CLINICAL ARTICLE

Role of the Lumbosacral Transition Vertebra and Vertebral Lamina in the Pathogenesis of Lumbar Disc Herniation

Lin Jin, MD[1,2], Yingchao Yin, MD[1,2], Wei Chen, MD[1,2], Ruipeng Zhang, MD[1,2], Jialiang Guo, MD[1,2], Shiwu Tao, MD[1,2], Zheming Guo, MD[1,2], Zhiyong Hou, MD[1,2], Yingze Zhang, MD[1,2]

[1]*Department of Orthopedic Surgery, Third Hospital of Hebei Medical University and* [2]*NHC Key Laboratory of Intelligent Orthopaedic Equipment (Third Hospital of Hebei Medical University), Shijiazhuang, China*

Objective: To investigate the prevalence of lumbosacral transition vertebrae (LSTVs) in both the normal population and the lumbar disc herniation (LDH) population and to determine the risk factors for LDH.

Methods: Between January 2019 and September 2020, all patients aged 18–39 years and underwent an anteroposterior (AP) X-ray of the lumbar vertebrae were retrospective reviewed in our institution. Those patients who were diagnosed with LDH were eligible for inclusion in the LDH group. During the same period, those patients admitted to our hospital who underwent an anteroposterior X-ray of the lumbar spine and had not been diagnosed with LDH were included in the control group. Those patients with disease that might affect the lumbar anatomy were excluded from both groups. The type of LSTV was classified according to the Castellvi classification. The height of the lumbar vertebral lamina was evaluated through the h/H index. The inter- and intra-observer reliability was evaluated by one senior radiologist and one senior orthopedist using intraclass correlation coefficient (ICC). The association between the LSTV and the herniation level was also investigated. Binary logistic regression was used to explore the association of different factors between the LDH group and the control group.

Results: Two hundred LDH patients (115 male and 85 female) and 200 individuals (108 male and 92 female) were investigated retrospectively. The prevalence of LSTVs was 71.5% (n = 143) in the LDH group and 34.0% (n = 68) in the control group. The most frequent LSTV types were type Ib and type IIa. The inter- and intra-observer ICCs of the measurement of "h/H" index and the classification of LSTV were all "excellent" (ICC > 0.90). The median h/H index in the control group was significantly higher than that in the LDH group (0.28 (0.26, 0.31) *vs* 0.34 (0.31, 0.37), $P = 0.000$). The distribution of the Castellvi classification in the L4/5 and L5/S1 herniation patients was significantly different ($P = 0.048$). LSTVs, BMI and the h/H index were closely associated with LDH, with odds ratios of 3.06 (95% CI: 2.12–4.43), 1.23 (95% CI: 1.13–1.33) and 0.09 (95% CI: 0.05–0.15), respectively. The incidence of L4/5 disc herniation in patients with an LSTV was significantly more common than that in patients with L5/S1 disc herniation ($P = 0.048$).

Conclusion: The prevalence of LSTVs was 34.0% in the control group and 71.5% in the LDH group; LSTVs and BMI were positively correlated with LDH, and h/H was negatively correlated with LDH.

Key words: Lumbar disc herniation; Lumbosacral transitional vertebra; Odds ratios; Vertebral lamina

Address for correspondence Zhiyong Hou, MD, Chief Surgeon & Prof., Department of Orthopedic Surgery, Third Hospital of Hebei Medical University, Shijiazhuang, Hebei, China 050051; NHC Key Laboratory of Intelligent Orthopedic Equipment (Third Hospital of Hebei Medical University), Shijiazhuang, Hebei, China 050051 Tel: +86 18533112800; Fax: 0086-0311-87023626; Email: drzyhou@gmail.com

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Introduction

Lumbar intervertebral discs consist of annulus fibrosus, endplates and the nucleus pulposus. Axial loading, lateral bending and rotational stress are applied to the intervertebral disc during people's daily life. The nucleus pulposus is the inner substance of the disc and contains abundant proteoglycans, which could resist the weight above the waist[1]. Along with the axial stresses applied to the lumbar intervertebral disc, the nucleus gradually flatten and squeeze the surrounding annulus fibrosus. When the pressure reaches a certain level, or repeated pressure for a long period of time, the annulus fibrosis will disrupt, resulting in lumbar disc herniation (LDH). Due to the avascular nature of intervertebral disc, LDH is a common disease which is caused by chronic vertebral instability[2]. LDH is a common cause of low back pain and radicular pain in the lower extremities, with a prevalence of 4%–6%[3]. Some patients may also present with restricted flexion of the trunk, increased lower extremity pain when sneezing or coughing. Several factors, such as genetic factors[4], congenital malformations[5], spinal stability[6] and trauma[7], have been identified as potential causes of LDH. Anteroposterior and lateral X-ray view, CT and MRI is the most commonly examination to evaluate and diagnose the LDH patients.

The human lumbar spine is commonly made up of five vertebrae. The sacrum is a continuation of the lumbar spine and involved in maintaining the stability of the pelvis, which also transfers the body weight from the spine to the lower limbs. However, some people have vertebral variation with six or four lumbar vertebrae due to the existence of a lumbarized first sacral vertebra or a sacralized fifth lumbar vertebra[8]. The shape of the sacrum is widely varied in these individuals and those variant vertebrae are called lumbosacral transitional vertebrae (LSTVs)[9]. LSTVs were first observed by Mario Bertolotti in 1917[10], and the prevalence of LSTVs varies from 3.3% to 35.6% as reported in previous studies[9, 11, 12]. According to anatomical changes, LSTVs include unilateral/bilateral L5 sacralization and unilateral/bilateral S1 lumbarization[13, 14]. This special anatomy was found to be correlated with low back pain, which is also called Bertolotti syndrome[10, 15]. In 1984, Castellvi first proposed the classification of LSTV base on the anteroposterior X-ray view of the junction of lumbosacral[16]. The presence of LSTVs has the potential to alter the alignment and biomechanics of the lumbar spine[17], which can lead to early degenerative changes in the disc and joint facet of the vertebra. Hence, the importance of LSTVs has been gradually recognized by orthopedists[18–20]. Otani *et al.*[21] conducted a study to explore whether the presence of LSTV accelerate the development of the radicular symptom. The result of their study revealed that the incidence of LDH was higher than those patients without LSTV and the symptomatic level was just above the LSTV.

Spinal bifida occulta is a congenital defect of the vertebral lamina[22]. Genetic factors, such as HOX genes, are considered to be responsible for the development of the lumbosacral spine[23, 24]. It has been confirmed that the spinal bifida occulta has a high coincidence with lumbar spondylolysis[25]. Lumbar spondylolysis is the bone defect in the interarticularis or isthmus of the vertebra. The prevalence of lumbar spondylolysis in general population is about 7% and varies according to gender and ethnicity[26]. Nearly 95% spondylolysis cases involved the L5 vertebra and the incidence rate reduces in the cephalic vertebrae. Besides, Tao *et al.* found that among the normal population, the heights of the vertebral lamina vary widely as well[27]. Previous studies reveal, lumbar spondylolysis is the most common cause of low back pain in adolescents and young adults[26].

In 1970, Holdsworth divided the spine into two columns to analyze the stability of spine after injuries[28]. However, flexion distraction type of spine injuries was not involved in this classification system. Denis first proposed the "three-column" concept of spinal stability in 1983[29]. He divided the anterior longitudinal ligament, the anterior hemi-vertebra and annulus fibrosus into the anterior column; posterior longitudinal ligament, the posterior hemi-vertebra and annulus fibrosus were divided into the middle column. Both the vertebral lamina and the presence of an LSTV belonged to the posterior column according to Denis' "three column" theory. Based on this, the width of the vertebral lamina and the presence or absence of LSTV will affect the stability of the vertebral body.

To our knowledge, no previous study has comprehensive evaluated the influence of the posterior column stability structure of the spine, including the vertebral lamina and LSTV, on LDH patients. The purposes of this study are including to compare the anatomical parameters and the occurrence of LSTV in these two groups, to explore the relationship between LSTV and LDH level, and establishing a multiple regression model to infer which index is the risk factor for LDH. The authors hypothesized that a narrow lamina and LSTV were risk factors for LDH.

Materials and Methods

This retrospective research was approved by the Institutional Review Board at our hospital. Between January 2019 and September 2020, patients between 18 and 39 years old who underwent an anteroposterior (AP) X-ray of the lumbar vertebrae were reviewed. Patients who were diagnosed with LDH based on their symptoms and physical examinations were included in the LDH group, and the diagnoses were confirmed by MRI. Those patients who were admitted to our department and underwent a plain AP X-ray of the lumbar spine during the same period were included as the control group. Those patients who were diagnosed with LDH were excluded in control group. Patients who had a history of lumbar trauma or spinal surgery, lumbar spondylolisthesis, spinal tumor or infections, etc., that might affect the lumbar anatomy were excluded from both groups. Patients with poor-quality radiographs were also excluded.

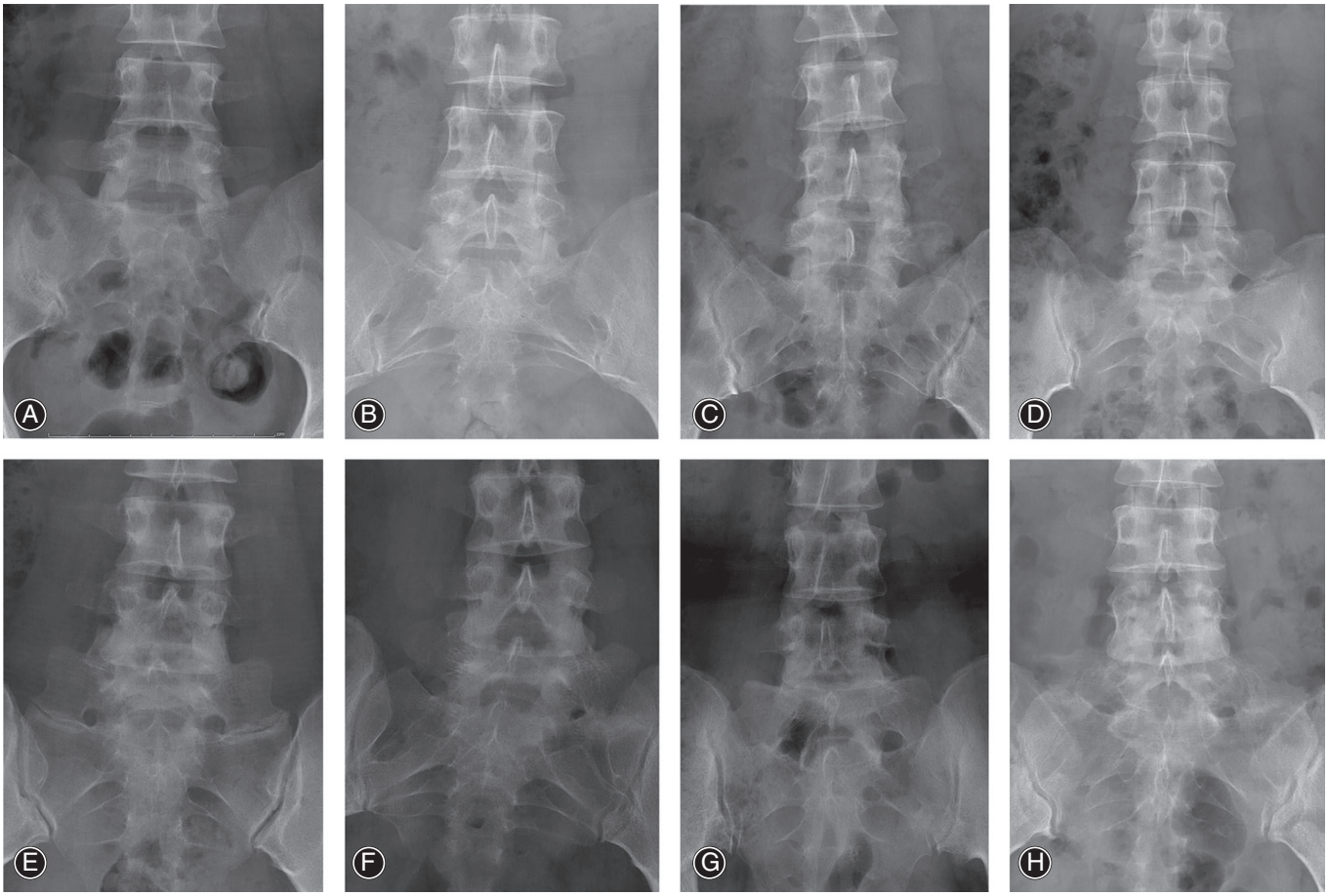

Fig 1 (A) Normal lumbar vertebrae and sacrum. (B–H) Typical radiographs demonstrating the Castellvi classification of LSTVs. (B, C) Type I, enlarged TP; (D, E) Type II, incomplete fusion of the TP and the sacrum; (F, G) Type III, complete fusion of the TP and the sacrum; (H) Type IV, pseudoarticulation on one side and complete fusion on the other side.

Classification of the LSTV

All the patients' AP lumbar X-rays and lumbar spine MRIs (LDH group) were retrieved from the Picture Archiving and Communication Systems (PACS) of our institution. The anatomical type of LSTV was identified according to the Castellvi classification[16], as shown in Fig. 1. Type Ia: A unilateral transverse process (TP) height greater than or equal to 19 mm (Fig. 1B); Type Ib: The height of both sides of the TP greater than or equal to 19 mm (Fig. 1C); Type IIa: Unilateral articulation present between the TP and the sacrum (Fig. 1D); Type IIb: Bilateral articulation present between the TP and sacrum (Fig. 1E, Fig. 2); Type IIIa: Unilateral fusion of the TP and the sacrum (Fig. 1F); Type IIIb: Bilateral fusion of the TP and the sacrum (Fig. 1G); Type IV: Type II (articulation) on one side and Type III (fusion) on the contralateral side (Fig. 1H).

Measurement of the Vertebral Lamina Index (r/H Ratio)

To evaluate the anatomical parameters of the lumbar vertebral lamina, we introduced the h/H ratio. "h" is defined as the vertical height (from the superior edge to the inferior edge) of the L5 lamina. "H" is defined as the vertical height of the superior edge of the S1 lamina to the inferior edge of the L4 lamina (Fig. 3). Both the classification of the LSTV and the measurement of the vertebral lamina index (h/H) were evaluated by a senior orthopedic surgeon.

Inter- and Intra-Observer Reliability

In order to evaluate the inter- and intra-observer reliability of LSTV classification and "h/H" index. One senior radiologist (observer A) and one senior orthopedist (observer B) were classified and measured all the included 400 patients (both in LDH group and the control group). At 1 months after the first measurement, the same two experts were requested to classify all the patients again in a random order.

Statistical Analysis

Statistical analysis was performed *via* SPSS statistical software version 23.0 for Windows (SPSS, Inc., Chicago, IL). The normality of the variables was checked by the Kolmogorov–Smirnov test. Independent samples *t* tests or U

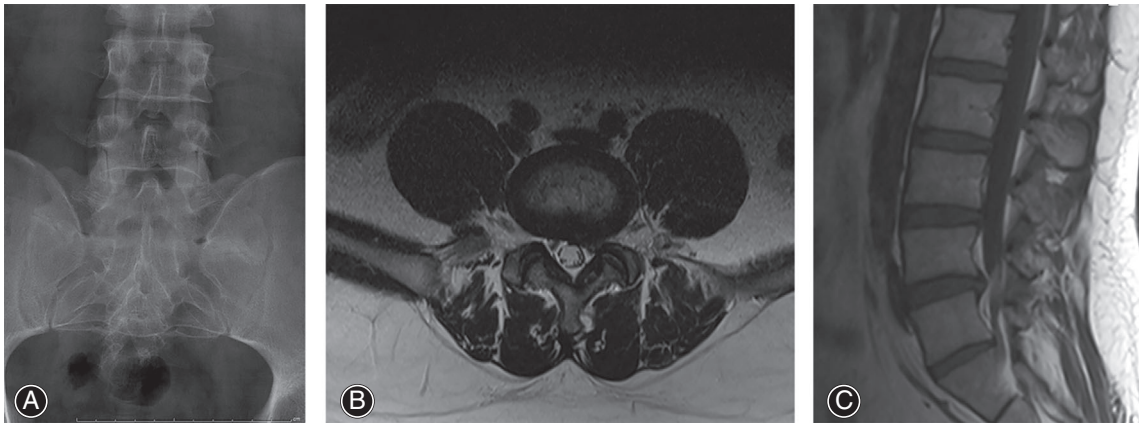

Fig 2 A 23-year-old male patient. Anteroposterior X-ray of the lumbar vertebra shows a Castellvi type IIb LSTV (A), and axial and sagittal CT views of MRI show that the L4/5 nucleus pulposus protrudes to the left and compresses the nerve root (B, C).

tests were used for between-group comparisons of continuous variables, where x^2 tests were performed for categorical variables. Continuous variables are presented as the mean and standard deviation or as the median with interquartile range, and categorical variables are presented as the frequency.

The inter-observer reliability comparing the measurements of "h/H" and classification of the LSTV made by the two observers and intra-observer reproducibility comparing the first with the second measurements of these two observers was assessed with intraclass correlation coefficient (ICC)[30]. The ICC between 0.75–1.00 was considered excellent, an ICC between 0.60–0.74 was considered good, ICC between 0.40–0.59 was fair, ICC less than 0.40 was poor[31]. Multivariable models were used to evaluate the relationship between LDH and LSTV. Sex, age, height, BMI, smoking status and h/H index were modeled using binary logistic regression. The odds ratios (ORs), 95% confidence intervals (CIs) and *P* values were calculated from this multinomial model by comparison of the LDH group with the control group. The "h/H" index was converted to binary data centered around the median during logistic regression. Significance was defined as $P < 0.05$.

Results

Patient Characteristics and Inter- and Intra-Observer Reliability

In total, 200 LDH patients (115 male and 85 female) were included in the LDH group, with a median age of 29 (24, 34) years. Two hundred patients (108 male and 92 female) were included in the control group, with a median age of 30 (24, 34) years. The mean BMI of the LDH group and control group were 25.27 ± 4.02 kg/m^2 and 23.04 ± 2.63 kg/m^2, respectively ($P = 0.000$). The inter- and intra-observer ICCs of the measurement of "h/H" index and the classification of LSTV were all "excellent" (ICC > 0.90) (Table 1).

The Incidence of LSTV and its Relationship with LDH Level

An LSTV was found in 143 patients (71.5%) in the LDH group. Sixty-eight patients (34.0%) were found to have an

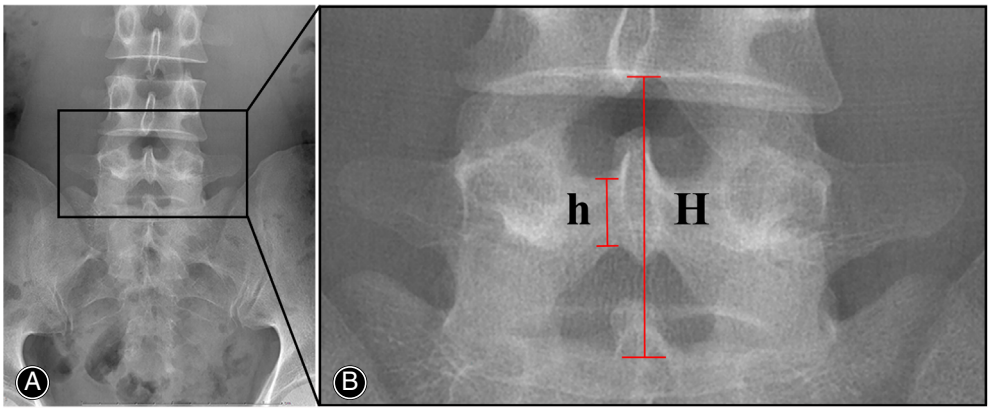

Fig 3 Measurement of the "h/H" index in an AP X-ray of the lumbar vertebra. **h:** The height of the vertebral lamina; **H:** The height from the superior edge of S1 to the inferior edge of L4. Fig 3B is the partial enlargement of Fig 3A.

TABLE 1 Intra- and inter-observer ICCs of the measurement of "h/H" and LSTV classification (Radiologist as observer A, Orthopedist as observer B)

	"h/H" index	LSTV classification
Inter-observer ICCs		
1st evaluation A-B	0.991	0.980
2nd evaluation A-B	0.978	0.975
Intra-observer ICCs		
1st A - 2nd A	0.993	0.981
1st B - 2nd B	0.976	0.966

LSTV in the control group. The median h/H index in the control group was significantly higher than that in the LDH group (0.28 (0.26, 0.31) *vs* 0.34 (0.31, 0.37), $P = 0.000$) (Table 2).

Subgroup Analysis of Different LSTV Types

The gender distribution of all the 400 enrolled patients in different LSTV types is shown in Fig. 4. Among all the patients in the LDH group, 93 patients had LDH at the L4/5 level and 107 at the L5/S1 level. There was no difference in gender distribution between the two groups ($P = 1.000$). The mean age in the L5-S1 disc herniation group was higher than that in the L4-L5 disc herniation group ($P = 0.015$). The distribution of the Castellvi classification in the L4/5 and L5/S1 herniation patients was significantly different ($P = 0.048$) (Table 3).

Analysis of Logistic Regression (The Risk Factors for LDH)

Binary logistic regression was used to evaluate the relationship between LDH and LSTV. Sex, age, height, BMI, smoking status and h/H index were included in this multivariable model. In terms of LDH, patients with LSTVs (OR: 3.06, 95% CI: 2.12–4.43, $P = 0.000$) were more likely to be diagnosed with LDH. BMI was highly correlated with LDH

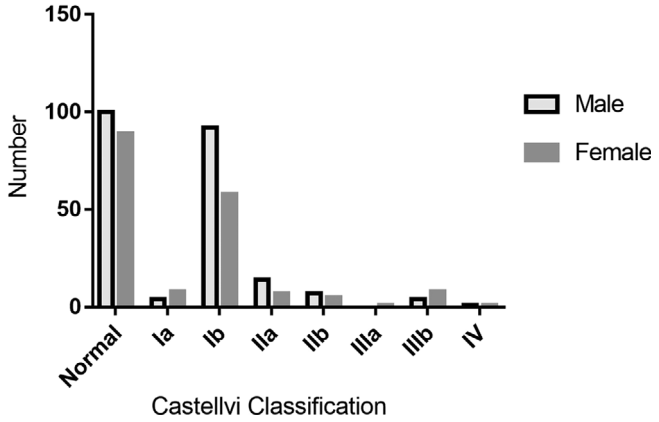

Fig 4 The gender distribution of all the 400 enrolled patients in different LSTV types.

(OR: 1.23, 95% CI: 1.13–1.33, $P = 0.000$). However, the h/H index was found to have a negative correlation with LDH (OR: 0.09, 95% CI: 0.05–0.15, $P = 0.000$), which means that a wider lamina is a protective factor to prevent the occurrence of LDH (Table 4).

Discussion

Main Results in this Present Study

LDH usually causes back pain and/or radicular pain in the lower extremities, which further leads to patient dysfunction and socioeconomic problems. Risk factors such as lumbar trauma and disc degeneration are thought to be the cause of LDH[32]. In this study, all the enrolled patients were between 18 and 39 years of age, and the restriction to this age range partially eliminated age-related lumbar disc degeneration, which can lead to LDH. A comprehensive analysis of the influence of posterior column stabilization with LDH was conducted in this study. The results revealed that the prevalence of LSTVs in this study was 34% in the control group

TABLE 2 Demographic characteristics of LDH and control group

	LDH Group (n = 200)	Control Group (n = 200)	*P* Value
Gender			0.497
Male	115	108	
Female	85	92	
Mean age (years)	29 (24,34)	30 (24,34)	0.598
BMI (kg/m^2)	25.27 ± 4.02	23.04 ± 2.63	0.000
Castellvi classification			0.000
Normal	57	132	
Ia	7	6	
Ib	100	50	
IIa	15	6	
IIb	10	2	
IIIa	1	0	
IIIb	8	4	
IV	2	0	
h/H index	0.28 (0.26,0.31)	0.34 (0.31,0.37)	0.000

TABLE 3 Association between LSTV types and LDH level in LDH group patients

	L4/5 Herniation	L5/S1 Herniation	*P* value
Gender			1.000
Male	53	62	
Female	40	45	
Mean age (years)	28 ± 6	30 ± 6	0.015
Castellvi Classification			0.048
Normal	21	36	
I	52	55	
II	17	8	
III	3	6	
IV	0	2	

and 71.5% in the LDH group. The binary logistic regression results demonstrated that LSTVs and BMI were positively correlated with LDH, and the "h/H" index was negatively correlated with LDH.

LDH Group had more LSTVs than the Control Group

As previous studies reported, an LSTV is a common anatomical variation with a prevalence of 4%–36%[12]. LSTVs include four types according to the Castellvi classification: enlarged TP (type I), incomplete (type II) or complete fusion (type II) of the TP and the sacrum, incomplete fusion on one side and complete fusion on the other side (type IV)[16]. The presence of an LSTV has a definite impact on the normal anatomical alignment and biomechanical stability of the lumbar spine[17], which can also disrupt the balance of soft tissues. Apaydin *et al.*[33] conducted a retrospective study to evaluate the prevalence of LSTVs in young male populations with low back pain. They found that subtype I LSTV mostly occurred in young male patients, which is consistent with the findings of the present study. The present study's results showed that the LDH group had more LSTVs than the control group. These findings imply that abnormal changes in LSTVs may increase lumbosacral stability and break the load-bearing balance of the lumbar spine, which might accelerate the process of disc degeneration or disc herniation.

The Segment above the LSTV is More Likely to Develop LDH

The results of this study also showed that L4/5 herniation patients present more LSTVs than L5/S1 herniation patients.

TABLE 4 ORs of LSTV, BMI and h/H index compared within LDH group and control group

Variable	OR*	95%CI	*P* value
LSTV	3.06	2.12–4.43	0.000
BMI	1.23	1.13–1.33	0.000
h/H index	0.09	0.05–0.15	0.000

* OR, 95% CI and *P* value were calculated from multinomial model.

In other words, an LSTV is a relative protective factor for disc degeneration at the incomplete/complete fusion segment, but the segment above the LSTV is more likely to develop LDH. The reason for this result is similar to that for adjacent level degeneration after lumbar fusion surgery[34]. The increased stability of the fusion level (L5/S1) leads to a concentrated stress force in the above segment (L4/L5). Therefore, motion-preserving spine surgery was introduced and seems superior for avoiding degeneration of adjacent segments[35]. Imagama *et al.*[36] performed a retrospective clinical study to compare the 5-year postoperative adjacent segment degeneration after posterior lumbar interbody fusion and decompression surgery. Their results indicated that decompression surgery with preservation of the posterior components could avoid adjacent disc degeneration. Several other studies have attempted to use bisphosphonates and parathyroid hormone to prevent disc degeneration after lumbar fusion surgery[37, 38]. Hence, when formulating treatment plans for lumbar disease, surgeons should always be aware that the presence of internal fixation may lead to the degeneration of adjacent segments.

The Term "LSTV" Avoids the Problem of Counting the Vertebral Number

Normally, the sacrum is triangular bone at the end of the spine that is formed by five sacral vertebra segments[39]. The shape of the sacrum and the number of foramens are commonly affected by lumbarization of the S1 vertebra or sacralization of the L5 vertebra. Raising the prospect of an LSTV has allowed clinicians to avoid deciding whether the abnormal vertebra is a lumbarized S1 or a sacralized L5 when viewing the entire spine is impossible[13, 16, 40]. In other words, the presence of the term "LSTV" avoids the problem of counting the vertebral number.

The "h/H" Index was a Protective Factor for LDH

Otani *et al.*[21] found that the average age of LDH patients with an LSTV was significantly younger than that of LDH patients without an LSTV. However, the researchers considered only one factor in the stability of the posterior column of the spine. Spine bifida occulta is one of the most common abnormalities of the lumbosacral vertebra[22]. This congenital

disease will cause poor fusion of the vertebral posterior elements. As Denis[29, 41] proposed in the "three-column" theory, the stability of the posterior column is formed by the posterior bony arch (including the vertebral lamina and intervertebral joint), ligaments and capsule. Thus, a new index (h/H) was introduced in the present study to evaluate the influence of the lumbar vertebral lamina, and a multinomial model was established to analyze each factor. The results showed that the h/H index was a protective factor for LDH with an OR of 0.09, which means that a wider lamina will prevent LDH from occurring to some extent. Although this study could not directly identify the reason for this phenomenon, it may provide some reference for spinal surgery strategies.

Limitations

There are certain limitations of the present investigation. First, this was a retrospective comparative study with a relatively small sample size. Second, the existence of an LSTV results in the asymmetrical transition of the body weight from the transitional lumbar region to the sacrum. However, the relationship of disc herniation sides and the unilateral type of LSTV was not fully investigated in this study. Third, the patients included in the control group were not totally healthy humans; however, strict exclusion criteria were set to screen for diseases that might affect the anatomy of lumbosacral segments. Further biomechanical studies, prospective studies and finite element analyses should be conducted to prove the pathogenic mechanism of LDH.

Conclusion

The incidence of LSTVs was 34.0% in the control group and 71.5% in the LDH group. The prevalence of LSTVs in the LDH group was significantly higher than that in the control group, with an OR of 3.06. The h/H index was negatively correlated with LDH with an OR of 0.09. The incidence of L4/5 disc herniation in LSTV patients was greater than that in L5/S1 disc herniation patients.

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Authors Contributions

Lin Jin and Yingchao Yin contributed to the work equally and should be regarded as co-first authors. Lin Jin, Zhiyong Hou, and Yingze Zhang designed the study. Wei Chen, Ruipeng Zhang, Jialiang Guo and Shiwu Tao collected all the data. Lin Jin and Yingchao Yin completed all the statistical analysis and wrote the manuscript. Zheming Guo and Ruipeng Zhang edited all the figures in this manuscript. All authors discussed the results and reviewed the manuscript.

Ethical Approval

This retrospective research was approved by the Institutional Review Board at our hospital.

Consent to Participate

Informed consent was obtained from all the included patients in this study.

Consent to Publish

This manuscript has been read and approved by all the authors.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request. Additional data from this study are available from the corresponding author Zhiyong Hou (drzyhou@gmail.com).

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