Evaluation of the Relationship Between L5-S1 Spondylolysis and Isthmic Spondylolisthesis and Lumbosacral-Pelvic Morphology by Imaging via 2- and 3-Dimensional Reformatted Computed Tomography

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Purpose

Lumbar spondylolysis is an anatomic defect in the pars interarticularis or isthmus. It is present in more than 14 million individuals in the United States. It is usually asymptomatic. However, it may cause low back pain or sciatica secondary to muscle or ligament strain, spinal or foraminal stenosis, facet degeneration or related disk degeneration, and herniation. It is considered to be formed secondary to repetitive stress or trauma. Although it has been reported that genetic factors are important in the development of isthmic spondylolisthesis, predisposing anatomic factors in the formation of spondylolysis have not been clearly revealed yet.

Normal orientation of lumbosacropelvic structure plays an important role in the determination of shear and compressive forces applied onto the pars interarticularis. Therefore, the interest in the relationship between the lumbosacropelvic morphology and isthmic spondylolisthesis has increased recently. However, almost all of the studies in this direction have been conducted by digital roentgenography at the sagittal plane.

The values obtained at lateral radiography could be affected by factors such as superimposition of anatomic structures and magnification of structures further from the film.

The purpose of this study was to investigate the differences in the axial and coronal parameters of lumbosacropelvic morphology among a population with spondylolysis and healthy individuals by using 2- and 3-dimensional (3D) reformatted computed tomographic images. Moreover, this study aimed to evaluate the differences in sagittal geometry.
Methods and Materials

Sampling

The stone protocol abdominal CT images of 386 patients referred to our clinic with the preliminary diagnosis of urinary system stones during the years 2007 to 2009 were retrospectively evaluated. Patients with a history of lumbar surgery or those with tumor, degenerative spondylolisthesis, severe congenital anomaly, severe scoliosis, osteomyelitis, incomplete or complete lumbosacral transition, and lumbar vertebral fracture as revealed by their lumbar CTs were not included. Thirty individuals who had spondylolysis at L5-S1 level were included in the study. Moreover, a control group of individuals free of spondylolysis and spondylolisthesis was formed, similar in age and sex to the study group (to prevent the differences observed in the spinal column depending on age and sex). Twenty-one individuals in the patient and control groups were males and 9 were females. The age of the patients in the study group varied between 13 and 74 years, the mean age being 41.96 (15.29) years; and the age of the individuals in the control group varied between 14 and 72 years, the mean age being 41.6 (15.49) years. There was no statistically significant difference between the study and control groups with respect to age (P = 0.929).

Imaging Parameters

Lumbosacropelvic morphology of all individuals was evaluated in the 2D and 3D reconstructed CT images. All evaluations were performed with 2-detector MDCT device (Siemens Sensation 4, Siemens, Erlangen, Germany). The 3-mm section thickness images were obtained without intravenous contrast administration, at 100 to 120 mA, 120 to 240 kilovolt (peak), and a pitch of 1. Spiral CT data were loaded into the Advantage Windows GraphicWorkstation (General Electric Medical System, Milwaukee, Wis).

Evaluation of Spinopelvic Morphology and the Method of Measurement

The horizontal length of L5 vertebral upper endplate, the
interlaminar angle, and the area of the paravertebral muscles were analyzed in the reformatted CT image that was parallel to the L5 vertebral upper endplate. To obtain this image, the cursor allowing for the generation of reformatted CT images was placed on the midpoint of the L5 vertebral upper endplate, and the images were rotated to be parallel to the L5 vertebral upper endplate (Figs. 1A, B).

Interpedicular angle, interpedicular distance, and transverse process width and length of the L5 vertebra were evaluated on the axial reformatted CT image passing through the midpoint of and parallel to the L5 vertebral pedicle. To obtain this image, a similar process was performed by taking the midpoint of L5 vertebral pedicle as the reference point (Fig. 2).

The horizontal length of the S1 vertebral upper endplate, the interfacet distance, the axial angle of the facet joint, the transverse articular dimension of facet joints, and surface type of facet joint were evaluated on the axial reformatted CT image parallel to the upper endplate of the S1 vertebra. To obtain this image, the cursor was placed on the midpoint of S1 vertebral upper endplate, and the images were rotated to be parallel to S1 vertebral upper endplate (Fig. 3).

The sagittal angle of the facet joint was evaluated on the sagittal reformatted CT image. To obtain this image, the cursor was placed on the top point of S1 vertebral upper endplate at the sagittal image. After that, on the axial image formed on this plane, the cursor was placed on the medial pole of each facet joint and a sagittal image was obtained for each facet joint (Fig. 4).

The distance between the iliac wings, the sacrum length, the distance between L5 vertebral transverse process and the iliac crest, L5 vertebral transverse process thickness (Fig. 5), the interiliac angle, the intersacroiliac joint angle (Fig. 6), pelvic incidence (PI; Fig. 7), and the iliac crest height (Fig. 8) were analyzed on the 3D reformatted CT image.

The lumbar angle, the sacral slope (Fig. 9A), the sagittal length of L5 and S1 vertebral upper endplate, the length of the anterior and posterior elements of the L5 vertebra, sacral kyphosis (Fig. 9B), the anterior and posterior heights of the
L5 vertebral corpus, and the sacral table angle (STA; Fig. 9C) were analyzed on the sagittal reformatted CT image obtained at midsagittal level. To obtain this image, the cursor was placed on the midpoint of the S1 vertebral corpus on the axial CT image, and the sagittal reformatted CT image passing through the midsagittal level was obtained.

On all reformatted CT images, the asymmetry generated owing to the patient's position was corrected to prevent measurement errors, and the images were recorded to the workstation. All measurements were accomplished in a virtual electronic environment. Each measurement was repeated twice, and the mean was used to minimize random errors. The whole lumbar spine was evaluated for each of the cases by using bone and soft tissue window.

Reformatted CT analyses of all individuals were conducted collaboratively by a radiologist experienced in neuroradiology and an orthopedic surgeon experienced in spinal surgery.

**Statistical Method**
The mean values and SDs for each of the measurements were calculated. The data for the isthmic group were compared with those of the control population using an unpaired Student t test. A P $\leq$ 0.05 was considered significant. Statistical analyses were carried out using SPSS 11.0 (version 11.0, SPSS Inc., Chicago, Ill). The study was approved by the hospital ethics committee. No signed patient consent form was necessary.
**Fig. 1:** Axial reformatted CT image that was parallel to the L5 vertebra upper endplate. A, Horizontal length of L5 vertebra upper endplate (a); interlaminar angle: the # angle. B, Area of paravertebral muscles

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Fig. 2: Axial reformatted CT image that passes through the midpoint of the L5 vertebral pedicle and is parallel to the pedicle. Interpedicular angle: the angle between a and b; interpedicular distance: d; transverse process width of L5 vertebra: e; and transverse process length of L5 vertebra: c.

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Fig. 3: Axial reformatted CT image that was parallel to the upper endplate of the S1 vertebra. Horizontal length of S1 vertebra upper endplate: a; interfacet distance: c; axial angle of facet joint: the # angle; transverse articular dimension of facet joints: b.

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**Fig. 4:** Sagittal reformatted CT image. Sagittal angle of facet joint: the $\alpha$ angle.

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**Fig. 5:** Three-dimensional reformatted CT image. Distance between iliac wings: $a$; sacrum length: $b$; distance between L5 vertebra transverse process and the iliac crest: $c$; L5 vertebral transverse process thickness: $d$.

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Fig. 6: Three-dimensional reformatted CT image. Interiliac angle: the angle between a and b; intersacroiliac joint angle: the angle between c and d.

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Fig. 7: Three-dimensional reformatted CT image of pelvic incidence: the \# angle.

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Fig. 8: Three-dimensional reformatted CT image of iliac crest height: a.

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**Fig. 9:** Sagittal reformatted CT image passing through midsagittal level. A, Lumbar angle: the angle between a and b; sacral slope: the # angle. B, Sagittal length of L5 vertebra upper endplate: a; sagittal length of S1 vertebra upper endplate: b; length of the anterior elements of L5 vertebra: c; length of the posterior elements of L5 vertebra: d; sacral kyphosis: the # angle. C, STA: the # angle; anterior height of vertebrae: a; posterior height of vertebrae: b.

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Results

Differences between healthy individuals and the lysis group were observed on a large number of parameters in the morphologic analysis of the spinopelvic structure.

The mean sagittal angle of facet joint (117.45 [4.24]-) was bigger in the lysis group than in the control group (108.91 [6.35]-), the difference being statistically significant (P = 0.0001). The articular surface type was observed to be 23% flat and 67% concave in the control group. In the lysis group, the joint was flat type in 50% of the cases and concave type in 50% of the cases. There was a statistically significant difference with regard to the joint surface type between the lysis group and the control group (P = 0.034). The mean transverse articular dimension of the joint in the healthy individuals and in the lysis group was 17.63 (2.66) mm and 14.72 (2.74) mm, respectively, and the difference was statistically significant (P = 0.0001).

The interpedicular angle was found to be significantly greater in the healthy group (mean, 72.23 [9.12]-) than in the patient group (mean, 49.23 [14.86]-). The difference was found to be statistically significant (P = 0.0001).

The lumbar indices have been observed as 0.76 (0.07) and 0.85 (0.04) in the patient group and the healthy individual group, respectively, and a close relation has been observed between trapezoidal-shaped L5 vertebra and spondylolysis (P = 0.0001).

The anterior element lengths of the L5 vertebra were measured to be 33.25 (2.92) mm and 32.44 (2.44) mm in healthy individuals and in the group with lysis, respectively, and the difference was not statistically significant (P = 0.249). The posterior element lengths of the L5 vertebra were found to be 45.53 (5.37) mm in the group with lysis and 43.43 (3.95) mm in healthy individuals, and the difference was not statistically significant (P = 0.09). However, there was a statistically significant difference in favor of the healthy group in the measurement of L5 vertebral sagittal index (P = 0.014).

In the lysis group, the paravertebral muscle area (mean,
2339 [625.18] mm) was larger than that in the healthy individuals (mean, 2052.5 [415.34] mm), the difference being statistically significant (P = 0.004).

The distances between the iliac wings in healthy individuals and in the lysis group, respectively, were 272.05 (17.59) mm and 273.84 (20.42) mm, and the difference was not statistically significant (P = 0.718). The mean sacrum length was found to be 117.06 (14.41) mm in the lysis group and 114.46 (6.65) mm in healthy individuals, the difference being statistically insignificant (P = 0.374). Moreover, no statistically significant difference was observed between the 2 groups in interiliac angle (P = 0.844) and intersacroiliac joint angle (P = 0.555). On the other hand, there was a statistically significant difference in favor of the control group with regard to the iliac crest height (P = 0.027). Besides, in the lysis group, the distance between the L5 vertebral transverse process and the iliac crest was observed to be less than that in healthy individuals (P = 0.001).

The length, the thickness, and the width of the L5 vertebral transverse process were 15.63 (2.58) mm, 14.36 (1.86) mm, and 14.11 (2.8) mm in the healthy group and 16.34 (2.37) mm, 14.75 (2.21), and 12.88 (2.54) mm in the lysis group, respectively. There was a statistically significant difference with regard to the transverse process width between the 2 groups (P = 0.013).

There was an association between spondylolysis and decreased interpedicular angle and S1 vertebra interfacet index, increased distance between the iliac crest and L5 vertebral transverse process, decreased L5 pedicle width, and increased height of the iliac crest and decreased L5 vertebra sagittal index. The paravertebral muscle area was larger in the lysis group when compared with the healthy individuals.
Conclusion

A large number of radiological parameters that analyze especially the sagittal orientation and shape of the pelvis and the sacrum have been defined, and important differences between the population with spondylolysis and the healthy individuals have been found. Also, in our study, statistically significant differences between the individuals with spondylolysis and the healthy group in lumbar angle, STA, sagittal STI, sacral kyphosis, sacral slope, PI, interpedicular angle, S1 vertebra IFI, L5 vertebra SI, lumbar index, the distance between L5 vertebra transverse process and the iliac crest, the height of the iliac crest, sagittal angle of the facet joint, transverse articular dimension of facet joint, surface type of the facet joint, paravertebral muscle area, and width of transverse process were observed.

However, to the best of our knowledge, there are no literature reports assessing the difference in interpedicular angle between healthy individuals and group with lysis. In this study, the interpedicular angle in the patient group was observed to be significantly lower than that in the healthy individuals (P = 0.0001). This finding indicates that the pedicle with coronal orientation has a higher risk of defect development in pars interarticularis.

Another important result of our study was that although there was no statistically significant difference between the lengths of anterior and posterior elements of the L5 vertebra, the L5 vertebral sagittal index was detected to be higher in healthy individuals than in the group with lysis (P = 0.014). This finding indicates that the spinal column overload point posed by gravity is closer to the vertebral corpus (which is supported by other vertebrae and intervertebral disks) in healthy individuals and at pedicle level in individuals with lysis. Consequently, this ratio is important for its showing the place of spinal overload and its being a determining factor in the development of pars defect.

Our study had some limitations. The first limitation was that because the analysis was performed in a supine position, we were not able to classify the patients as the slip and nonslip groups. The second limitation was that the study was not conducted as a
blind study. The third limitation was that the number of cases in the patient group was low, and the final limitation was that although all measurements were performed with the joint decision of both experts, it was not possible to assess intraobserver and interobserver variability.

Despite these limitations, our study indicates that multiple factors (interpedicular angle, S1 vertebra IF index, the distance between the iliac crest and the L5 vertebral transverse process, L5 pedicle width, and height of the iliac crest and L5 vertebra sagittal index) in lumbosacropelvic morphology affect the defect development in pars interarticularis. Moreover, this study puts forth that hypertrophy develops in paravertebral muscles in cases with spondylolysis as a secondary adaptive change.
References


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