Lumbar plain radiograph is not reliable to identify lumbosacral transitional vertebra types according to Castellvi Classification principle

Lisheng Hou (nghohls@163.com)
PLA Army General Hospital
Xuedong Bai
PLA Army General Hospital
Haifeng Li
PLA Army General Hospital
Tianjun Gao
PLA Army General Hospital
Wei Li
PLA Army General Hospital
Tianyong Wen
PLA Army General Hospital
Qing He
PLA Army General Hospital
Dike Ruan
PLA Army General Hospital
Lijing Shi
PLA Army General Hospital
Wei Bing
PLA Army General Hospital

Research article

Keywords: lumbosacral transitional vertebra, lumbar plain radiograph, Castellvi classification, coronal reconstructed CT image, misclassification

Posted Date: March 17th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-17532/v1

Version of Record: A version of this preprint was published at BMC Musculoskeletal Disorders on May 29th, 2020. See the published version at https://doi.org/10.1186/s12891-020-03358-3.

Abstract

Background: The anteroposterior view of lumbar plain radiograph (AP-LPR) was chosen as the original and first radiographic tool to determine and classify lumbosacral transitional vertebra with morphological abnormality (MA-LSTV) according to Castellvi Classification. However, recent studies found that AP-LPR might not sufficient to detect or classify MA-LSTV correctly. The present study aims to verify the reliability of AP-LPR on detecting and classifying MA-LSTV types, taking coronal reconstructed CT images (CT-CRIs) as gold criteria.

Methods : Patients with suspected MA-LSTVs determined by AP-LPR were initially enrolled. Among them, those who received CT-CRIs were formally enrolled to verify the sensitivity of AP-LPR on detecting and classifying MA-LSTV types according to Castellvi classification principle.

Results : 298 cases were initially enrolled as suspected MA-LSTV ones, among whom 91 cases who received CT-CRIs were enrolled into the final study group. All suspected MA-LSTVs were verified to be real MA-LSTV ones by CT-CRIs. However, 35.2% of the suspected MA-LSTVs types judged by AP –LPR were not consistent with final types judged by CT-CRIs. Two suspected type IIIa and 20 suspected IIIb ones were verified to be true, while 9 of 39 suspected IIa, 9 and 3 of 17 suspected IIb , and 11 of 13 suspected IV ones were verified to be real type IIIa, IIIb, IV and IIIb ones by CT-CRIs, respectively. Incomplete joint-like structure (JLS) or bony union structure (BUS), and remnants of sclerotic band (RSB) between the transverse process (TP) and sacrum were considered to be the main reasons for misclassification.

Conclusion : Although AP-LPR could detect MA-LSTV correctly, it could not give accurate type classification. CT-CRIs could provide detailed information between the TP and sacrum area, and could be taken as gold standard to detect and classify MA-LSTV.

Background

Lumbosacral transitional vertebra (LSTV) is regarded as a congenital anomalous vertebra that has morphologic characteristics mixed between those of sacral and lumbar vertebrae, including lumbarization of the highest sacral segment (S_1) and sacralization of the most inferior lumbar segment (L_5) [1,2].

Some LSTV ones exhibit obvious morphological abnormality (MA-LSTV), with or without numerical variance [3], while others exhibit only numerical variance (NV-LSTV) [4–6]. Lumbar plain radiograph (LPR) could detect MA-LSTV while misinterpret NV-LSTV as normal spinal sequence for the latter’s insidious characteristics. Only whole spinal images could discern NV-LSTV [4–6].

Various LSTV categories exist [3–5]. The widely-accepted Castellvi System is a classification of MA-LSTV based on the relationship assessment between transverse process (TP) of suspected MA-LSTV and the sacrum at unilateral or bilateral sides. Four types were classified: type I exhibits enlarged TP measuring at least 19 mm in craniocaudal dimension (a, unilateral; b, bilateral); type II exhibits a joint-like structure

(JLS. a, unilateral; b, bilateral) with sclerotic band(s); type III exhibits a bony union structure (BUS. a, unilateral; b, bilateral), and type IV includes a unilateral type II transition along with a type III on the contralateral side.

Initially, Castellvi types was identified on a 30^0 angled anteroposterior view of lumbar spine which is regarded as true AP of lumbosacral joint (Ferguson view) aiming to decrease the radiographic overlap of MA-LSTV's TP(s) on sacrum [3]. However, Ferguson view is not routinely taken as the standard radiographic assessment of lumbar spine which typically includes standard AP-LPR and lateral LPR [5]. Type I MA-LSTV was not regarded as true LSTV by many specialists,for standard AP-LPR might produce false positive findings due to the overlap effect of TP on sacrum. Moreover, this type had little clinical significance [7]. It seems easy for AP-LPR to detect other three MA-LSTV types for their obvious abnormal characteristics [3].

The opinion that AP-LPR could detect MA-LSTV does not mean that AP-LPR could classify MA-LSTV types accurately. Plain radiograph has some inherent limitations, it frequently misses subtle or occult fractures [8], or fails to evaluate bony union state accurately [9]. Recently, some studies pointed out that coronal MRI is superior to standard AP-LPR in detecting and classifying of MA-LSTV [5, 10]. Therefore, we hypothesize that the objective anatomic relationships between TP of MA-LSTV and sacrum might not be always distinguished accurately by AP-LPR.

Helical CT could provide multiplanar reconstructed CT images as desired and exhibit precise anatomic details [9]. Coronal reconstructed CT images (CT-CRIs) could provide detailed osseous anatomic structures for accurate Castellvi type identification. The present retrospective study is to verify the sensitivity and specificity of AP-LPR to detect and classify MA-LSTV types according to Castellvi Classification principal, using CT-CRIs at bone window from 256-slice helical CT machine as gold reference standard.

Methods

The Ethics Committee Approval was obtained from the sixth Medical Center of PLA General Hospital. The data of patients with low back pain who received AP-LPR in our hospital between June 2014 and June 2018 were extracted from the electronic database. All AP-LPRs were assessed regarding the presence of MA-LSTVs (II to IV types according to Castellvi Classification principle). The suspected MA-LSTVs judged by AP-LPRs were primarily enrolled. Among them, those who received helical CT (256-slice spiral CT, Philips,) scanning with CT-CRIs at lumbosacral region were formally enrolled into the formal study group.

Standard AP-LPRs were taken for all enrolled patients. The x-ray beam was positioned approximately 7 cm above the pubic symphysis. All images were obtained with digital radiograph (DR) equipment. For CT scanning, the individual lied on the examination bed on supine position with longitudinal spinal axis coincident with the machine's longitudinal axis. Then the patient was scanned by 256-slice spiral computed tomography from T12 to sacrum. Images were photographed in bone detail. Raw transaxial sectional CT images were then reconstructed by interpolation reconstruction method to get reconstructed CT images including sagittal and coronal images at bone window (window width: 2000, window level: 350). All images were reviewed and reconstructed at the terminal computer of picture archiving and communication system (PACS).

The finally enrolled cases were then classified into different types base on AP-LPRs and CT-CRIs respectively, according to Castellvi Classification Principle. All AP-LPRs and CT-CRIs were respectively reviewed to identify different types of MV-LSTVs by two experienced spine doctors independently. Six months later, in a second reading, the radiographs were reviewed in a random order by the same spine doctors. In the case of different opinions, two more doctors including one professor on spine research and one senior radiologist were collected together to draw the final conclusions.

The types of MA-LSTVs determined by CT-CRIs were used as gold criteria, and compared with the suspected types determined by AP-LPR to testify AP-LPR’s sensitivity in the classification of MA-LSTV types.

The orientation of each JLS side of MA-LSTV was observed at AP-LPR, oblique LPR and raw transaxial CT images to see whether orientation of JLS was parallel to horizontal line on coronal plane, to inferior endplate of MA-LSTV on oblique LPR, or to coronal line on transaxial plane.

Statistical analysis

Kappa statistics was used to assess the inter- and intra-observer differences for the classification of MA-LSTV types. The reliability of classification of MA-LSTV types by AP-LPR method comparing with the CT method was also assessed by Kappa statistics.

Kappa values greater than 0.75 are defined as excellent agreement, and values below 0.50 as poor agreement [11].

Results

2026 cases who received AP-LPR were collected from the database. Among them, 298 cases including 104 males and 94 females with an average age of 48.3 ± 7.6 yrs old ranging from 16 to 85 yrs were suspected to be MA-LSTV ones (Castellvi II to IV types) determined by AP- LPRs. The exposure settings for AP- LPRs were 80–90 kV and 20–30 mA. Among these 298 ones, 91 cases including 43 males and 48 females with an average age of 47.5 ± 17.8 yrs ranging from 17 to 85 yrs received CT-CRIs at lumbar region, and were enrolled in the final study. The exposure settings for CT scan were 100–140 kV and 100-180mAs, 2-mm slices were obtained with 1 mm reconstruction intervals. Among the 91 cases, 41 were associated with disc herniation, 9 with spondylolysis, 5 with degenerative spondylolisthesis, 7 with spondylolytic spondylolisthesis, and 4 with vertebral fractures.

Among these 91 finally enrolled cases, there were 7 cases of disagreements determined by AP-LPRs, and 1 case of disagreements determined by CT-CRIs on type classification between the two spine doctors. However, after discussion on these cases by all the four doctors, clear conclusions were made without different opinions. The inter-and intra-observer variations of the spine doctors by both AP-LPR and CT method was shown in Table 1. The mean Kappa coefficient ranges from 0.874 to 0.969, indicating excellent agreement for each method. All of the suspected MA-LSTV ones determined by AP-LPRs were verified to be real MA-LSTV ones by CT-CRIs.

Table 1
The inter-and intra-observer variation for classification of MA-LSTV types by both AP-LPR method and CT method

Reading	**Kappa (95% conf. limit)**	
	LPR	**CT**
First inter-observer variation	0.893(0.855–0.931)	0.921(0.887–0.955)
Second inter-observer variation	0.880(0.840–0.920)	0.874(0.832–0.916)
intra-observer variation of observer 1	0.955(0.929–0.981)	0.969(0.947–0.991)
intra-observer variation of observer 2	0.939(0.910–0.968)	0.952(0.925–0.979)

39,17,2,20 and 13 of the 91 ones were suspected to be type IIa, IIb, IIIa, IIIb and IV based on AP-LPRs, respectively. Taking CT-CRIs as gold criteria, all of the suspected type IIIa and IIIb MA-LSTV ones were verified to be unquestioned, while 9 of the 39 suspected IIa, 9 and 3 of the 17 suspected IIb, and 11 of the 13 suspected IV were verified to be real type IIIa, IIIb, IV and IIIb, respectively. The accuracy rates of classification of type IIa, IIb, IIIa, IIIb and IV MA-LSTV by AP-LPR were 76.9%, 29.4%,100%,100% and 15.4%, respectively. Generally, 32 ones were misclassified by AP-LPRs, the overall misclassified rate was 35.2% (Table 2). The Kappa values for agreement on the different types in MA-LSTV types classification system between the LPR and CT groups was 0.502(0.446–0.561) for the first reading, and 0.493(0.434–0.552) for the second reading, namely poor to moderate agreement.

Table 2
The MA-LSTV types suspected by AP-LPR and verified by CT-CRIs
(n = 91)

Types	suspected by AP LPRs	Confirmed by CT-CRIs				
		IIa	IIb	IIIa	IIIb	IV
IIa	39	30	0	9	0	0
IIb	17	0	5	0	9	3
IIIa	2	0	0	2	0	0
IIIb	20	0	0	0	20	0
IV	13	0	0	0	11	2

The 32 misclassified cases could be further divided into 41 misclassified sides (9, 21 and 11 sides in suspected type IIa, IIb and IV ones, respectively). All misclassified sides were verified to be type IIIa transitional side while misclassified as type IIa by AP-LPR. They were further divided into five situations.

1. Typical JLS was found in most CT-CRIs while BUS was found in only a few CT-CRIs at the connection region . This happened in 9 sides (Fig 1, left side).
2. Typical BUS was found in most CT-CRIs, while JLS appeared in only a few CT-CRIs. This happened in 8 sides (Fig 2, right side).
3. JLS and BUS was found simultaneously in most CT-CRIs, with or without the remnant of sclerotic band (RSB) . This was found in 8 sides (Fig2, left side).
4. In 3 true IIIb but suspected IV cases, the real type IIIa but suspected IIa side was narrower than its contralateral side at medial-to-lateral dimension with RSB (Fig3).
5. Thicken RSB made BUS region misinterpreted as JLS by AP-LPR. This happened in 13 sides (Fig4, left side).

According to the figures of our study, the JLS was not parallel to horizontal line on AP-LPR (Fig 5A), not parallel to inferior endplate of MA-LSTV on oblique LPR (Fig 5B), and not parallel to coronal plane on transaxial CT image (Fig 5C).

Discussion

LSTV was first regarded as a cause of low back pain by Bertolotti in 1917 [12]. Although there have been many studies on LSTV, a lot of misunderstandings about its anatomical characteristics existed. Some anatomical landmarks suggested previously for determining spinal counts and LSTV were verified unreliable [5, 13], while were still taken as criteria by some other studies [14, 15].

Castellvi Classification System was widely accepted for its simplicity. Prominent characteristics of each Castellvi type of MA-LSTV were initially extracted from Ferguson view of LPR [3]. Considering that radiographic image forms as a result of differing attenuation of the x-ray beam by various tissues within the patient, characteristics of concerned bony structures might be disturbed or covered by other surrounding structures. Recently, Farshad-Amacker et al reported that coronal MRI is superior to standard AP-LPR in detecting and classifying of MA-LSTV [10]. However, MRI is inferior in detecting bony details compared with CT-CRIs. Moreover, coronal MRI is not routinely taken in routine clinical practice.

In our series, we found all suspected MA-LSTVs diagnosed by AP-LPR were verified to be true MA-LSTVs by CT-CRIs, however, AP-LPR could not classify MA-LSTV types with 100% accuracy. Type IIIb MA-LSTV might be wrongly classified as type IV or IIb, while type IV and IIIa wrongly classified as type IIb and IIa respectively. The agreement of classification between LPR and CT groups was poor to moderate according to the statistical analysis.

What caused such misclassification? The following were our analysis.

1. BUS might not occupy the full space between the anomalous TP and sacrum at the type III transitional side.
According to Castellvi classification principle, if continuous bone bridge forms between the TP of MA-LSTV and sacrum, the anomalous side belongs to a type III transition. One might take it for granted that bone bridge formation means that all space between the TP and sacrum should be fully occupied by continuous bone with disappearance of RSB. In reality, such condition really exists (Fig. 3, left side). But this only occurred in 48.8% (39/80) of type III sides in our series, other situations might also exist. For example, only limited percent of the space might reach bony fusion while the remnant was occupied by JLS, under such condition, the abnormal side was a type III transition, but there was a high possibility that the side was misinterpreted as a type II side by AP-LPR. This could be further divided into 3 subcategories: (1) BUS only occupied limited region while JLS occupied most region (Fig. 1, left side); (2) BUS occupied most region while JLS occupied limited region (Fig. 2, right side); (3) JLS and BUS shared almost equal space (Fig. 2, left side). These situations occurred in 31.3% (25/80) type III transitional sides, and occupied 61.0% (25/41) of all misclassified sides.
2. Existence of RSB might lead a type III transitional side misdiagnosed as type II transition side on AP-LPR.
In some cases, complete fusion between TP from MA-LSTV and sacrum had reached, while irregular RSB at the inferior boundary of TP from MA-LSTV and/or that at the superior boundary of sacrum still existed. This might form a false image of anomalous articulation on AP-LPR, resulting in a type IIIa transition being misdiagnosed as a type IIa transition (Fig. 3–4). If discrepancy of width at the connection space existed at bilateral sides in a type IIIb case, there was a higher possibility that the narrower side with RSB was misdiagnosed as a type II transition. These situations occurred in 20.0% (16/80) of type III sides and occupied 39.0% (16/41) misdiagnosed sides.
3. There might exist a progressive transformation process from type II transition to type III transition.

In our series, we found type Ⅲ transitional side in many cases was consisted of both JLS and BUS at connection space instead of only occupied by BUS, the former occurred in 31.3%(25/80) of all type Ⅲ sides, verified by CT-CRIs, while the distribution area or percentage of JLS or BUS varied in different cases. In the remaining 55 sides, 16 were found existing RSB, this further occupied 19.8% (16/80) of type Ⅲ transitional sides. Previously, we had taken it for granted that there only existed two clear categories at the space between abnormal TP of MA-LSTV and sacrum: one situation was that all space was replaced by continuous bone connection with complete disappearance of RSB, another was that all space was replaced by abnormal articulation structure. No transitional process existed between these two definite categories. When the reality revealed there existed the above-mentioned situations, that is, both JLS and BUS co-existed at the connection space to different distribution, or RSB left at the connection region, we hypothesized boldly that type Ⅱa transitional side might develop into type Ⅲa transitional side under some special conditions. Initially, one type Ⅱ transitional side might develop to the stage that bony connection developed only at limited region. Gradually, more JLS was replaced by bony bridge, till all connection space was replaced by bony bridge but with RSB remaining. At final stage, RSB disappeared with complete rigid bony connection. Recently, Hou et al reported one case who developed type Ⅲa MA-LSTV from type Ⅱa following discectomy and fusion at lumbosacral level [16]. This phenomenon partially supported our hypothesis. However, to verify this assumption, further follow-up on MA-LSTV with CT examination was needed. Also, if the hypothesis was true, the type of MA-LSTV should not be thought as congenital, but acquired, at least in some cases.

4. AP view instead of Ferguson view LPR was used for MA-LSTV type classification.

In Castellvi's original literature, 30°angled AP view (Ferguson view) of lumbar spine was regarded as true AP of lumbosacral joint, which could reach the purpose of removing the radiographic overlap of abnormal TP from MA-LSTV on sacrum [3,4,10]. This viewpoint might be based on the following assumptions: (1) 30° angled AP view of lumbar spine indeed was the true AP of lumbosacral joint; (2) coronal plane of abnormal TP form MA-LSTV was perpendicular to inferior endplate of MA-LSTV; (3) inferior edge of abnormal TP from MA-LSTV was parallel to inferior endplate of MA-LSTV; (4) the cleft between TP of MA-LSTV was parallel to coronal plane observed from transaxial view. However, Ferguson view is not routinely taken as the standard radiographic assessment of lumbar spine in clinical practice. As a retrospective study, we took AP view instead of Ferguson view LPR for MA-LSTV type classification. This might result in more misclassifications. However, according our image data, we found the orientation of JLS is irregular, neither parallel to horizontal plane on AP view, nor to coronal plane on transaxial view, nor to endplate on oblique view (Fig. 5), which was theoretically impossible to offset by Ferguson view LPR. A recent study indicated that Ferguson view had no superiority over the standard AP pelvis view for grading of sacroiliitis [17]. Further study might be needed to compare the AP view with the Ferguson view of the LPR in order to resolve whether one modality has a clear advantage for classification of MA-LSTV types.

Previously, conclusions of relationship between various MA-LSTV types and their clinical significance were based on suspected MA-LSTV classification identified by LPRs, which might be questionable. The real relationship should be re-evaluated based on real MA-LSTV types identified by CT-CRIs.

Conclusion

LPR was not reliable to identify MA-LSTV types according to Castellvi classification principle. CT-CRIs could detect anatomic details at the connection region between anomalous TP and sacrum, thus give reliable LSTV type identification. Future studies on the relationship between MA-LSTV types and their clinical significance should take CT-CRI as a gold standard in MA-LSTV's classification.

Abbreviations

LPR: Lumbar plain radiograph; AP-LPR: Anteroposterior view of lumbar plain radiograph; LSTV: Lumbosacral transitional vertebra; MA-LSTV: Lumbosacral transitional vertebra with morphological abnormality; NV-LSTV: Lumbosacral transitional vertebra with numerical variance; CT-CRIs: Coronal reconstructed CT images; JLS: Joint-like structure; BUS: Bony union structure; RSB: Remnants of sclerotic band; TP: Transverse process; IAIE: inclination angle of inferior endplate

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee of the sixth Medical Center of PLA General Hospital. All patients provided written informed consent prior to their inclusion in this study.

Consent for publication

Not applicable.

Availability of data and materials

Data will be available upon request by the first and correspondence author Lisheng Hou.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors ' contributions

LH and XB designed the study and wrote the manuscript. HL, TG, WL, TW, QH, DR, LS, and BW participated in the data collection, analysis, and interpretation. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

References

1. 1Khashoggi KG, Hafiz RM, Bock YM, Kaki AM (2017) Determination of lumbosacral transitional vertebrae in kidney urinary bladder x-ray films in the Saudi population. Saudi Med J 38(8): 794-7972
2. Sekharappa V, Amritanand R, Krishnan V, David KS (2014) Lumbosacral transition vertebra: prevalence and its significance. Asian Spine J 8(1):51-58
3. Castellvi AE, Goldstein LA, Chan DP (1984) Lumbosacral transitional vertebrae and their relationship with lumbar extradural Defects.Spine (Phila Pa 1976) 9(5):493-495
4. Tins BJ, Balain B (2016) Incidence of numerical variants and transitional lumbosacral vertebrae on whole-spine MRI. Insights Imaging 7(2):199-2035
5. Hanson EH, Mishra RK, Chang DS, Perkins TG, Bonifield DR, Tandy RD, Cartwright PE, Peoples RR, Orrison WW Jr (2010) Sagittal whole-spine magnetic resonance imaging in 750 consecutive outpatients: accurate determination of the number of lumbar vertebral bodies. J Neurosurg Spine 12(1): 47-556
6. Hu Z, Zhang Z, Zhao Z, Zhu Z, Liu Z, Qiu Y (2016) A neglected point in surgical treatment of adolescent idiopathic scoliosis: Variations in the number of vertebrae. Medicine (Baltimore) 95(34):e46827
7. Paik NC, Lim CS, Jang HS (2013) Numeric and morphological verification of lumbosacral segments in 8280 consecutive patients. Spine (Phila Pa 1976) 38(10):E573- E5788Sadozai Z, Davies R, Warner J (2016) The sensitivity of ct scans in diagnosing occult femoral neck fractures. Injury 47(12):2769-2771
8. Pai VS, Hodgson B (2006) Assessment of bony union following surgical stabilisation for lumbar spondylolysis: a comparative study between radiography and computed tomography. J Orthop Surg (Hong Kong) 14(1):17-20
9. Farshad-Amacker NA, Lurie B, Herzog RJ, Farshad M (2014) Interreader and intermodality reliability of standard anteroposterior radiograph and magnetic resonance imaging in detection and classification of lumbosacral transitional vertebra.Spine J 14(8):1470-1475
10. Thomsen N. O. B, Jensen C. M, Skovgaard N, Pedersen M. S, Pallesen P, Soe-Nielsen N. H., A. Rosenklint (1996) Observer variation in the radiographic classification of fractures of the neck of the femur using Garden’s system. International Orthopaedics (SICOT) 20: 326 – 329
11. Usmani S, Ahmed N, Marafi F, Al Kandari F (2017) Bertolotti Syndrome Demonstrated on 18F-NaF PET/CT. Clin Nucl Med 42(6):480-482
12. 13Tokgoz N, Ucar M, Erdogan AB, Kilic K, Ozcan C (2014) Are spinal or paraspinal anatomic markers helpful for vertebral numbering and diagnosing lumbosacral transitional vertebrae? Korean J Radiol 15(2):258-266
13. Farshad-Amacker NA, Aichmair A, Herzog RJ, Farshad M (2015) Merits of different anatomical landmarks for correct numbering of the lumbar vertebrae in lumbosacral transitional anomalies. Eur Spine J 24(3): 600-608

14. Bron JL, van Royen BJ, Wuisman PI (2007) The clinical significance of lumbosacral transitional anomalies. Acta Orthop Belg 73(6):687-695
15. Hou L, Bai X, Li H, Cheng S, Wen T, He Q, Ruan D (2018)"Acquired" type Castellvi-IIIa lumbarization transformed from Castellvi-IIa following discectomy and fusion at lumbosacral level, a case report.Spine (Phila Pa 1976) 43(22):E1364-E1367
16. Omar A, Sari I, Bedaiwi M, Salonen D, Haroon N, Inman RD (2017) Analysis of dedicated sacroiliac views to improve reliability of conventional pelvic radiographs. Rheumatology (Oxford) 56(10):1740-1745

Figures

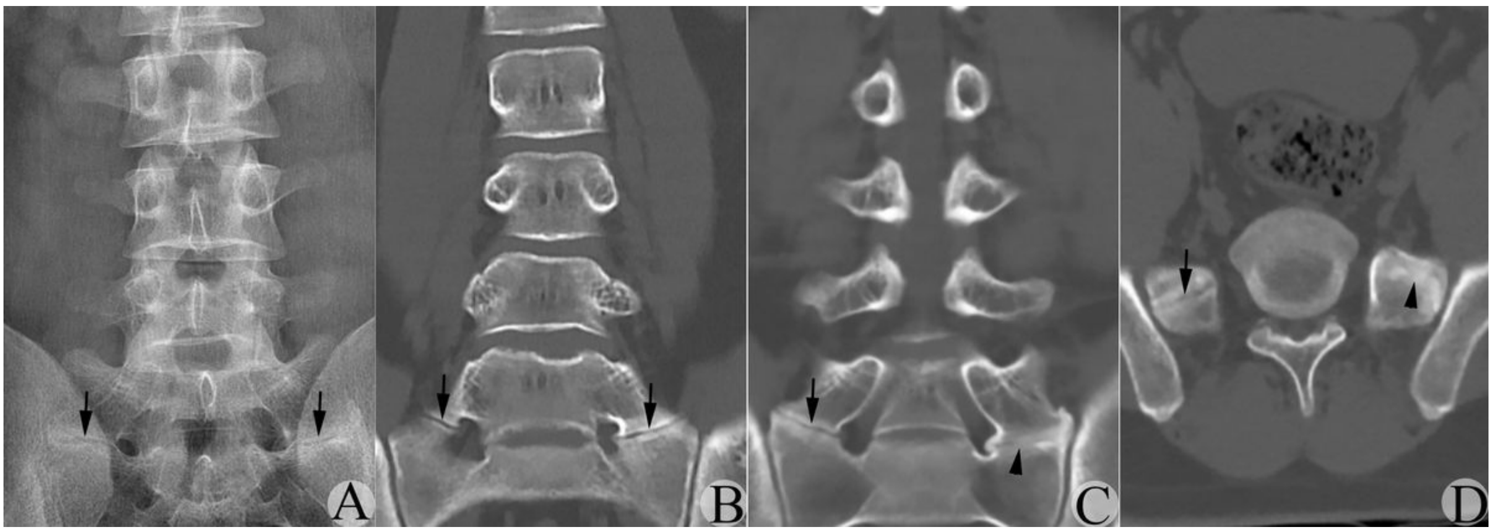

Figure 1

A suspected type IIb MA-LSTV judged by AP-LPR was verified to be type IV by CT-CRIs. A: AP-LPR image, showing suspected JLS between transverse process (TP) of MA-LSTV and sacrum bilaterally. Arrow indicates the suspected JLS. B: CT-CRI, showing JLS was found in most CT-CRIs bilaterally. Arrow indicates the JLS. C: CT-CRI, showing detected BUS at left side in only a few CT-CRIs through the posterior vertebral body. Arrow indicates the JLS, arrow head indicates the BUS. D: Transverse CT image verified JLS at the right side while BUS at the left side. Arrow indicates JLS, arrow head indicates BUS.

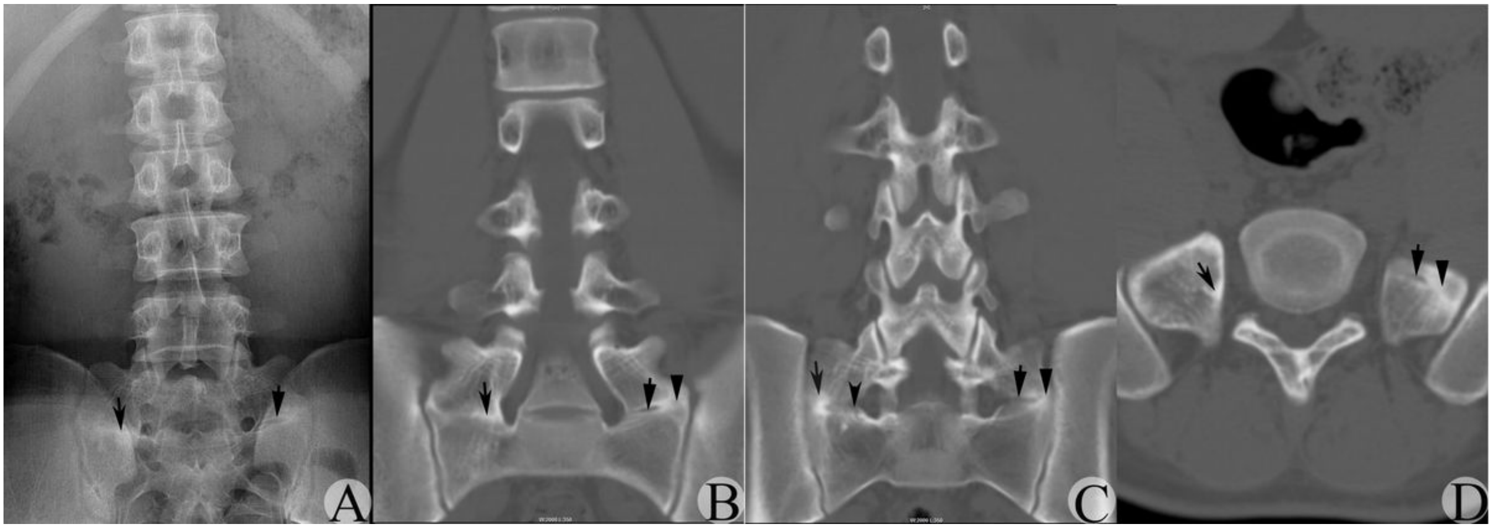

Figure 2

A suspected type IIb MA-LSTV judged by AP-LPR was verified to be type IIIb by CT-CRIs. A: AP-LPR image, showing suspected JLS existed bilaterally, and suspected JLS at right side was narrower than that at left side in craniocaudal direction. Arrow indicates the suspected JLS at left side, concave arrow indicates suspected JLS at right side. B : CT-CRI, showing BUS was found in most CT-CRIs while vague remnants of sclerotic band (RSB) reserved at medial region at right side, meanwhile, intermittent JLS and BUS appeared simultaneously at left side. Arrow, arrow head and concave arrow indicates JLS, BUS with remnants of sclerotic band at left side, and BUS with RSB at right side, respectively. C: CT-CRI, showing detected JLS at the medial region in a few planes at right side, intermittent JLS and BUS appearing simultaneously at each plane at left side.Arrow, arrow head, concave arrow and concave arrow head indicates JLS, BUS at left side, BUS and JLS at right side, respectively. D: transverse CT image confirmed JLS and BUS appeared in the same plane at left side, BUS with RSB at right side . Arrow, arrow head and concave arrow indicates JLS, BUS at left side, and BUS with RSB at right side, respectively.

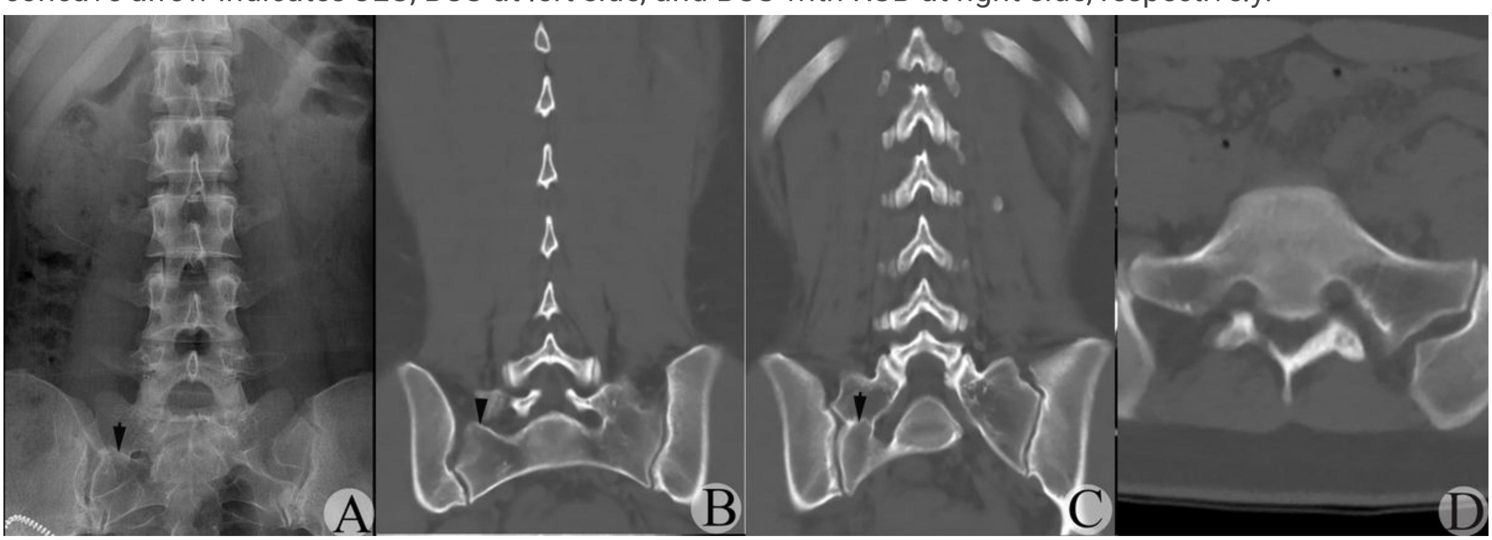

Figure 3

A suspected type IV MA-LSTV judged by AP-LPR was verified to be type IIIb by CT-CRIs. A: AP-LPR image, showing suspected JLS existed at the right side with narrowed connection width and RSB. Arrow indicates the suspected JLS.B: CT-CRI, showing right TP of MA-LSTV separated from sacrum in some CT-CRIs through the vertebral arch planes. Arrow head indicates JLS with vague RSBs at the right side. C: CT-CRI, showing BUS at the right side with RSB. Arrow indicates BUS with RSB. D: transverse CT image confirmed bony connection bilaterally, while the connection region was much narrower and shorter at the right side than that at the left side.

Figure 4

A suspected type IIa MA-LSTV judged by AP-LPR was verified to be type IIIa by CT-CRIs. A:AP-LPR image, showing suspected JLS at left side. Arrow indicates the suspected JLS. B: CT-CRI through vertebral body planes, showing the suspected JLS to be RSB located at bony fusion region. Arrow indicates BUS with RSB.C:CT-CRI through vertebral arch, showing the suspected JLS to be RSB located at bony fusion region, no JLS was detected. Arrow indicates BUS with RSB. D:transverse CT image, showing BUS with RSB at left side. Arrow indicates BUS with RSB at left side.

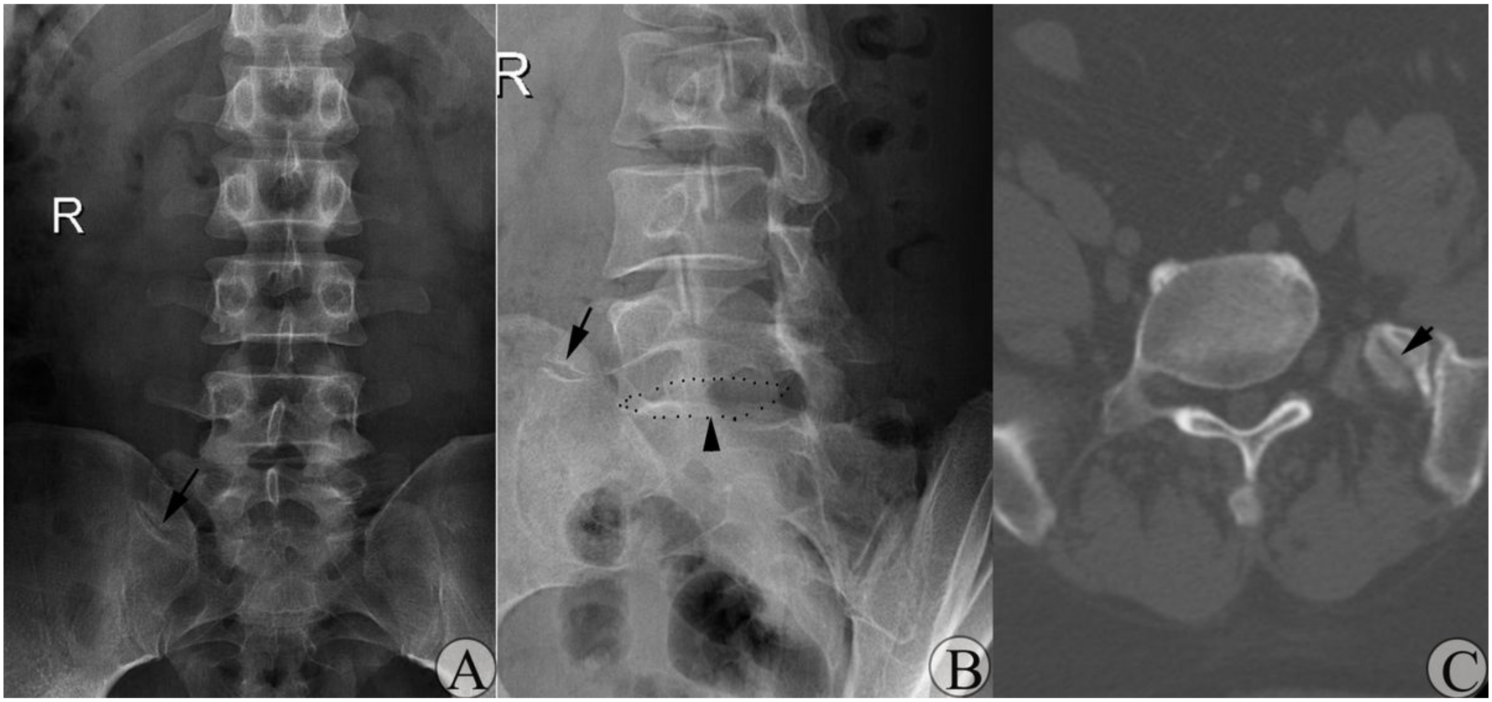

Figure 5

Variance of JLS' orientation seen at type IIa MA-LSTV individuals. A: AP-LPR image, showing that orientation of JLS pointed upward when moving laterally instead of parallel to horizontal line. Arrow indicates the JLS. B: oblique LPR, showing orientation of JBS was not parallel to the inferior endplate of MA-LSTV. Arrow indicates the JBS. Arrow head indicates the inferior endplate of MA-LSTV. C: transaxial CT imges, showing orientation of JBS was not parallel to coronal plane . Arrow indicates the JLS.