While performing the posterior *in situ* fusion technique using bone grafts in patients with posterior column dysplasia, the problem arises due to their tinier transverse processes.[23] To tackle the chances of pseudoarthrosis, bone graft substitutes such as demineralized bone matrix and synthetic bone graft extenders such as bone morphogenetic proteins can be utilized
3. High sacral slope, increased pelvic incidence,[21] and increased lordosis
4. Smaller vertebral transverse width.

While many of these radiological findings are yet to be conclusively proven in LS, it is prudent and beneficial to consider these parameters during the preoperative planning of LS patients, ensuring a safer approach to patient care.

Understanding the dysplastic nature of this condition can lead to more informed and effective treatment strategies, ultimately improving patient outcomes and quality of life.

As such, there should not be any compromise in the radiological examination, as a part of preoperative planning for dysplastic and LS. Spinopelvic parameters should be utilized in determining the level of fusion, lordosis for an acceptable biomechanism of the spine, and to assess the progression of listhesis.[24]

It is essential to acknowledge the limitations of this study, such as its retrospective design and the utilization of T1-weighted MRI scans instead of CT scans, which offer a less comprehensive assessment of bony details. However, owing to the inherent radiation risks associated with CT scans, MRI is typically chosen as the primary imaging modality for preoperative planning purposes. Other limitations involved the omission of patients without instability and the specific emphasis on certain levels and radiological features of spondylolisthesis. The radiological measurements were executed by a single investigator, which may introduce bias, compromise reliability, and hinder the generalization of the results.

CONCLUSIONS

After comparing low-grade DS with low-grade LS, our study revealed distinct morphological differences. The presence of a smaller pedicle, increased medial orientation of pedicles, and trapezoidal-shaped vertebral bodies in low-grade LS align closely with the characteristics observed in dysplastic spondylolisthesis. These findings support the notion that low-grade LS has a dysplastic etiology.

Given these significant morphological variations, it is crucial to conduct a thorough radiological evaluation before proceeding with any surgical interventions for low-grade LS.

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Conflicts of interest

There are no conflicts of interest.

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