Clinical Anatomy 20:905–914 (2007)

ORIGINAL COMMUNICATION

Identification and Prediction of Transitional Vertebrae on Imaging Studies: Anatomical Significance of Paraspinal Structures

CHANG HEE LEE,[1] CHEOL MIN PARK,[1]* KYEONG AH KIM,[1] SUK JOO HONG,[1] HAE YOUNG SEOL,[1] BAEK HYUN KIM,[2] AND JUNG HYUK KIM[3]

[1]*Department of Radiology, Korea University College of Medicine, Guro Hospital, Guro-Ku, Seoul, South Korea*
[2]*Department of Radiology, Korea University College of Medicine, Ansan Hospital, Ansan City, Kyungki-Do, South Korea*
[3]*Department of Radiology, Korea University College of Medicine, Anam Hospital, Sungbuk-Ku, Seoul, South Korea*

The aim of our study was to examine the locational distribution of paraspinal structures on MRI and to determine any predictable parameters that may be used for the identification of transitional vertebra (TV). We enrolled 534 patients who underwent MRI of their lumbosacral spine. The locations of the paraspinal structures, such as aortic bifurcation (AB), IVC confluence (IC), right renal artery (RRA), celiac trunk (CT), SMA root (SR), and iliolumbar ligament (ILL), were determined using ''cross link'' in PACS. We also assessed the morphology of the TV. The MRI showed that the most common site of the paraspinal structures in the normal group was AB at the lower L4, IC at the L4-5 disc space, RRA at the L1-2 disc space, CT at the T12-L1 disc space, SR at the upper L1, and ILL at the L5. The frequency of TV was 23.8% (lumbarization, 9.9%; sacralization, 13.9%). The paraspinal structures of the S1 lumbarization were positioned more toward the caudal location, whereas the paraspinal structures of the L5 sacralization were positioned more toward the cephalic location ($P < 0.01$). In conclusion, AB, IC, RRA, CT, SR, and ILL are useful landmarks for predicting the presence of TV on MRI. TV is possible when these paraspinal structures are in positions outside of the frequent locations. Clin. Anat. 20:905–914, 2007.

Key words: anatomy; anomaly; MRI; spine; vertebra

INTRODUCTION

A transitional vertebra (TV) is a common congenital anomaly in the lumbosacral area. Precise localization of the vertebral segment on lumbosacral images is important (Tini et al., 1977; Castellvi et al., 1984; Williams et al., 1989a; Hahn et al., 1992; Lee et al., 2004). In lumbar magnetic resonance imaging (MRI), radiologists usually determine the level of the lumbar vertebra from the vertebral body morphology, the lumbosacral angle on a sagittal view, and the configuration of the intervertebral discs (MacGibbon and Farfan, 1979; Nicholson et al., 1988).

However, inaccurate results occur frequently when the location is only determined from a lumbar radiograph or when MRI is used alone. The reason for such results in most cases is due to the presence of an accompanying TV. Moreover, surgery could be performed on areas other than those intended because the localization of the condition could be potentially flawed (Tini et al., 1977; Hahn et al.,

*Correspondence to: C.M. Park, Department of Radiology, Korea University College of Medicine, Guro Hospital, No. 80 Guro-Dong, Guro-Ku, Seoul 152-703, South Korea. E-mail: radpic@hanmail.net

Received 4 February 2007; Revised 10 July 2007; Accepted 5 August 2007

Published online 18 September 2007 in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/ca.20540

1992; Malanga and Cooke, 2004). For a TV of the lumbosacral area, an anatomically S1 vertebra that appears morphologically as an L5 vertebra is referred to as lumbarization. In contrast, an L5 vertebra that appears as an S1 vertebra is referred to as sacralization (Tini et al., 1977; Castellvi et al., 1984; Williams et al., 1989a; Hahn et al., 1992; Lee et al., 2004).

The incidence of TV has been reported to range from 3 to 21% (Tini et al., 1977; Hahn et al., 1992; Lee et al., 2004). Despite the fact that TV has a pattern that is manifested relatively frequently, not many reports have been produced on the anatomical characteristics of TV nor have predictive markers been determined by various imaging studies. Therefore, our study was designed to evaluate the locational distribution of the paraspinal structures that are located in a relatively constant area and to investigate any predictable parameters for TV.

MATERIALS AND METHODS

Patient Population

The study was approved by our medical ethics committee. Informed consent for the review of patient records and images was not a prerequisite for the approval and was not obtained. Among the patients who underwent lumbar MRI at our hospital during a 6-month period, we excluded cases with inadequate images, spinal deformities, vertebral anomalies (Klippel-Feil syndrome), vertebral compression fractures, vascular anomalies, and extremely tortuous aorta that may distort the paraspinal structure. We obtained lumbar radiographs from a total of 534 cases. The mean age of the study subjects was 44.5 years (18–66 years) and the male to female ratio was 263:271.

Machines

Thorax radiographs as well as lumbar radiographs were obtained from all the study subjects. The MRI was performed using a 1.5 T (Tesla) machine (Sonata, Siemens, Germany). The MRI sequences that were performed on all the patients were sagittal T1-weighted, axial T1-weighted, coronal T2-weighted, sagittal T2-weighted, and axial T2-weighted fast spin-echo imaging as well as T2-weighted Cervico-Thoracic sagittal localizer imaging. The T1 weighted image (WI) was approached with a short TR and TE compared with the long TR and TE of the T2 WI.

Vertebrae Numbering

To accurately determine the location of the vertebral body on MRI, the C1 vertebra must be counted. Therefore, we obtained cervico-thoracic sagittal localizer images (C-T localizer) from the C1 to T12 vertebrae in addition to the conventional lumbar MRI. We used an oil capsule as a skin marker at the level of the lower thoracic spine by palpating the xiphoid process located between T10 and T11. The number of cervical, thoracic, and lumbar vertebrae was 7, 12, and 5, respectively. Using the C-T localizer, we counted the vertebral body from C1 to the oil capsule area and the vertebral body level from the oil capsule area to S1 on the lumbar sagittal images.

Determining the Locational Distribution of the Paraspinal Structures on MRI

After the vertebrae were numbered, we examined the location of the paraspinal structures. The paraspinal structures including the aortic bifurcation (AB), inferior vena cava confluence (IC), proximal right renal artery (RRA), celiac trunk (CT), SMA root (SR), and iliolumbar ligament (ILL) were detected in a constant area. We used the following method to determine the location of the paraspinal structures. The site of the AB was defined as the point wherein both common iliac arteries were seen on an axial T2-weighted image (WI) as complete independent circles in addition to a fat signal between the two arteries. AB was evaluated using the ''cross-link function'' of the PACS (picture archiving and communication system) to determine the relationships among the sagittal, axial, and coronal images (Figs. 1, 2A, and 3A). The IC was difficult to determine accurately as a point on the MRI and therefore was defined as the area where the left common iliac vein was detected in the space between both common iliac arteries on an axial T2 WI (Figs. 2B and 3B). The location was also determined using the PACS cross-link function. The RRA was defined as the area that is a small round signal void on a sagittal T1 and T2 WI between the IVC and aorta. The location of the RRA was determined by drawing a vertical line from the signal void to the adjacent vertebral body (Figs. 2D and 3D). The locations of the CT and the SR were determined on a sagittal T1 and T2 WI by drawing a vertical line to the vertebral body that was adjacent to the site of their origin (Figs. 2E and 3E). The ILL is the structure that connects the transverse process of the lumbar vertebra and the ilium. This ligament was assessed on an axial T1, axial T2, and coronal T2 WI. The location of the ILL was determined using the cross-link function (Figs. 2F and 3F).

On the basis of the assumption that the height of the disc is comparable to half of the vertebral body height, we divided the location of the above-mentioned paraspinal structures into the upper vertebral body, the lower vertebral body, and the disc space. For the statistical analysis, we defined the T11/T12 disc space as 0 and the L5/ S1 disc space as 18. For example, the upper half of the L1 was defined as 4. On a sagittal image, the L5 vertebra usually has a rectangular shape and the S1 vertebra exhibits a rhombus shape. However, if the TV was accompanied, the morphology of the L5 may be seen as a rhombus shape or the shape of the S1 is seen as a rectangle, which may cause confusion when determining the vertebral location. Therefore, to examine the morphology of L5 and S1, we assessed the ratio of the endplates (ER) by measuring the length of the upper and lower endplate of each vertebral body and we defined the ratio as the value of the inferior endplate length divided by the length of the superior endplate of each vertebral body.

Transitional Vertebra: Anatomical Significance and Localization of the Paraspinal Structure

We examined the incidence of TV in the 534 patients. We classified lumbarization in the TV cases when the shape of the S1 was similar to L5. In contrast, we classified sacralization of the L5 in the TV cases when the shape of the L5 was difficult to distinguish from the S1.

Fig. 1. Determination of paraspinal structures on MRI. Aortic bifurcation: Using the ''cross link'' function on the PACS program, both of the common iliac arteries are completely separated at the upper half of the L5 as the point of aortic bifurcation (arrow).

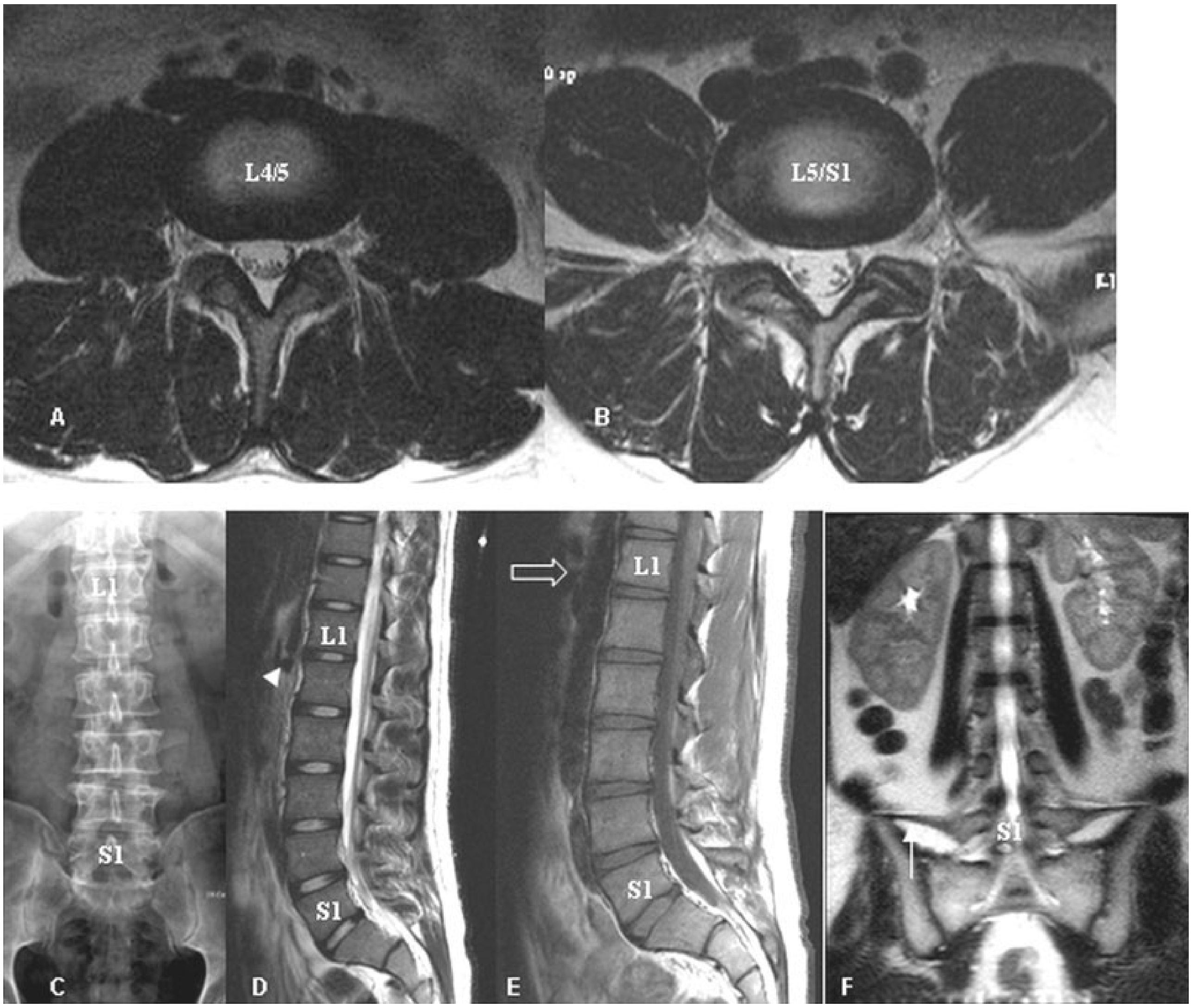

Fig. 2. Forty-eight-year-old man with S1 lumbarization. Note that the paraspinal structures are located more caudally than normal. **A:** Axial T2 WI shows aortic bifurcation at the level of the L4-5 disc space. **B:** Axial T2 WI shows IVC confluence at the level of the L5-S1 disc space. **C:** In the lumbar AP radiograph, the S1 vertebra shows complete lumbarization. **D:** Sagittal T2 WI shows the proximal right renal artery (arrow head) at the upper half of the L2. **E:** Sagittal T1 WI shows the celiac trunk at the upper half of the L1 and the root of SMA (open arrow) at the lower half of the L1. **F:** Coronal T2 WI shows the iliolumbar ligament (arrow) from transverse process of the S1. When the vertebral segment is counted using the L5 morphological standard, the paraspinal structures are located at a higher place than normal.

We also divided lumbarization into the following three types of classification (Fig. 4): (1) Complete lumbarization, in which both transverse processes of the S1 did not form a joint with the transverse process of the S2 and appeared to be separated; (2) Incomplete lumbarization, in which both transverse processes of the S1 formed a pseudoarthrosis with the transverse process of the S2, or only one side formed a pseudoarthrosis and the other side showed normal fusion; and (3) Mixed lumbarization, in which one side was a complete type and the other was incomplete or normal.

In addition, we classified three types of sacralization (Fig. 5): (1) Complete sacralization, in which both transverse processes of the L5 were completely fused with the transverse process of the S1; (2) Incomplete sacralization, in which both transverse processes of the L5 formed a pseudoarthrosis with the transverse process of the S1, or one side formed a pseudoarthrosis and the other side showed normal separation; and (3) Mixed sacralization, in which one side was a complete type and the other was incomplete or normal.

We examined the incidence of each type of lumbarization and sacralization according to the earlier classifications. For each classification, we also examined the anatomical location and distribution of the paraspinal structures on the MRI. We included the dysplastic transverse process, which is frequently known as one particular type of TV, as the normal group for this study.

On the basis of these findings, we analyzed the differences in the locational distribution of the paraspinal structures

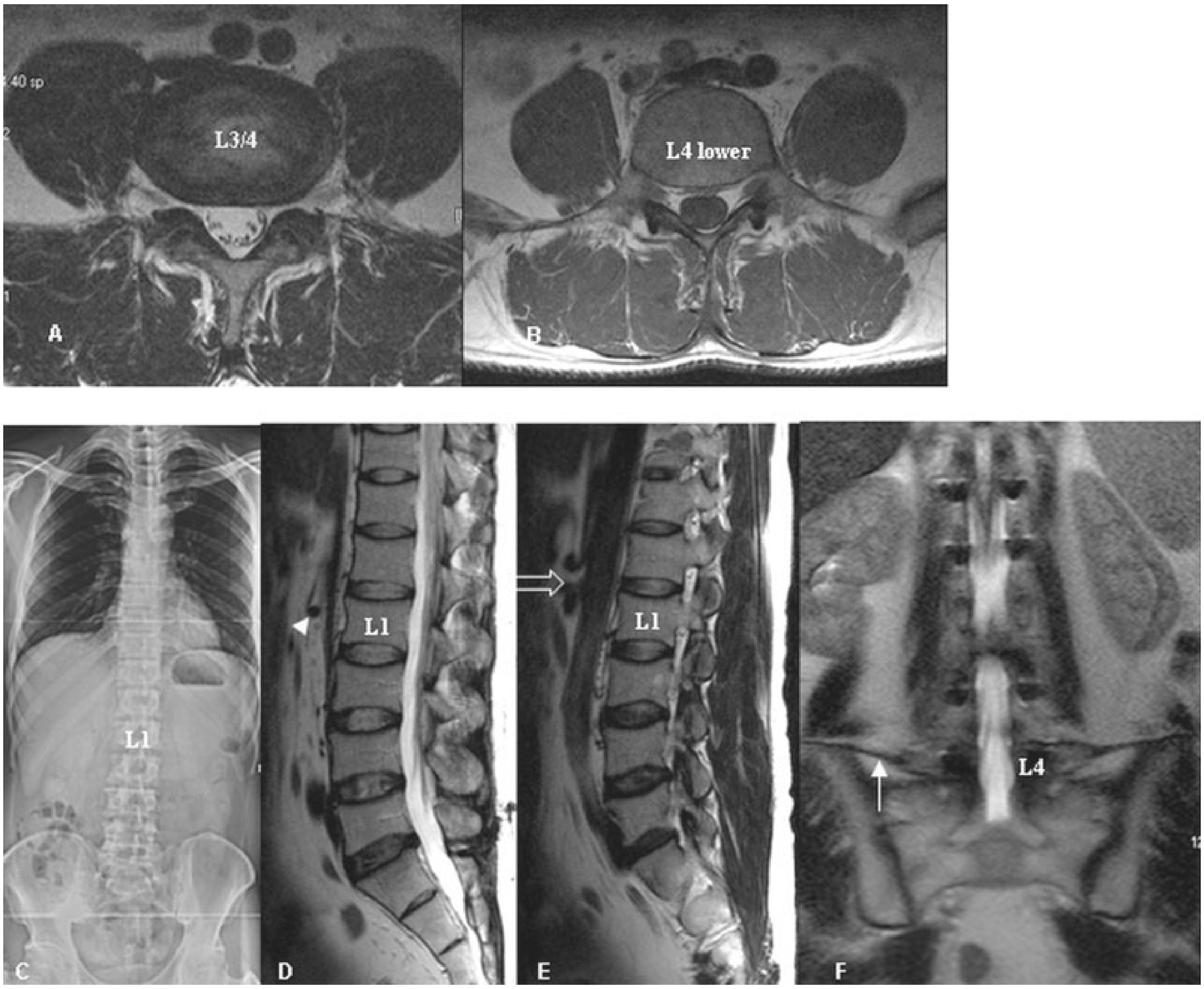

Fig. 3. Thirty-nine-year-old man with L5 sacralization. Note that the paraspinal structures are positioned more cephalad than normal. **A:** Axial T2 WI shows the aortic bifurcation at the level of the L3-4 disc space. **B:** Axial T1 WI reveals IVC confluence at the lower half of L4. **C:** In the lumbar AP radiograph, the L5 vertebra shows the complete type of sacralization. The 12th rib is also absent. **D:** Sagittal T2 WI shows the proximal right renal artery (arrow head) at the upper half of the L1 vertebra. **E:** Sagittal T2 WI reveals the celiac trunk at the lower half of the T12 and the root of the SMA (open arrow) at the T12-L1 disc space. **F:** Coronal T2 WI demonstrates an iliolumbar ligament (arrow) from the transverse process of the L4. When the vertebral segment is counted using the L5 morphological standard, the paraspinal structures are located at a lower place than normal.

that were determined from the normal, lumbarization, and sacralization groups, and we also classified the TV based on the findings generated by the plain radiographs and MRI. Furthermore, we evaluated the parameters that allowed the TV to be predicted.

Data and Statistical Analysis

For analysis, we divided the 534 patients into normal, lumbarization, and sacralization groups and statistically analyzed the average values for AB, IC, RRA, CT, SR, ER of L5, and ER of the S1 using one-way ANOVAs with the Tukey method. We performed frequency analysis for the ILL measurements on the MRI that did not have a normal distribution. For the subdivision of the lumbarization group, we performed multiple comparisons of the paraspinal structures. However, for the sacralization group, we combined the mixed type with the incomplete type due to the small number of mixed-type cases (n = 5 mixed-type cases). Consequently, we divided the sacralization group into complete group and incomplete group and compared their mean values (t test). We considered P values <0.05 to be statistically significant.

RESULTS

Incidence of Transitional Vertebra

Among the 534 subjects, we determined that 407 cases were in the normal group and 127 cases (23.8%) were in

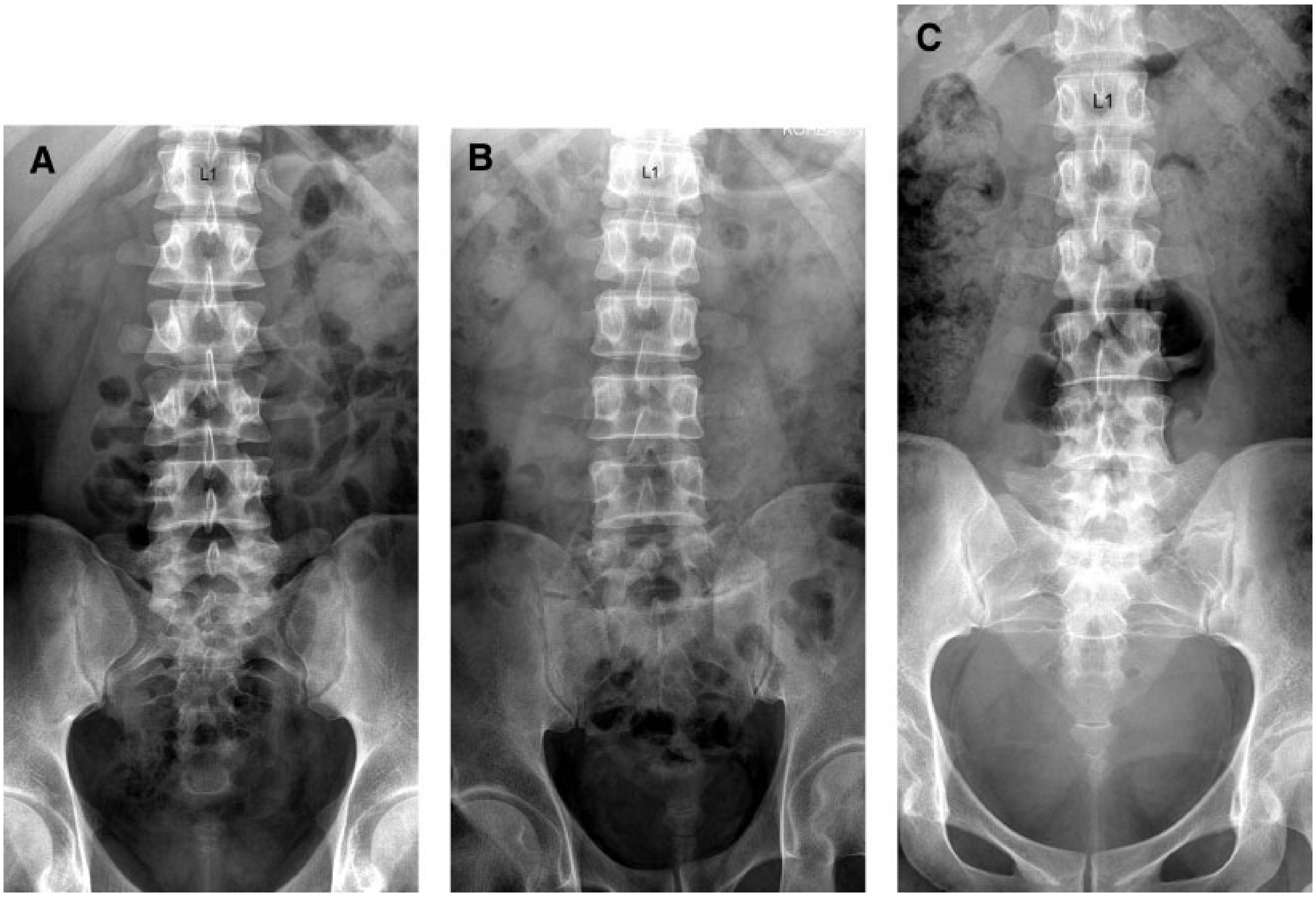

Fig. 4. Type of lumbarization. **A:** Complete lumbarization. Lumbar AP radiograph shows a completely separated transverse process of the S1 vertebra. The accessory of a 13th rib is also revealed. **B:** Incomplete lumbarization. Lumbar AP radiograph reveals bilateral pseudoarthrosis of the enlarged S1 transverse process with the S2 vertebra. **C:** Mixed type. The right transverse process of the S1 is the complete type, but the left side is the incomplete type.

the TV group. Among the 127 cases in the TV group, we observed lumbarization and sacralization in 53 (9.9%) and 74 (13.9%) of the cases, respectively. Among the 53 cases showing S1 lumbarization, we observed the complete, incomplete, and mixed types in 24 (45.3%), 14 (26.4%), and 15 (28.3%) cases, respectively. Among the 74 cases that had L5 sacralization, we observed the complete, incomplete, and mixed types in 24 (45.3%), 44 (59.5%), and 5 (6.8%) of the cases, respectively. We also found 153 (37.8%) subjects with dysplastic transverse processes that were higher than 19 mm, a condition that was previously defined as a classifier for TV.

Locational Distribution of the Paraspinal Structures

The AB point was most prevalent at the lower half of L4 (167 cases, 41.2%) in the normal group (Table 1). In most cases (94.8%), the AB was concentrated on the area between the upper half of the L4 and the L4/L5 disc space. In the lumbarization group (Table 2), the AB was most prevalent in the L4/5 disc space, which was one level lower than that in the normal group (41.5%) and was concentrated in the area between the L4/5 disc space and the lower half of L5 in most cases (88.7%). In the sacralization group (Table 3), we found that the AB was primarily in the upper half of the L4, which was one level higher than that in the normal group (33.8%) and was distributed in the area between the L3/4 disc space and the lower half of the L4 in a substantial number of cases (91.8%). A statistically significant difference was detected within and between the three groups ($P < 0.01$).

The inferior vena cava confluence (IC) was most prevalent at the L4/L5 disc space (37.5%) in the normal group (Table 1) and was concentrated in the area between the lower half of the L4 and the upper half of the L5 in most cases (95.5%). In almost all the cases, we detected the IC in the area approximately one level lower than AB. In the lumbarization group (Table 2), the IC was most prevalent in the upper half of the L5 (43.4%) and was concentrated in the area between the upper half of the L5 and the lower half of the L5 in most cases (83%). In the sacralization group (Table 3), the IC was most prevalent in the lower half of the L4 (39.2%) and was distributed in the area between the upper half of the L4 and the L4/5 disc space in a substantial number of cases (85.2%). We detected a statistically significant difference within and between the three groups ($P < 0.01$).

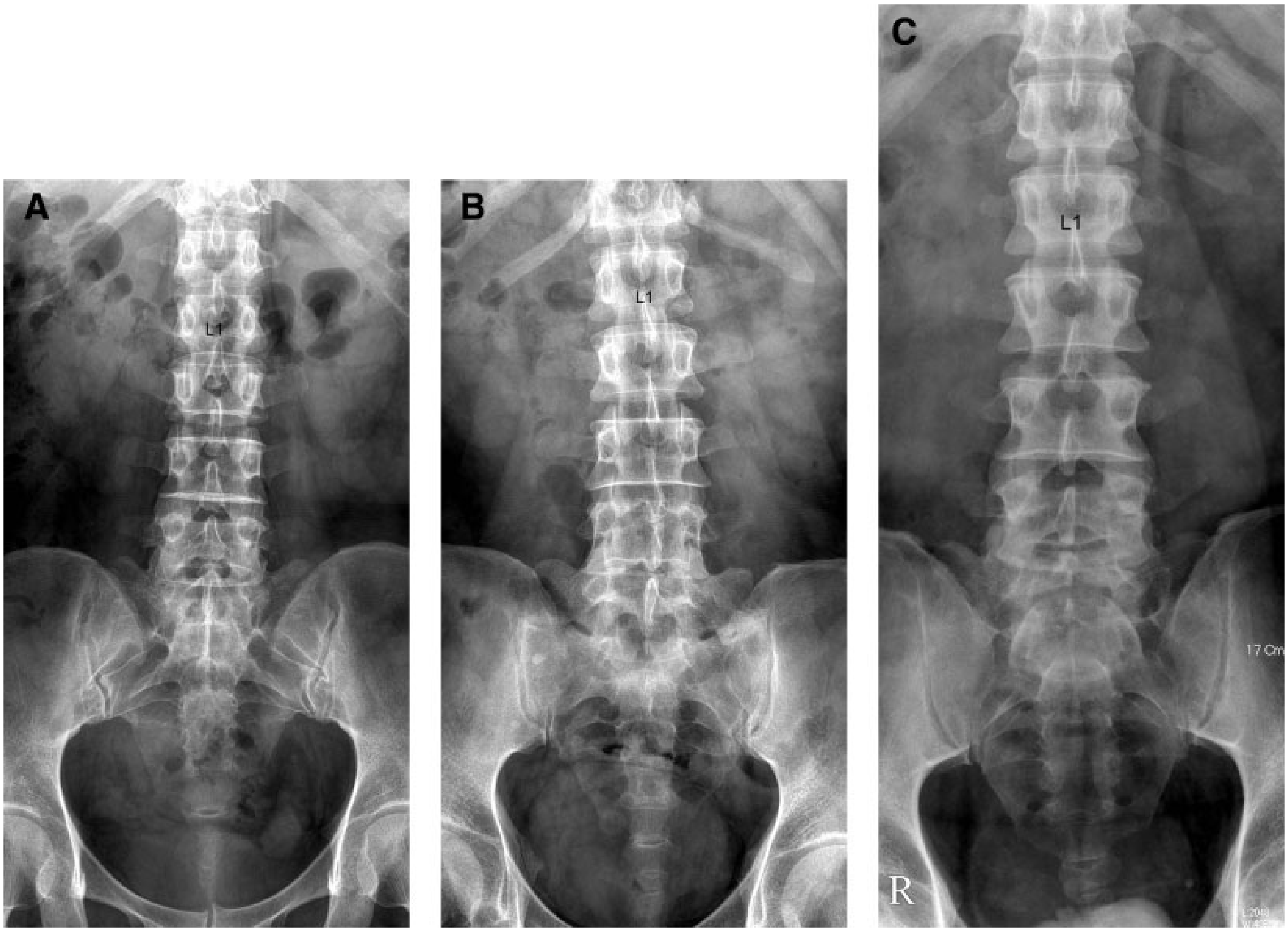

Fig. 5. Type of sacralization. **A:** Complete sacralization. Lumbar AP radiograph shows the complete fusion of the L5 transverse process with the S1 vertebra. The absence of a 12th rib is also apparent. **B:** Incomplete sacralization. Lumbar AP radiograph reveals bilateral pseudoarthrosis of the enlarged L5 transverse process with S1 vertebra. **C:** Mixed type. The right transverse process of L5 is the complete type, but the left side is an incomplete type. Hypoplasia of the 12th rib is also demonstrated.

The proximal RRA was most prevalent at the L1/L2 disc space (43.7%) in the normal group (Table 1) and was concentrated in the area between the L1/L2 disc space and the lower half of the L1 in most cases (77.8%). In the lumbarization group (Table 2), the RRA was most commonly located in the upper half of the L2 in 18 cases and was the most prevalent (34%) as well as one level lower than the normal group. In most cases (94.3%), the RRA was concentrated in the area between the disc space of the L1/L2 and the lower half of L2. In the sacralization group (Table 3), we located the RRA in the lower half of the L1 in 29 cases, which was one level higher than that in the normal group and the most prevalent (39.2%). Furthermore, we located the RRA in the L1 vertebral body in a substantial number of cases (71.6%). We observed a statistically significant difference within and between the three groups ($P < 0.01$).

The CT was most commonly located at the T12/L1 disc space (39.3%) in the normal group (Table 1) and was concentrated in the area between the lower half of T12 and the upper half of L1 in a substantial number of cases (89.9%). In the lumbarization group (Table 2), the CT was most commonly located in the upper half of the L1 in 23 cases (43.4%), which was approximately one level lower than that seen in the normal group. The origin of the CT was located in the L1 vertebral body in a large proportion of cases (67.9%). In the sacralization group (Table 3), the CT was most commonly found in the lower half of the T12 in 33 cases (44.6%), which was approximately one level higher than in the normal group and was located in the area between the lower half of the T12 and the T12/L1 disc space in a substantial number of cases (86.5%). We observed statistically significant differences within and between the three groups ($P < 0.01$).

The SR was most commonly located at the upper half of the L1 (44.7%) in the normal group (Table 1), which was approximately one level lower than the origin of the CT. The SR was concentrated in the area between the T12/L1 disc space and the upper half of the L1 in a substantial number of cases (73.8%). In the lumbarization group (Table 2), the SR was most commonly located in the lower half of the L1 in 25 cases (47.1%) and was located in the area between the lower half of the L1 and the L1/L2 disc space in many cases (73.6%). In the sacralization group (Table 3), the SR was most commonly located in the T12/L1 disc

TABLE 1. Locations of Paraspinal Structures in Normal Group (*n* = 407)

	CT	SR	RRA	AB	IC
T11/12	4				
T12(U)	31	3			
T12(L)	129	28			
T12/L1	159	118	6		
L1(U)	68	181	41		
L1(L)	16	67	139		
L1/2		10	178		
L2(U)			37		
L2(L)			6		
L2/3					
L3(U)					
L3(L)					
L3/4				16	1
L4(U)				119	11
L4(L)				167	117
L4/5				99	152
L5(U)				6	119
L5(L)					7
L5/S1					

AB, Aortic bifurcation; IC, IVC confluence; RRA, proximal right renal artery; CT, celiac trunk; SR, root of SMA; U, upper half; L, lower half.

space in 26 cases (35.1%) and in the area between the lower half of T12 and the upper half of L1 in most cases (87.8%). We observed statistically significant differences within and between the three groups ($P < 0.01$).

The average ER of the L5 was 0.97 ± 0.04 in the normal group, while for the TV group, the average ER was 0.99 ± 0.04 in the lumbarization group and 0.93 ± 0.08 in the sacralization group. The sacralization group had a significantly ($P < 0.01$) lower value than the other two groups. This result suggests that the L5 shape of the sacralization group was similar to the S1. In addition, in the sacralization group, 18 cases showed an ER lower than 0.9, which is indicative of a rhombus shape. Among them, 15 cases were in the complete sacralization group and three cases were in the incomplete sacralization group.

TABLE 2. Locations of Paraspinal Structures in Lumbarization Group (*n* = 53)

	CT	SR	RRA	AB	IC
T11/12					
T12(U)					
T12(L)	6	1			
T12/L1	7	4			
L1(U)	23	6			
L1(L)	13	25	2		
L1/2	3	14	17		
L2(U)	1	2	18		
L2(L)		1	15		
L2/3			1		
L3(U)					
L3(L)					
L3/4					
L4(U)				2	
L4(L)				4	1
L4/5				22	3
L5(U)				19	23
L5(L)				6	21
L5/S1					5

AB, Aortic bifurcation; IC, IVC confluence; RRA, proximal right renal artery; CT, celiac trunk; SR, root of SMA; U, upper half; L, lower half.

TABLE 3. Locations of Paraspinal Structures in Sacralization Group (*n* = 74)

	CT	SR	RRA	AB	IC
T11/12	7				
T12(U)	14	6			
T12(L)	33	20	1		
T12/L1	17	26	7		
L1(U)	2	19	24		
L1(L)	1	2	29		
L1/2		1	13		
L2(U)					
L2(L)					
L2/3					
L3(U)				1	
L3(L)				3	1
L3/4				21	3
L4(U)				25	17
L4(L)				22	29
L4/5				2	17
L5(U)					7
L5(L)					
L5/S1					

AB, Aortic bifurcation; IC, IVC confluence; RRA, proximal right renal artery; CT, celiac trunk; SR, root of SMA; U, upper half; L, lower half.

The average ER of the S1 was 0.67 ± 0.08 in the normal group while for the TV group, the average ER was 0.94 ± 0.05 in the lumbarization group and 0.66 ± 0.07 in the sacralization group. The lumbarization group showed a significantly ($P < 0.01$) higher ER value than the other two groups. This suggests that the S1 body of the lumbarization group showed a rectangular shape, which is similar to L5. In addition, in the lumbarization group, 45 cases (85%) had a S1 ER that was more than 0.9 and could be considered rectangular. Therefore, the shape of S1 was rectangular in most of the cases from the lumbarization group.

The ILL began from the transverse process of the L5 in 394 cases (97.3%) of the normal group. In seven cases, the ILL began simultaneously in the transverse process of the L4 and L5, while in three cases the ILL began simultaneously in the L5 and S1. The ILL originated from the S1 in one case. In the lumbarization group, 34 cases (64%) had an ILL that originated in the S1, 14 cases (26%) had an ILL that originated simultaneously in the L5 and S1, and 5 cases (10%) had an ILL that started from the L5. In the sacralization group, 50 cases (67.6%) had an ILL that originated in the L5, 14 cases (18.9%) had an ILL that originated from the L4, and 10 cases (13.5%) had an ILL that was simultaneously in L4 and L5.

The Locational Distribution of the Paraspinal Structures According to the TV Subdivision

We divided the lumbarization group into complete, incomplete, and mixed groups and found the following statistically significant results. In the complete group, the RRA, CT, and SR were located approximately one level lower to the caudal portion when compared with the incomplete and mixed groups ($P < 0.01$). The S1 ER of the complete group was somewhat larger than the ER of the incomplete and mixed groups ($P < 0.01$). In the complete lumbarization group, the ILL originated from the S1 in 22 of the cases (65%).

Similarly, the sacralization group could be divided into complete, incomplete, and mixed groups. The results that were statistically significant were as follows: the AB and IC were located more in the cephalic portion, while the L5 ER and the S1 ER was lower in the complete group than in the incomplete group. All cases with an ILL that originated from the L4 (14 cases, 100%) belonged to the complete group, whereas most cases with an ILL that originated at the transverse process of the L5 belonged to the incomplete group.

DISCUSSION

The TV is frequently encountered anomaly and the most common site for a TV to occur is at the lumbosacral junction. The last lumbar vertebra may have some or all of the anatomic characteristics of the first sacral segment (sacralization). Conversely, the first sacral segment may have the radiographic appearance of a lumbar vertebra (lumbarization) (Castellvi et al., 1984; Elster, 1989; Williams et al., 1989a; Lee et al., 2004). In 1917, Bertolotti first described the association between low back pain and lumbosacral transitional vertebrae, hence this condition is sometimes referred to as Bertolotti's syndrome (Elster, 1989; Brault et al., 2001; Connolly et al., 2003; Taskaynatan et al., 2005). However, Tini et al. demonstrated no relationship between low back pain and the presence of a TV in a study of 4,000 patients (Tini et al., 1977).

The reported incidence of TV ranges from 3 to 21% (Tini et al., 1977; Hahn et al., 1992; Lee et al., 2004; Hughes and Saifuddin, 2004). However, a higher incidence (23.8%) was detected in our study. Among our patients, 10% showed lumbarization of the S1, and 13.8% showed sacralization of the L5. Our study has a higher incidence than previous studies because the previous studies did not count the entire number of vertebral bodies and only used lumbar radiographs to obtain their results (Tini et al., 1977; Castellvi et al., 1984; Delport et al., 2006). When only lumbar radiographs or MRI are used, wrong numbering may occur in cases involving a supernumerary rib, hypoplastic rib, or cervical rib. The same result may also be found in patients with Klippel-Feil syndrome, which is characterized by the presence of single or multiple congenitally fused cervical vertebrae (Ulmer et al., 1993).

For TV cases, disc surgery at the wrong level is uncommon, but can have significant consequences to the patient (Malanga and Cooke, 2004). In addition, the position of lumbosacral dermatomes may vary in the presence of TV (Seyfert, 1997). Furthermore, vascular injury may occur during anterior lumbar interbody fusion because of the altered vascular anatomy (Weiner et al., 2001).

The morphology of the vertebral body on the sagittal images, the lumbosacral angle on the sagittal view, and the observed configuration of the intervertebral discs have all been frequently used as factors for determining the location of the vertebral body on the lumbar MRI when the C-T localizer could not be applied (MacGibbon and Farfan, 1979; Nicholson et al., 1988). Generally, the last vertebral body that appears as a rectangle is considered to be the L5 vertebra, and the first vertebral body that appears to be a rhombus is considered to be the S1 vertebra (Castellvi et al., 1984; Lee et al., 2004). In addition, the level of the L5-S1 shows a greater lumbosacral angle (MacGibbon and Farfan, 1979). However, in cases with TV, the S1 was rectangular under conditions of complete lumbarization and the L5 was a rhombus under conditions of complete sacralization. Hence, errors can be made when determining the location of the vertebral body. Therefore, paraspinal structures that appear with a relatively constant pattern on the MRI need to be used as landmarks. Such paraspinal structures are the AB, IC, RRA, CT, SR, ILL, the ER of the L5, and the S1 vertebral body.

The point of the AB in most cases is the anterior aspect of the L4 vertebral body (Kornreich et al., 1998; Chithriki et al., 2002; Lee et al., 2004). However, the lower half of the L4 was the most common site for the AB localization in our study, which is due to a difference in the definition of the AB. In our study, the point of the AB was defined to be the position in which both the common iliac arteries first appear as a complete independent circular shape. We found a 95% probability that the disc space showing both common iliac arteries on the axial image of a lumbar MRI for the first time was at the L4/5 disc level.

Previous reports have indicated that the IC is most prevalent at the L4/5 disc space (Williams et al., 1989a; Kornreich et al., 1998). In many cases, the IVC collapses at the time it is measured on the MRI and the left common iliac vein forms a more obtuse angle than the AB angle, which makes it difficult to measure. Therefore, we defined the IC point as the point immediately before the left common iliac vein that forms the confluence, i.e., the point where the left common iliac veins is detected between both common iliac arteries. Such a point was easy to find on all images.

We measured the RRA between the aorta and the IVC and found that the RRA was concentrated in the L1/2 disc space, a finding which is similar to the previous reports (Williams et al., 1989a; Verschuyl et al., 1997; Lee et al., 2004). Therefore, the RRA is a useful paraspinal structure that could be readily detected and is always located on a sagittal image.

The ILL is the ligament connecting the L5 vertebra to the ilium and has been reported to provide additional stability to the lumbosacral junction (Luk et al., 1986; Williams et al., 1989b; Maigne and Maigne, 1991; Basadonna et al., 1996; Aihara et al., 2005). The ILL originates from the L5 transverse process and is inserted into the iliac crest toward the posteromedial direction. Sometimes the ILL has a weak attachment to the L4 vertebrae (Luk et al., 1986; Williams et al., 1989b; Hughes and Saifuddin, 2006). In our study, the ILL originated from the L5 in most cases. However, in more than half of the lumbarization group, the ILL originated from the S1, while in the sacralization group, the ILL originated from the L4 in $\sim$20% of the group. In addition, a few cases had two main bands from the L4/L5 or the L5/S1 transverse processes.

The ER could be measured easily on a sagittal MRI and on the lateral view of a plain radiograph. In our study, the ER was measured to obtain more objective information on the morphology of the L5 and the S1 vertebral bodies. A ratio closer to 1 suggests a rectangular shape, while a ratio less than 0.9 suggests a rhombus shape. Generally, in determining the location of the vertebral body, the last vertebra with a rectangular shape is considered to be the L5 and then the vertebral body is numbered from the bottom to the top. However, as shown in our study, the shape of the S1 vertebral body was more rectangular in the lumbarization group than in the other groups. In fact, the L5 vertebral body in the sacralization group tended to have a rhombus shape compared with the other groups. Therefore, errors can occasionally be made if the location of the vertebral body is determined only by shape.

For cases of TV, the paraspinal structures had a definite locational distribution. In the lumbarization cases, the paraspinal structures such as AB, IC, RRA, CT, and SR tended to be located from one to three levels more to the caudal portion than in the normal cases (Fig. 2). In the sacralization cases, these structures had a tendency to be distributed from one to three levels more to the cephalic portion than in the normal cases (Fig. 3). The ILL generally originates from the transverse process of L5. However, in more than half of the cases in the lumbarization group, the ILL originated from the S1 and in $\sim$20% of cases in the sacralization group the ILL arose from the L4 transverse process.

Three factors can be used to predict TV using MRI. First, when the last vertebral body with a rectangular shape is assumed to be the L5, ''lumbarization'' can be suspected if the location of the RRA, CT, and SR are more toward the cephalic portion than normal on a sagittal image. On the other hand, ''sacralization'' can be suspected if the location of these parameters is more toward the caudal portion. This is because in the cases of lumbarization, the vertebra that is assumed to be the L5 is actually the S1. Hence, paraspinal structures appear to be located in an area higher than normal. For example, in the case of lumbarization where the RRA actually appears to be in the upper half of the L2, if only the sagittal images are examined, the S1 would appear to be just like the L5. Therefore, the RRA ''pretends'' to be located in the upper half of the L1. Second, assuming that the last rectangular-shaped vertebral body on the sagittal image is L5, ''lumbarization'' can be suspected if the location of the AB and IC on the axial image is more towards the cephalic portion than normal. On the other hand, ''sacralization'' can be suspected if these parameters are more toward the caudal portion. Third, the ILL originates from the L5 transverse process. Therefore, the possibility of TV should be considered in cases where the origin of the ILL and the location of the other paraspinal structures are mismatched.

In the case of lumbarization, the shape of the S1 is seen as rectangular in 85% of the cases. In addition, the above predictive factors can also be applied. However, in the sacralization group, the shape of the L5 is seen as a rectangle in a substantial portion of the incomplete and the mixed groups. Therefore, these three factors cannot be applied in some cases.

In conclusion, AB, IC, RRA, CT, SR, and ILL are useful landmarks for predicting the presence of TV on MRI. A TV is expected when these paraspinal structures are in positions outside of their main locations. The three predictable factors described earlier are expected to become useful standards for the clinical imaging field in the future.

REFERENCES

Aihara T, Takahashi K, Ogasawara A, Itadera E, Ono Y, Moriya H. 2005. Intervertebral disc degeneration associated with lumbosacral transitional vertebrae: A clinical and anatomical study. J Bone Joint Surg Br 87:687–691.

Basadonna PT, Gasparini D, Rucco V. 1996. Iliolumbar ligament insertions. In vivo anatomic study. Spine 21:2313–2316.

Brault JS, Smith J, Currier BL. 2001. Partial lumbosacral transitional vertebra resection for contralateral facetogenic pain. Spine 26:226–229.

Castellvi AE, Goldstein LA, Chan DP. 1984. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine 9:493–495.

Chithriki M, Jaibaji M, Steele RD. 2002. The anatomical relationship of the aortic bifurcation to the lumbar vertebrae: A MRI study. Surg Radiol Anat 24:308–312.

Connolly LP, d'Hemecourt PA, Connolly SA, Drubach LA, Micheli LJ, Treves ST. 2003. Skeletal scintigraphy of young patients with low-back pain and a lumbosacral transitional vertebra. J Nucl Med 44:909–914.

Delport EG, Cucuzzella TR, Kim N, Marley J, Pruitt C, Delport AG. 2006. Lumbosacral transitional vertebrae: Incidence in a consecutive patient series. Pain Physician 9:53–56.

Elster AD. 1989. Bertolotti's syndrome revisited: Transitional vertebrae of the lumbar spine. Spine 14:1373–1377.

Hahn PY, Strobel JJ, Hahn FJ. 1992. Verification of lumbosacral segments on MR images: Identification of transitional vertebrae. Radiology 182:580–581.

Hughes RJ, Saifuddin A. 2004. Imaging of lumbosacral transitional vertebrae. Clin Radiol 59:984–991.

Hughes RJ, Saifuddin A. 2006. Numbering of lumbosacral transitional vertebrae on MRI: Role of the iliolumbar ligaments. AJR Am J Roentgenol 187:W59–W65.

Kornreich L, Hadar H, Sulkes J, Gornish M, Ackerman J, Gadoth N. 1998. Effect of normal ageing on the sites of aortic bifurcation and inferior vena cava confluence: A CT study. Surg Radiol Anat 20:63–68.

Lee CH, Seo BK, Choi YC, Shin HJ, Park JH, Jeon HJ, Kim KA, Park CM, Kim BH. 2004. Using MRI to evaluate anatomic significance of aortic bifurcation, right renal artery, and conus medullaris when locating lumbar vertebral segments. AJR Am J Roentgenol 182:1295–1300.

Luk KD, Ho HC, Leong JC. 1986. The iliolumbar ligament. A study of its anatomy, development and clinical significance. J Bone Joint Surg Br 68:197–200.

MacGibbon B, Farfan HF. 1979. A radiologic survey of various configurations of the lumbar spine. Spine 4:258–266.

Maigne JY, Maigne R. 1991. Trigger point of the posterior iliac crest: Painful iliolumbar ligament insertion or cutaneous dorsal ramus pain? An anatomic study. Arch Phys Med Rehabil 72:734–737.

Malanga GA, Cooke PM. 2004. Segmental anomaly leading to wrong level disc surgery in cauda equina syndrome. Pain Physician 7:107–110.

Nicholson AA, Roberts GM, Williams LA. 1988. The measured height of the lumbosacral disc in patients with and without transitional vertebrae. Br J Radiol 61:454–455.

Seyfert S. 1997. Dermatome variations in patients with transitional vertebrae. J Neurol Neurosurg Psychiatry 63:801–803.

Taskaynatan MA, Izci Y, Ozgul A, Hazneci B, Dursun H, Kalyon TA. 2005. Clinical significance of congenital lumbosacral malformations in young male population with prolonged low back pain. Spine 30:E210–E213.

Tini PG, Wieser C, Zinn WM. 1977. The transitional vertebra of the lumbosacral spine: Its radiological classification, incidence, prevalence, and clinical significance. Rheumatol Rehab 16:180–185.

Ulmer JL, Elster AD, Ginsberg LE, Williams DW. 1993. Klippel-Feil syndrome: CT and MR of acquired and congenital abnormalities of cervical spine and cord. J Comput Assist Tomogr 17:215–224.

Verschuyl EJ, Kaatee R, Beek FJ, Pasterkamp G, Bush WH, Beutler JJ, van der Ven PJ, Mali WP. 1997. Renal artery origins: Location and distribution in the transverse plane at CT. Radiology 203:71–75.

Weiner BK, Walker M, Fraser RD. 2001. Vascular anatomy anterior to lumbosacral transitional vertebrae and implications for anterior lumbar interbody fusion. Spine J 1:442–444.

Williams PL, Warwick R, Dyson M, Bannister LH. 1989a. Iliolumbar ligament. In: Williams PL, Warwick R, Dyson M, Bannister LH, editors. Gray's Anatomy. 37th Ed. New York: Churchill Livingstone. p 491.

Williams PL, Warwick R, Dyson M, Bannister LH. 1989b. Sacralization and lumbarization. In: Williams PL, Warwick R, Dyson M, Bannister LH, editors. Gray's Anatomy. 37th Ed. New York: Churchill Livingstone. p 326.