RESEARCH ARTICLE

Lumbosacral Vertebral Angles can Predict Lumbosacral Transitional Vertebrae on Routine Sagittal MRI

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Abstract

Objectives: We aimed to measure lumbosacral vertebral angles in routine lumbar sagittal MRIs and assess their association with lumbosacral transitional vertebrae (LSTV).

Methods: We recruited 220 patients referring to our hospital for routine lumbar MRI during 2020-2021. All the participants were subject to routine sagittal lumbar MRI, whole spine localizer scan, and coronal MRI to numerate lumbar vertebrae. Five vertebral angles (A, B, C, D, and delta) and dehydration in L4-L5 and L5-S1 discs were assessed in sagittal MRI scans. Data were analyzed using SPSS 26.

Results: Out of 220 participants (mean age: 44.29 ± 14.14 years), 36 (16.36%) were diagnosed with LSTV. Among those diagnosed with LSTV, L5-S1 dehydration was less frequently observed compared to other participants ($P < 0.001$). Multivariate regression showed that dehydrated L4-L5 disc, non-dehydrated L5-S1 disc, increased A-angle, and decreased D-angle can independently predict LSTV. The median A-angle was significantly larger in LSTV patients than in non-LSTV participants ($P = 0.038$), while the medians of C-angle, D-angle, and delta-angle were significantly smaller in the LSTV group ($P < 0.05$). A C-angle ≤ 35.5° could diagnose LSTV with sensitivity and specificity of 72.2% and 57.6%, respectively. A delta angle ≤ 8.5° could diagnose type 2 LSTV with 92.3% sensitivity and 87.9% specificity.

Conclusion: Measuring lumbosacral vertebral angles, especially delta-angle, in routine sagittal MRI can potentially alert physicians of a likely LSTV diagnosis.

Level of evidence: III

Keywords: Angle, Diagnosis, Lumbosacral transitional vertebrae, Magnetic resonance imaging

Introduction

Lumbosacral transitional vertebrae (LSTV) are congenital anomalies that challenge the accurate numbering of lumbar vertebral bodies. In LSTV, fusion of the last lumbar vertebral transverse process with the sacral segment occurs in various degrees from partial to complete lumbarization or sacralization, namely separation of S1 from the sacrum or fusion of L5 to the sacrum, which results in either 6 or 4 lumbar vertebrae.[1]

In 1984, Castellvi et al. classified LSTV into four types according to the degree of observed vertebral fusion between L5 and the sacral segment. The anatomical variations resulting from LSTV type 1 are not considered clinically significant since most patients are asymptomatic[1]; however, higher degrees of fusion observed on other LSTV types have been associated with lower back pain.[2] Even so, the direct association between LSTV and spinal pathology is controversial. Several studies suggest that a supra-adjacent disc to LSTV is at an increased risk for disc herniation or

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degeneration,[3-5] an effect that has been more noticeable in younger populations.[6] Arguably, however, the most tangible impact of LSTV presents when therapeutic interventions at the spinal level are necessary. In practice, LSTV may interfere with anatomical landmarks used for epidural or intradural anesthetics, while incorrect spine numbering may result in wrong-level spinal surgery.[7,8] MRI is advisable for clinical assessment of LSTV given the radiation hazard of computed tomography (CT) scans and the insufficient ability of lumbar radiographs to distinguish tissues around the lumbar spine.[9,10] Nevertheless, due to resource restrictions, whole spine MRI scans are often not available in routine lumbar MRI.

Recognizing the L5 vertebra and accurately determining disc pathology levels pose minimal challenges in individuals with typical anatomy. However, identifying the L5 vertebra becomes notably less certain in patients with LSTV,[11] which can result in misidentifications of L5 and subsequent issuance of erroneous reports regarding pathological levels.[7] Therefore, it is imperative to diagnose LSTV and explicitly document its pathology in MRI reports.

The optimal approach for enumerating vertebrae entails whole spine imaging and a caudal count starting from C2, a procedure regrettably absent from routine MRI scans.[12] Furthermore, the absence of coronal lumbar MRI in our routine MRI scans leaves us with only one avenue to detect LSTV, namely identifying fusion or pseudoarthrosis involving the lateral processes of L5 and S1 vertebrae in axial images, a crucial detail that may inadvertently escape notice.

To address this diagnostic challenge, it is crucial to identify discerning features indicative of LSTV on sagittal lumbar MRI scans, which are standard in lumbar MRI examination.

Many studies have aimed to investigate paraspinal structures that may contribute to identifying L5, including the iliolumbar ligament, aortic bifurcation, and right renal artery.[13,14] Similarly, several novel parameters have been introduced to distinguish LVST in PET/CT scans, including the anterior-edge vertebral angle (AVA) and the length ratio of the inferior endplate to that of the superior endplate (RISE).[15] However, there is no consensus in this regard so far. For example, the iliolumbar ligament once believed to have originated at L5 and hence assumed to be a reliable landmark for numerating lumbar spine,[16] appears to have multiple origins in some LSTV patients.[17] In 2012, Chalian et al. proposed that measuring two angles (A and B) from sagittal lumbar MRI scans could diagnose LSTV with a sensitivity and specificity of 80%.[18] To our knowledge, no study has yet tried to replicate their results.

We have introduced novel angles to measure in sagittal MRI scans to achieve an objective approach to diagnosing LSTV. In this regard, the angles formed by lines parallel to the lumbar and sacral vertebrae sides were collectively considered to calculate two angles (C-angle and delta-angle). While vertebral angles have been previously studied to assist in the enumeration of spinal vertebrae, their application for diagnosing LSTV is not well established. This study uniquely investigates the diagnostic value of vertebral angle measurements in routine sagittal MRI scans to offer a potential alternative to conventional anatomical landmarks. This will reduce the need for a whole spine MRI as well as the likelihood of therapeutic intervention at the wrong level.

Materials and Methods

Study Settings and Design

The cross-sectional observational study was conducted throughout 2020-2021. The authors ensured the confidentiality of data from all participants who provided written informed consent under the Helsinki Declaration following the STROBE statement.

Participants

The participants of this study were recruited via convenience non-probability sampling from among patients referring for routine MRI of the lumbar spine until reaching the required sample size of 220. The exclusion criteria were as follows: congenital lumbar defects such as severe scoliosis, vertebral fracture, contraindications for MRI (e.g., metallic implants and foreign bodies), and inadequate MRI quality. The excluded patients were replaced until reaching the required sample size.

Data Collection

After collecting basic demographic details from participants (i.e., sex and age), routine MRI sequences of the lumbar spine were obtained; additionally, a coronal lumbar sequence and a whole spine localizer sequence were taken to aid in determining the vertebral segments and confirming LSTV. MRI scans were performed using a Magnetom Avanto (Siemens) scanner with a 1.5 field strength. The sequences included sagittal T1-weighted as well as sagittal, coronal, and axial T2-weighted and total spinal localizer to enumerate the spinal vertebrae. The slice thickness was determined to be 4 millimeters.

Detailed imaging protocols ensured the high-resolution visualization of vertebral structures. We defined the reference standard for diagnosing LSTV based on the categories suggested by Castellvi et al. and applied them to MR images. According to these categories, LSTV is identified as one of four major types:

-1A (unilateral dysplastic transverse process, with at least 19 mm in craniocaudal dimension),
-1B (bilateral variant of type 1A), 2A (unilateral incomplete lumbarization or sacralization with an enlarged transverse process, forming a diarthrodial joint with the sacrum),
-2B (bilateral variant of type 2A), 3A (complete unilateral osseous fusion between the transverse process to the sacrum; lumbarization or sacralization),
-3B (bilateral variant of type 3A), 4 (unilateral type 3 transverse process with a type 2 contralateral transition).[1]

In all participants, the measurement of five angles was recorded to analyze their predictions of LSTV. As described by Chalian et al.,[18] the A-angle (formed by a line parallel to the superior surface of the sacrum and a line perpendicular to the axis of the scan table) and B-angle (formed by a line parallel to the superior endplate of L3 vertebra and a line parallel to the superior surface of the sacrum) were measured and recorded [Figure 1a and Figure 2a]. To measure the C-angle, lines parallel to the posterior surface of vertebral bodies were drawn for the most caudal lumbar vertebra and the most cranial sacral vertebra as well as

their supra-adjacent and infra-adjacent vertebrae [Figure 1b]; the largest angle formed by these lines was defined as C-angle [Figure 2b]. D-angle was formed by the line parallel to the superior surface of the most cranial sacral vertebra and the line parallel to the superior surface of the most caudal lumbar vertebra. The angle formed by a line parallel to the superior surface of the most caudal lumbar vertebra and a line parallel to the superior surface of its supra-adjacent vertebra was termed D1-angle [Figure 1c, Figure 3, and Figure 4]. The difference between D-angle and D1-angle was calculated and documented as delta-angle [Figure 3 and Figure 4].

Statistical analysis

Data were analyzed using SPSS, version 26 (IBM Statistics, Chicago, IL, USA). The required sample size was estimated as 220 using 80% sensitivity of A-angle and B-angle as reported by Chalian et al.,[18] an alpha level of 0.05, 5% LSTV prevalence, and d=0.3p. An independent samples t-test was used to compare normal variables, while the Mann-Whitney test was employed to compare non-normal variables. Multiple regression was used to determine LSTV predictors, and receiver operating characteristic (ROC) curves were utilized to determine diagnostic value and cut-off points. The sensitivity and specificity of A-angle and B-angle were determined through the cut-off points proposed by Chalian et al.[18] The alpha level was 0.05 for all tests. A P < 0 .05 was considered as statistically significant.

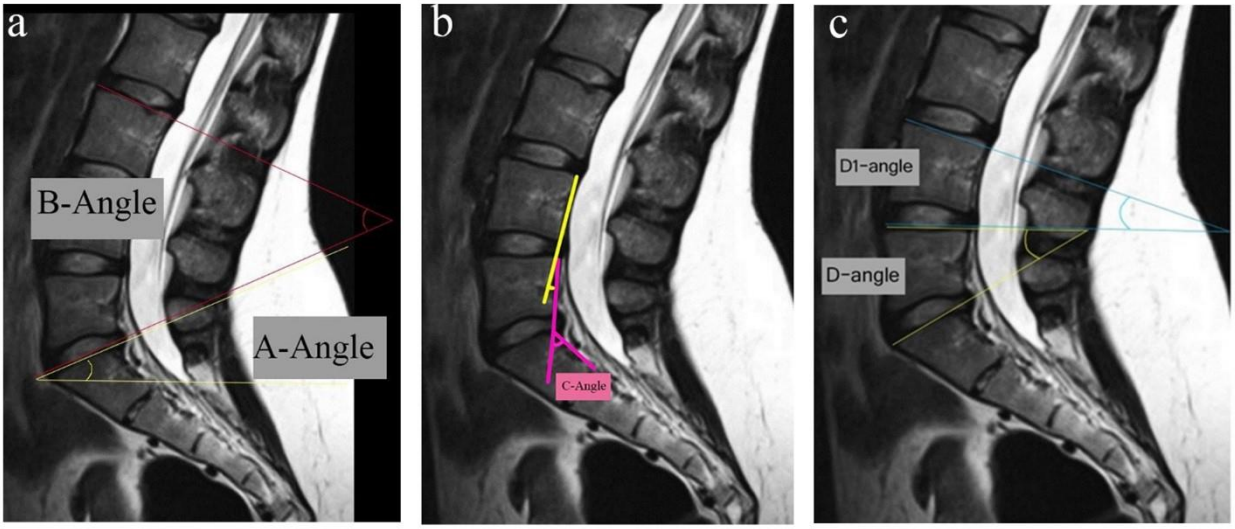

Figure 1. Sagittal MRI showing the measured angles (a) A-angle and B-angle (Chalian et al.), (b) Lines used to define C-angle, and (c) Lines forming D-angle and D1-angle

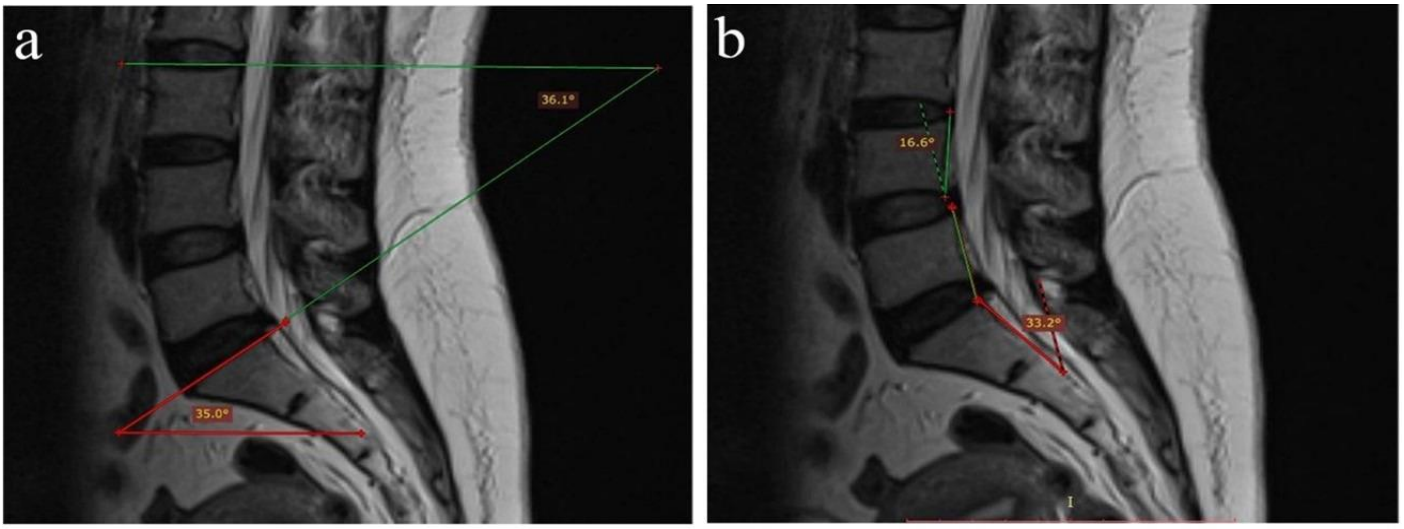

Figure 2. The methods used to measure angles in sagittal MRI (a) A-angle is 35.0° and the B-angle is 36.1°; (b) The largest angle formed by the lines is C-angle = 32.2°

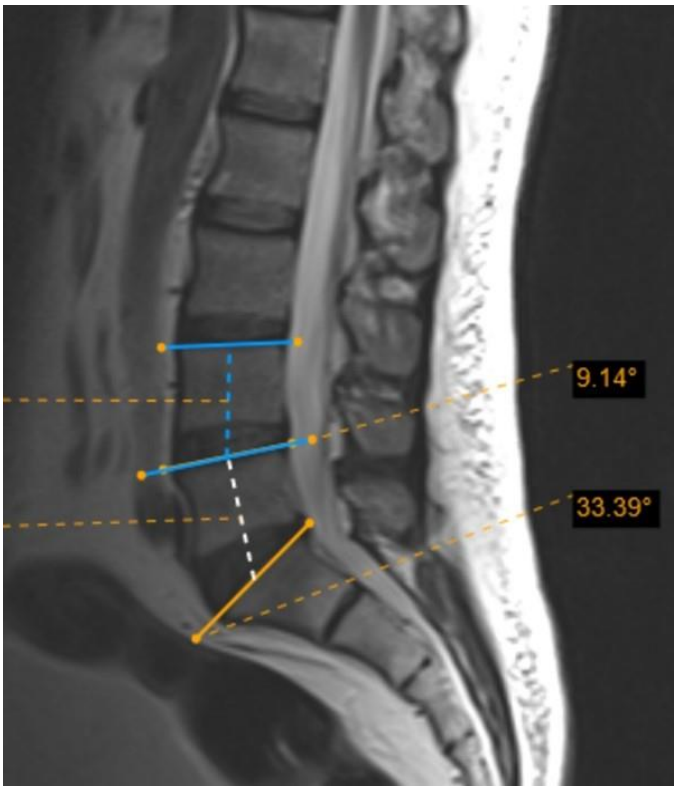

Figure 3. Normal patient with a 24° delta angle (calculated as 33° minus 9°). At L5-S1 junction, there is a distinct acute angle, whereas the other levels show a nearly parallel alignment

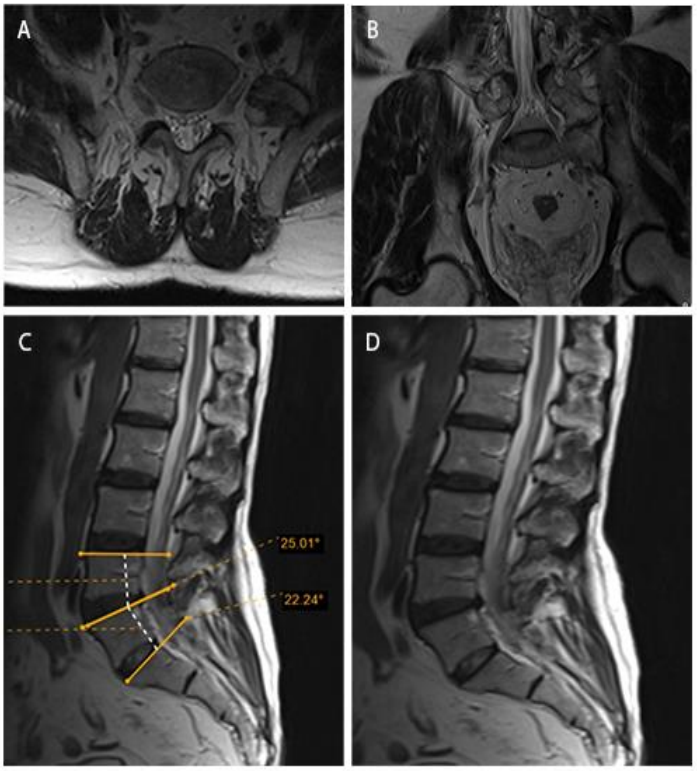

Figure 4. Axial (a) and coronal (b) T2W images show unilateral pseudoarthrosis of left L5 transverse process with adjacent sacral ala consistent with Castellvi type2a LSTV. In this case, there is a reduced delta angle of 2.8°, highlighting the influence of two specific levels in shaping the curvature of lumbosacral region (c). Also, note the hydrated L5-S1 disc in the presence of dehydrated L4-L5 disc (d)

Results

In total, 220 participants (44.29 ± 14.14 years old, age range: 24-68; 111 males, 50.5 %) were included in this study. LSTV was diagnosed in 36 patients (16.3 %). Table 1 shows the frequency of different LSTV types among these patients [Table 1]. As indicated in Table 2, LSTV diagnosis was significantly higher among females (P = 0.025) [Table 2].

Table 1. The prevalence of LSTV and its subcategories

Lumbosacral condition		Frequency (%), N=220
Normal		184 (83.6%)
Sacralization	*1B*	1 (0.5%)
	2A	6 (2.7%)
	2B	5 (2.3%)
	3A	4 (1.8%)
	3B	15 (6.8%)
	4	1 (0.5%)
Lumbarization	*2A*	4 (1.8%)
Total LSTV cases		36 (16.4%)

LSTV: lumbosacral transitional vertebrae

Table 2. Comparison of demographic characteristics and MRI findings the between LSTV and non-LSTV participants

Feature		LSTV (N=36)	Non-LSTV (N=184)	P
Age (years), mean ± *SD*		43.39 ± 14.75	44.46 ± 14.05	0.681*
Sex (male), *N* (%)		12 (33.3%)	99 (53.8%)	0.025**
L4-L5 disc dehydration, *N* (%)		25 (69.4%)	96 (52.2%)	0.057*
L5-S1 disc dehydration, *N* (%)		5 (13.9%)	104 (56.5%)	<0.001**
Dehydration intensity, *N* (%)	*Both discs equal*	13 (36.1%)	131 (71.2%)	<0.001**
	Greater in L4-L5 disc	22 (61.1%)	20 (10.9%)	
	Greater in L5-S1 disc	1 (2.8%)	33 (17.9%)	
Angle (degrees), median (IQR)	*A-angle*	41.50 (34.25-47.00)	37.00 (33.00-43.00)	0.038***
	B-angle	46.50 (39.00-51.50)	42.75 (37.00-50.00)	0.242***
	C-angle	31.10 (22.87-37.87)	37.00 (31.00-42.00)	<0.001***
	D-angle	23.50 (18.50-29.00)	26.00 (23.50-30.00)	0.028***
	Delta-angle	11.50 (2.62-17.50)	15.00 (10.00-19.00)	0.003***

LSTV: lumbosacral transitional vertebrae; IQR: inter-quartile range * Independent samples t-test ** Chi-square test *** Man-Whitney test

Disc Dehydration

According to Table 2, L4-L5 disc dehydration was observed in 121 patients (55%), while L5-S1 disc dehydration was observed in 109 patients (49.5%). In most cases, the dehydration intensity of L4-L5 and L5-S1 discs was similar (144, 65.5%), while L4-L5 was more severely dehydrated in 42 cases (19.1%). Among those diagnosed with LSTV, L5-S1 dehydration was less frequently observed than normal participants (P < 0.001). Table 3 shows that L5-S1 disc dehydration was less frequently observed among LSTV type 2 cases than non-LSTV type 2 patients (P = 0.002) [Table 3]. With regards to dehydration intensity, in most LSTV cases (22, n = 36, 61.1 %) L4-L5 disc was more intensity dehydrated than L5-S1 [Table 2], while in normal participants, L4-L5 and L5-S1 disc dehydration intensities were similar in most cases (131, n = 184, 71.2 %); this difference was statistically significant (P < 0.001). L4-L5 disc dehydration and the absence of dehydration in the L5-S1 disc were significantly associated with LSTV diagnosis [Table 4].

Table 3. Comparison of demographic and MRI findings between LSTV type IIA and other participants

Feature		LSTV 2A (N=13)	Non-LSTV 2A (N=207)	P
Age (years), mean ± *SD*		47.00 ± 12.90	44.12 ± 14.22	0.477*
Sex (male), *N* (%)		6 (46.2%)	105 (50.7%)	0.749**
L4-L5 disc dehydration, *N* (%)		8 (61.5%)	114 (55.1%)	0.649*
L5-S1 disc dehydration, *N* (%)		1 (7.7%)	109 (52.7%)	0.002**
Dehydration intensity, *N* (%)	*Both discs equal*	6 (46.2%)	138 (66.7%)	0.003**
	Greater in L4-L5 disc	7 (53.8%)	35 (16.9%)	
	Greater in L5-S1 disc	0 (0.0%)	34 (16.4%)	
Angle (degrees), median (IQR)	*A-angle*	43.00 (39.50-48.00)	37.00 (33.00-43.50)	0.016***
	B-angle	48.00 (40.00-50.50)	43.00 (37.00-50.00)	0.226***
	C-angle	24.00 (20.00-34.00)	36.50 (30.00-42.00)	<0.001***
	D-angle	22.00 (17.00-24.50)	26.00 (23.00-30.00)	<0.001***
	Delta-angle	2.00 (-0.50-7.25)	14.00 (10.00-19.00)	<0.001***

LSTV: lumbosacral transitional vertebrae; IQR: inter-quartile range * Independent samples t-test ** Chi-square test *** Man-Whitney test

Table 4. Multiple regression results for independent variables predicting LSTV diagnosis

Variable	Odds ratio	95% confidence interval	P
A-angle	1.141	1.019-1.279	0.023
D-angle	0.719	0.530-0.976	0.034
L4-L5 disc dehydration	0.157	0.057-0.430	<0.001
L5-S1 disc dehydration	19.869	5.743-68.741	<0.001

Diagnostic Value of Angle Measurements

Regarding the measured angles [Table 2], the median A-angle was significantly higher in LSTV patients than in non-LSTV participants (P = 0.038), while the medians of C-angle, D-angle, and delta-angle were lower among the LSTV group (P < 0.05). When comparing the LSTV type 2 group (n = 13) with the LSTV type 3 group (n=19), the medians of D-angle and delta-angle were significantly lower in the LSTV type 2 group (P = 0.018 and P < 0.001, respectively). Table 3 shows that C-angle, D-angle, and Delta-angle are significantly smaller in type 2 LSTV patients compared with non-LSTV type 2 cases (P < 0.001), while the A-angle is significantly higher in LSTV type 2 (P = 0.016).

Multiple regression was used to analyze the predicting factors of LSTV diagnosis. With LSTV as the dependent variable, demographic features (age and sex), as well as clinical findings (angle measurements and disc dehydration states), were defined as independent variables. As shown in Table 4, increased A-angle and decreased D-angle were independent predictors of LSTV, while L4-L5 disc dehydration and the absence of dehydration in L5-S1 disc were significantly associated with LSTV diagnosis.

ROC curves were plotted to analyze the diagnostic value of increased A-angle and B-angle as well as decreased C-angle, D-angle, and delta-angle for LSTV and type 2 LSTV diagnosis [Figure 5]. To diagnose LSTV, the largest area under the curve (AUC) pertained to C-angle and delta-angle (0.688 and 0.658, respectively) [Table 5]. With a cut-off point of 14.5, the delta-angle demonstrated a sensitivity of 66.7 %, a specificity of 52.2 %, a positive predictive value (PPV) of 24.4 %, and a negative predictive value (NPV) of 88.9 % for diagnosing LSTV. The C-angle, with a cut-off point of 35.5, diagnosed LSTV with a sensitivity of 72.2 %, a specificity of 57.6 %, a PPV of 25 %, and an NPV of 91.4 %. Regarding type 2 LSTV diagnosis, the delta-angle demonstrated the largest AUC, and using a cut-off point of 8.5˚, it was able to diagnose type 2 LSTV with 92.3 % sensitivity and 87.9 % specificity. The PPV was 32.4 %, and NPV was 99.5 %.

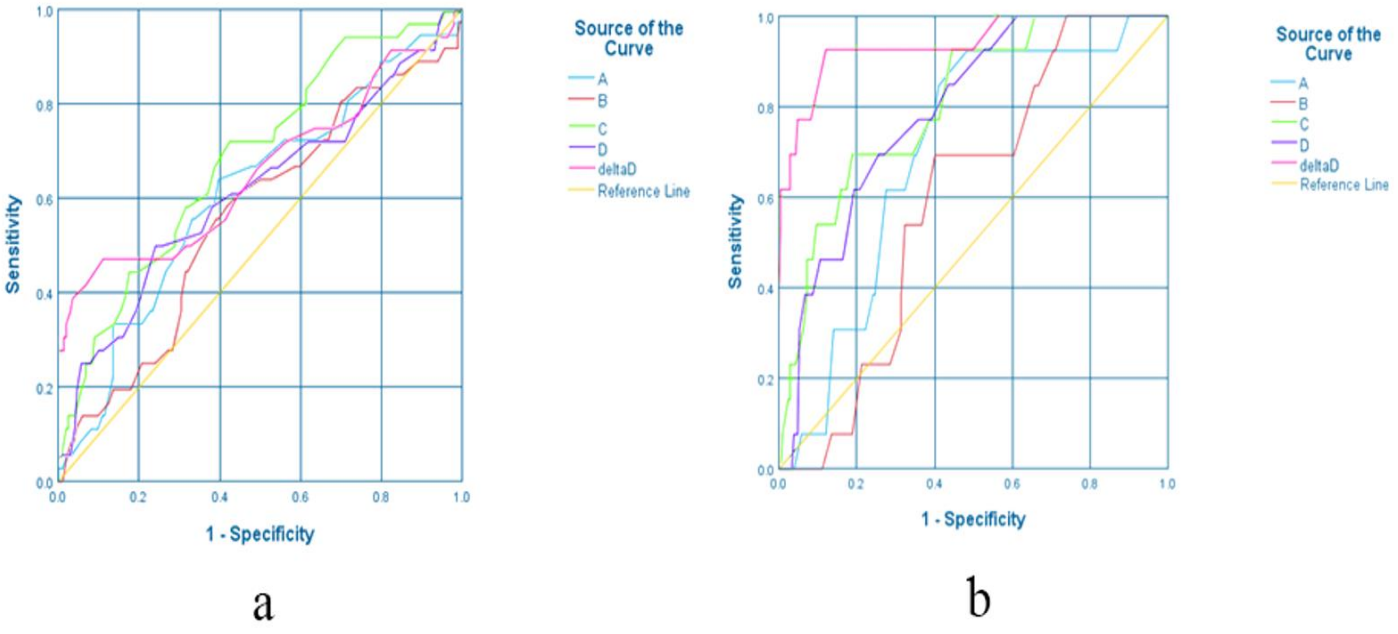

Figure 5. ROC curves for the diagnostic value of vertebral angles to diagnose (a) LSTV, and (b) LSTV type 2

Table 5. Results of angle measurement ROC curve plots for determining LSTV

Diagnosis		AUC	95% confidence interval	P value
LSTV	*A-angle*	0.610	0.506-0.714	0.038
	B-angle	0.562	0.456-0.667	0.243
	C-angle	0.688	0.594-0.782	<0.001
	D-angle	0.615	0.505-0.726	0.029
	Delta-angle	0.658	0.542-0.774	0.003
Type IIA LSTV	*A-angle*	0.700	0.581-0.820	0.015
	B-angle	0.599	0.483-0.715	0.232
	C-angle	0.805	0.693-0.916	<0.001
	D-angle	0.790	0.687-0.894	<0.001
	Delta-angle	0.937	0.860-1.000	<0.001

AUC: area under the curve; LSTV: lumbosacral transitional vertebrae

Discussion

Correct enumeration of lumbar vertebrae in LSTV patients is particularly challenging using routine lumbar MRI, posing potentially serious consequences for therapeutic interventions at the spinal level. In the current study, we investigated the diagnostic value of lumbar vertebrae angle measurements in sagittal MRI for LSTV. We found a prevalence of 16.3% for LSTV using whole spine localizer scans and coronal MRI. Other researchers have reported a prevalence range of 4-35% depending on the criteria used for diagnosis (some excluding LSTV type 1 due to clinical insignificance), while a systematic review denoted a mean prevalence of 12.3%.[19] We found that LSTV is more frequent in females, contradicting some reports.[20] These inconsistencies may be explained by the currently lacking understanding of etiology. The genes controlling the independent development of sacral and lumbar bodies have been identified (Hox10 and Hox11),[21,22] though no associations have been made with LSTV. We found that the age of patients with LSTV was not significantly different from normal cases. Interestingly, however, when comparing LSTV between age groups, some studies have reported that disc degeneration supra-adjacent to the LSTV is more frequent in younger patients.[23] Several studies have confirmed an increased risk for disc degeneration above LSTV.[3,4] Based on our findings, L4-L5 disc dehydration and the absence of dehydration at L5-S1 were significantly associated with LSTV diagnosis.

Many paraspinal structures have been investigated in an attempt to correctly enumerate the spine, including the iliolumbar ligament, right renal artery, aortic bifurcation, and the conus medullaris,[24] which have not been proven to be entirely reliable in identifying the lumbar vertebrae in sagittal scans. For example, the iliolumbar ligament originating at L5 in normal cases appears to have multiple origins in some LSTV cases.[17] A previous study has shown that the conus medullaris level is lower in lumbarization LSTV cases compared with those with sacralization; however, the conus medullaris level is not reliable for diagnosing LSTV, either.[25] Similarly, it has been observed that the coeliac artery and the superior mesenteric artery origin levels are lower in lumbarization LSTV compared with sacralization. However, this feature has also been unreliable for vertebral numbering.[26]

In 2012, Chalian et al. introduced the measurement of two angles for predicting LSTV in mid-sagittal MRI scans: the angles formed by a superior surface of the sacrum (A-angle) and superior endplate of L3 vertebra (B-angle). Upon investigating a total of 100 subjects (50 LSTV and 50 controls), they concluded that increased A-angle and B-angle were both able to predict LSTV with a sensitivity and specificity of 80%.[18] The same angles were measured in our study, while LSTV was confirmed via whole spine localizer MRI and coronal images, allowing for better differentiation of LSTV types. We found that the median A-angle was higher in LSTV patients and that increased A-angle was an independent predictor of LSTV; however, measuring the A-angle did not provide adequate sensitivity and specificity for LSTV. Neither of the aforementioned angles showed sufficient diagnostic value for type 2 or type 3 LSTV. The newly defined C-angle and delta-angle managed to diagnose LSTV with up to 72% sensitivity and 57% specificity. In particular, delta-angle < 8.5° was able to predict LSTV type 2 with 92.3 % sensitivity and 87.9 % specificity. Regarding type 2 LSTV, we found that C-angle, D-angle, and Delta-angle are smaller in type 2 LSTV patients than non-LSTV type 2 cases, while the A-angle is larger among LSTV type 2. However, all the angles measured in our study demonstrated lower values for diagnosing LSTV than what Chalian et al. had previously proposed; however, in the absence of whole spine images, these measurements are among the few viable methods for diagnosing LSTV from sagittal lumbar MRI.

Another study by Zhou et al. evaluated the ability of quantitative parameters, including the anterior-edge vertebral angle (AVA), to identify LSTV. The values of AVA were significantly different between the LSTV and control groups as AVA showed a sensitivity of 77.5% and specificity of 88.3% with a cutoff value equal to 73.0°.[15]

In contrast, the C-angle and delta-angle in our study demonstrated the best performance, differentiating LVST

from the control group. The C-angle revealed a cut-off point of 35.5 when diagnosing LSTV, with a sensitivity of 72.2 % and a specificity of 57.6 %. Similarly, the delta-angle showed a cut-off point of 14.5, a sensitivity of 66.7 %, and a specificity of 52.2 %. Compared to AVA studies by Zhou et al., these two angles were slightly inferior, especially in the case of specificity. Furthermore, a few studies evaluated the location of paraspinal structures to enumerate the vertebrae. In this regard, Lee et al. investigated the distribution of paraspinal structures on MRI to identify potential landmarks for detecting LSTV. They stated that the following parameters were potentially useful for this purpose: aortic bifurcation (AB), IVC confluence (IC), right renal artery (RRA), celiac trunk (CT), SMA root (SR), and iliolumbar ligament (ILL). They also identified LSTV in 23.8% of cases, lumbarization in 9.9%, and sacralization in 13.9% of cases. After revealing the common location of these structures, they mentioned that the abnormal displacement of these structures could be indicative of the potential presence of LSVT because their analysis indicated that paraspinal structures in S1 lumbarization were located further caudally, while those in L5 sacralization were positioned more cranially ($P < 0.01$). However, the sensitivity or specificity was not calculated for this purpose.[14] Another study by Tokgoz et al. attempted to enumerate vertebrae and diagnose LSTV by leveraging the morphological characteristics of vertebrae alongside the positions of spinal and paraspinal structures on lumbar MRI. The morphology of the S1-2 disc, L5 and S1 vertebral bodies, and lumbar spinous processes (SPs), as well as the locations of the right renal artery (RRA), superior mesenteric artery, aortic bifurcation (AB), and conus medullaris (CM), were utilized for this purpose. However, their findings disclosed that all these parameters had varying positions, and as a result, none of them could be reliable for diagnosing LSVT.[27] Similarly, studies conducted by Lian et al. and Peker et al. concluded that various paraspinal structures could not be considered landmarks for either vertebral numbering or LVST diagnosis.[12,28] However, according to Lian et al., when whole spine imaging is not available, the use of iliac crest tangent sign on coronal MRI could be a relatively reliable marker for spinal numeration and identification of LSVT by exhibiting a sensitivity of 81% and a specificity of 64-88%, respectively. They indicated that the most reliable approach for spinal numeration is still to count caudally from C2 on the sagittal whole spine view.[12]

Following their last attempt to measure mid-sagittal MRI angles for LSTV (A-angle and B-angle), Farshad et al. proposed new angle measurements that would predict symptomatic LSTV of higher degrees (Castellvi et al., type 2+3+4).[23] These researchers drew four vertical mid-vertebral lines starting cranially from the last vertebra with a fully developed disc; these lines formed three angles, and they termed the difference between the two most caudal angles Diff-VMVA. Investigating this new angle among 92 symptomatic LSTV patients showed that Diff-VMVA ≤10° could predict type 3 and type 4 LSTV with 100% sensitivity and 89% specificity. The symptomatic patients were assessed; hence, the results may not represent the whole population; nonetheless, these results are promising. In our study, the delta-angle was able to predict LSTV type 2 with high sensitivity and specificity. Even though it did not show sufficient value in diagnosing LSTV type 3 or 4, measuring the delta-angle can warn physicians about the presence of LSTV type 2 with great certainty.

Our study used a whole spine localizer to identify vertebral numbering. Interestingly, we encountered type 3 LSTV cases in which lumbar MRIs appeared to be entirely normal, but using a whole spine localizer, we found that the S1 vertebra was sacralized L5 (absence of one lumbar vertebra). This phenomenon led to some type 3 lumbosacral transitional vertebrae (LSTVs) closely resembling normal subjects with normal angles. Consequently, the delta angle proved ineffective in detecting these cases, perhaps due to this specific anatomical variation. However, it should be noted that both radiologists and surgeons always misinterpreted L5 as S1 in such instances, rendering the detection of these cases less clinically significant. As a result, our delta angle measurement gains greater importance in this context.

Mean differences in these angles that were observed in our results between normal individuals and LSTV patients can serve as indicators of altered lumbar spine morphology on sagittal scans, offering potential insights for LSTV diagnosis. Among these angles, the delta angle emerges as a good predictor for type 2 LSTV. Higher values of this angle signify the presence of a solitary acute angle between the lower lumbar and upper sacral levels, predominantly at the L5-S1 junction, while the remaining levels tend to align almost parallelly. Conversely, lower values of this angle suggest the involvement of a minimum of two levels responsible for shaping the lumbosacral curvature. This novel finding, unreported in the literature, holds promise for facilitating the identification of LSTV through sagittal MRI analysis. Combining the findings of our study with previous knowledge shows promise in using only sagittal lumbar MRI as a routinely available scan to diagnose LSTV and differentiate between LSTV types. Moreover, according to our results, observing a non-dehydrated L5-S1 disc coexisting with a dehydrated L4-L5 disc should serve as a cautionary signal regarding the potential presence of LSTV.

Our study is among the few attempts to measure vertebral angles in sagittal MRI scans for LSTV. Our report, however, was faced with limitations, including that we did not investigate the measured angles in spinal radiographs, which restricted our ability to expand the findings to a more readily available modality. Another inherent limitation is the potential variations in the number of vertebrae. To count vertebrae, we proceeded as follows. Firstly, we determined the C2 and counted six cervical vertebrae up to C7. Then, we counted 12 thoracic vertebrae and subsequently counted the number of lumbar vertebrae until we reached the sacrum. We selected this approach as we thought this would be a more reproducible method due to variations in cervical, thoracic, and lumbar vertebrae (e.g., the lack of a rib attachment to T12 or the attachment of a rib to L1). Although this approach caused three patients to be diagnosed with stage 3B sacralization, we believe this was the most

reproducible method we could have chosen. Furthermore, this study focused primarily on disc dehydration as a marker of degeneration. Other parameters, including disc narrowing, spinal canal narrowing, and disc herniation, were not analyzed. Future research should consider these additional factors to provide a more comprehensive understanding of degeneration in the context of LSTV. Expanding the sample size through multi-center collaborations could also enhance the generalizability and reliability of findings, decreasing the biases associated with single-center studies.

We also recommend that future studies correlate vertebral angle measurements with clinical findings, such as patient symptoms and functional outcomes, better to understand the implications of LSTV on patient management. Incorporating clinical data could provide valuable insights and strengthen the applicability of imaging findings in real-world scenarios.

Conclusion

Our study indicates that lumbosacral vertebrae angle measurements, particularly the Delta-angle, provide acceptable diagnostic value for detecting LSTV in sagittal MRI scans, especially when whole spine imaging is unavailable. Routine lumbar MRIs could alert clinicians to a likely LSTV diagnosis, indicating the need for further spine numeration with whole spine scans in ambiguous cases. This approach offers a practical, non-invasive tool for early LSTV detection and supports the integration of vertebral angle measurements into clinical practice. Future studies should validate these findings in larger, multi-center populations and investigate their relationship with clinical outcomes.

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References

1. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984; 9(5):493-5. doi: 10.1097/00007632-198407000-00014.
2 Hanhivaara J, Määttä JH, Karppinen J, Niinimäki J, Nevalainen MT. The association of lumbosacral transitional vertebrae with low back pain and lumbar degenerative findings in MRI: a large cohort study. Spine (Phila Pa 1976). 2022; 47(2):153-162. doi: 10.1097/BRS.0000000000004244.
3 Hsieh CY, Vanderford JD, Moreau SR, Prong T. Lumbosacral transitional segments: classification, prevalence, and effect on disk height. J Manipulative Physiol Ther. 2000; 23(7):483-9. doi: 10.1067/mmt.2000.108817.
4 Otani K, Konno S, Kikuchi S. Lumbosacral transitional

vertebrae and nerve-root symptoms. J Bone Joint Surg Br. 2001; 83(8):1137-40. doi: 10.1302/0301-620x.83b8.11736.

5 Jenkins III AL, Chung RJ, O'Donnell J, et al. Redefining the treatment of lumbosacral transitional vertebrae for Bertolotti syndrome: Long-term outcomes utilizing the Jenkins classification to determine treatment. World Neurosurg. 2023:175:e21-e29. doi: 10.1016/j.wneu.2023.03.012.

6 Luoma K, Vehmas T, Raininko R, Luukkonen R, Riihimäki H. Lumbosacral transitional vertebra: relation to disc degeneration and low back pain. Spine (Phila Pa 1976). 2004; 29(2):200-5. doi: 10.1097/01.BRS.0000107223.02346.A8.

7 Shah M, Halalmeh DR, Sandio A, Tubbs RS, Moisi MD. Anatomical variations that can lead to spine surgery at the wrong level: part III lumbosacral spine. Cureus. 2020; 12(7):e9433. doi: 10.7759/cureus.9433.

8 Tatara Y, Niimura T, Sekiya T, Mihara H. Changes in lumbosacral anatomy and vertebral numbering in patients with thoracolumbar and/or lumbosacral transitional vertebrae. JB JS Open Access. 2021; 6(3):e20.00167. doi: 10.2106/JBJS.OA.20.00167.

9 Staartjes VE, Seevinck PR, Vandertop WP, van Stralen M, Schröder ML. Magnetic resonance imaging–based synthetic computed tomography of the lumbar spine for surgical planning: a clinical proof-of-concept. Neurosurg Focus. 2021; 50(1):E13. doi: 10.3171/2020.10.FOCUS20801.

10 Kim GU, Park WT, Chang MC, Lee GW. Diagnostic technology for spine pathology. Asian Spine J. 2022 t; 16(5):764-775. doi: 10.31616/asj.2022.0374.

11 Becker L, Schönnagel L, Mihalache TV, et al. Lumbosacral transitional vertebrae alter the distribution of lumbar mobility–Preliminary results of a radiographic evaluation. PLoS One. 2022; 17(9):e0274581. doi: 10.1371/journal.pone.0274581.

12 Lian J, Levine N, Cho W. A review of lumbosacral transitional vertebrae and associated vertebral numeration. Eur Spine J. 2018; 27(5):995-1004. doi: 10.1007/s00586-018-5554-8.

13 Lee CH, Seo BK, Choi YC, et al. Using MRI to evaluate anatomic significance of aortic bifurcation, right renal artery, and conus medullaris when locating lumbar vertebral segments. AJR Am J Roentgenol. 2004; 182(5):1295-300. doi: 10.2214/ajr.182.5.1821295.

14 Lee CH, Park CM, Kim KA, et al. Identification and prediction of transitional vertebrae on imaging studies: anatomical significance of paraspinal structures. Clin Anat. 2007; 20(8):905-14. doi: 10.1002/ca.20540.

15 Zhou S, Du L, Liu X, et al. Quantitative measurements at the lumbosacral junction are more reliable parameters for identifying and numbering lumbosacral transitional vertebrae. Eur Radiol. 2022; 32(8):5650-5658. doi: 10.1007/s00330-022-08613-w.

16 Hughes RJ, Saifuddin A. Numbering of lumbosacral transitional vertebrae on MRI: role of the iliolumbar ligaments. American Journal of Roentgenology. AJR Am J Roentgenol. 2006; 187(1):W59-65. doi: 10.2214/AJR.05.0415.

17 Farshad-Amacker NA, Lurie B, Herzog RJ, Farshad M. Is the iliolumbar ligament a reliable identifier of the L5 vertebra in lumbosacral transitional anomalies?. Eur Radiol. 2014; 24(10):2623-30. doi: 10.1007/s00330-014-3277-8.

18 Chalian M, Soldatos T, Carrino JA, Belzberg AJ, Khanna J, Chhabra A. Prediction of transitional lumbosacral anatomy on magnetic resonance imaging of the lumbar spine. World J Radiol. 2012; 4(3):97-101. doi: 10.4329/wjr.v4.i3.97.

19 Bron JL, van Royen BJ, Wuisman PI. The clinical significance of lumbosacral transitional anomalies. Acta Orthop Belg. 2007; 73(6):687-95.

20 Nardo L, Alizai H, Virayavanich W, et al. Lumbosacral transitional vertebrae: association with low back pain. Radiology. 2012; 265(2):497-503. doi: 10.1148/radiol.12112747.

21 Weiner BK, Walker M, Fraser RD. Vascular anatomy anterior to lumbosacral transitional vertebrae and implications for anterior lumbar interbody fusion. Spine J. 2001; 1(6):442-4. doi: 10.1016/s1529-9430(01)00126-7.

22 Carapuço M, Nóvoa A, Bobola N, Mallo M. Hox genes specify vertebral types in the presomitic mesoderm. Genes Dev. 2005; 19(18):2116-21. doi: 10.1101/gad.338705.

23 Farshad M, Aichmair A, Hughes AP, Herzog RJ, Farshad-Amacker NA. A reliable measurement for identifying a lumbosacral transitional vertebra with a solid bony bridge on a single-slice midsagittal MRI or plain lateral radiograph. Bone Joint J. 2013; 95-B (11):1533-7. doi: 10.1302/0301-620X.95B11.32331.

24 Farshad-Amacker NA, Aichmair A, Herzog RJ, Farshad M. Merits of different anatomical landmarks for correct numbering of the lumbar vertebrae in lumbosacral transitional anomalies. Eur Spine J. 2015; 24(3):600-8. doi: 10.1007/s00586-014-3573-7.

25 Kershenovich A, Macias OM, Syed F, Davenport C, Moore GJ, Lock JH. Conus medullaris level in vertebral columns with lumbosacral transitional vertebra. Neurosurgery. 2016; 78(1):62-70. doi: 10.1227/NEU.0000000000001001.

26 Biyikli E, Sever I, BALTACIOĞLU F. Reliability of coeliac and superior mesenteric artery origin level in lumbosacral transitional vertebrae detection and vertebral numbering. Marmara Medical Journal. 2022; 35(1).

27 Tokgoz N, Ucar M, Erdogan AB, Kilic K, Ozcan C. Are spinal or paraspinal anatomic markers helpful for vertebral numbering and diagnosing lumbosacral transitional vertebrae?. Korean J Radiol. 2014; 15(2):258-66. doi: 10.3348/kjr.2014.15.2.258.

28 Peker E, Hürsoy N, Akkaya H, et al. Evaluation of spinal-paraspinal parameters to determine segmentation of the vertebrae. Pol J Radiol. 2019:84:e470-e477. doi: 10.5114/pjr.2019.90227.