Two- and three-dimensional reformatted computed tomography imaging analysis of the lumbosacropelvic structure in degenerative anterolisthesis

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Purpose

The normal orientation of lumbosacropelvic structure plays an important role in the determination of mechanical forces that are applied on the anterior and posterior elements of the lumbar vertebral column. Therefore, interest in the morphological analysis of lumbosacropelvic structure has increased recently. However, related studies have generally been conducted in patients with low-back pain or isthmic spondylolisthesis. There are few studies on patients with DS in the literature and these have mainly investigated the relationship between the morphology of facet joints and DS. In several studies, the relationship between DS and sagittal orientation has been evaluated. However, these studies have been conducted with lateral radiography and a limited number of parameters were analysed. The values obtained with lateral radiography only provide information about sagittal morphology.

The aim of the present study was to investigate the lumbosacropelvic morphological differences between pseudospondylolisthesis patients and a group of normal individuals using 2D and 3D reformatted CT imaging.
Methods and Materials

Sampling

Abdominal CT images acquired using a protocol to evaluate the presence of stones in the urinary system (which provide better reformatted imaging due to thinner sections) of 452 patients referred to our clinic with the preliminary diagnosis of urinary system stones during the years 2007e2009 were retrospectively evaluated. The study was approved by the Hospital Ethics Committee. No signed patient consent form was necessary.

Patients with a history of lumbar surgery, or those with tumours, isthmic spondylolisthesis, spondyloysis, severe congenital anomaly, severe scoliosis, osteomyelitis, incomplete or complete lumbosacral transition, hip abnormality, and lumbar vertebral fracture as revealed by lumbar CT examinations were not included. Patient and control groups were formed from the remaining individuals. Degenerative anterolisthesis at the L5eS1 level was observed in 20 patients. For each individual of the patient group an age (2 years) and gender-matched control group consisting of normal individuals was formed (to control for the differences observed in the spinal column depending on age and gender).

Imaging parameters

Lumbosacropelvic morphology of all individuals was evaluated using 2D and 3D reconstructed CT images. All evaluations were performed with a Siemens HiSpeed CT device (Siemens, Germany). 2-detector MDCT device (Siemens Sensation 4, Siemens, Erlangen, Germany). Images with a 3-mm section thickness were obtained without the administration of intravenous contrast medium, at a tube current of 100e120 mA; tube voltage 120e240 kVp, and pitch of 1. Spiral CT data were loaded into the Advantage Windows Graphic Workstation.

Evaluation of spinopelvic morphology
The interlaminar angle and the area of the paravertebral muscles were analysed using axial oblique reformatted CT images parallel to the L5 vertebral upper endplate. To obtain this image, the cursor allowing the generation of reformatted CT images was placed on the midpoint of the upper endplate of the L5 vertebra and the images were rotated to be parallel to the upper endplate of the L5 vertebra.

Measured parameters
Parameters evaluated on the axial 2D reformatted CT image were: (1) inter-laminar angle, which is the angle between the line passing through the centre of the spinolaminar intersection and the line passing through the centre of the narrowest points of the two laminae (Fig. 1a; the alpha angle); (2) paravertebral muscle area, which is the area bound by the lines passing through the external contour of the paravertebral muscles on both sides (Fig. 1b); (3) interpedicular angle, which is the angle between the longitudinal axis of both two pedicles (Fig. 2, the angle between line a and line b); (4) length of transverse process, which is the distance between the midpoint of the line connecting the most exterior points of the pedicle and the superior articular facet and the tip of the transverse process (Fig. 2; line c); (5) width of the transverse process, which is the distance between the lines connecting the most exterior points of the pedicle and the superior articular facet (Fig. 2; line d); (6) axial angle of the facet joint, which is the angle between the line passing through the anteromedial and posterolateral points of each facet joint and the line connecting the two extreme points on the posterior wall of the vertebra (Fig. 3, the alpha angle); (7) horizontal length of the upper endplate of the S1 vertebra, which is the distance between the most extreme points of the upper endplate of the S1 vertebral corpus on the horizontal plane (Fig. 3; line a); (8) transverse articular dimension of the facet joint, which is the distance between the medial and lateral border of the articular surface (Fig. 3; line b); (9) S1 vertebral interfacet distance, which is the shortest distance between the medial side of the facet joints (Fig. 3; line c).
Parameters evaluated on the sagittal 2D reformatted CT image were: (1) sagittal angle of facet joint, which is the angle between the line passing through the superomedial and inferolateral points of each facet joint and L5 vertebral...
upper endplate (Fig. 4; the alpha angle); (2) lumbar angle, which is the angle between the lines passing through the midpoints of L1 and L5 vertebral corpora (Fig. 9a; the angle between line a and line b); (3) sacral slope, which is the angle between sacral plate and the horizontal plan (Fig. 9a; the alpha angle); (4) sagittal length of L5 vertebra upper endplate, which is the longest distance of L5 vertebral upper endplate on the sagittal plane (Fig. 9b; line a); (5) sagittal length of S1 vertebra upper endplate, which is the longest distance of S1 vertebral upper endplate on the sagittal plane (Fig. 9b; line b); (6) sacral kyphosis, which is the angle between the line joining the midpoints of superior and inferior borders of S1 and line joining the midpoints of inferior borders of S2 and S4 (Fig. 9b; the alpha angle); (7) sacral table angle, which is the angle between the line along the sacral endplate and the line drawn along the posterior aspect of the S1 vertebral body (Fig. 9c; the alpha angle); (8) L5 vertebra posterior angle, which is the angle between the lower surface and back surface of L5 vertebra (Fig. 9c; the beta angle).

Parameters evaluated on the 3D CT images were: (1) the distance between the iliac wings, which is the distance between the most extreme points of both iliac wings (Fig. 5; line a); (2) sacrum width, which is the distance between the most extreme points of sacrum (Fig. 5; line b); (3) the distance between L5 vertebral transverse process and the iliac crest, which is the distance between the tip of the transverse process and the top points of the iliac crests on both sides (Fig. 5; line c); (4) thickness of the transverse process, which is the vertical length at the point where the transverse process is thickest (Fig. 5; line d); (5) inter-iliac angle, which is the angle between the lines connecting the posterolateral aspect of both iliac wings (Fig. 6; the angle between line a and line b); (6) intersacroiliac joint angle, which is the angle between the lines passing through both sacroiliac joints (Fig. 6; the angle between line c and line d); (7) pelvic incidence, which is the angle between the perpendicular line to the sacral endplate at its midpoint and the line connecting this point to the middle of the femoral heads (Fig. 7; the alpha angle); (8) the height of the iliac crest, which is the distance between the line connecting the top points of both iliac crests and the top point of sacral endplate (Fig. 8; line a).
Indices measured were: (1) the Iliac wing-sacrum index, which is the ratio of the distance between iliac wings to the sacrum width; (2) S1 vertebra interfacet index (IFI), which is the ratio of S1 vertebra interfacet distance to the horizontal length of S1 vertebral upper endplate; (3) sacral table index (STI), which is the ratio of the sagittal length of S1 vertebral upper endplate to the sagittal length of L5 vertebral upper endplate.

Statistical methods

Mean and standard deviations for each of the measurements were calculated. The data for the DS group were compared with the control population using an unpaired Student's t-test and Mann-Whitney U-test. P<0.05 was considered statistically significant. Statistical analyses were carried out using SPSS 11.0.
Fig. 1: Axial reformatted CT image that was parallel to the L5 vertebra upper endplate: (a) interlaminar angle: the alpha angle; (b) area of paravertebral muscles

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

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**Fig. 3**: Axial reformatted CT image that was parallel to the upper endplate of the S1 vertebra. Line a indicates the horizontal length of the S1 vertebra upper endplate; line b indicates the transverse articular dimension of the facet joints; line c indicates the interfacet distance; the alpha angle is the axial angle of facet joint.

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Fig. 4: Axial reformatted CT image that was parallel to the upper endplate of the S1 vertebra. Line a indicates the horizontal length of the S1 vertebra upper endplate; line b indicates the transverse articular dimension of the facet joints; line c indicates the interfacet distance; the alpha angle is the axial angle of facet joint.

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Fig. 5: 3D reformatted CT image. Line a indicates the distance between the iliac wings; line b indicates the sacrum width; line c indicates the distance between the L5 vertebra transverse process and the iliac crest; line d indicates the thickness of the transverse process of the L5 vertebra.

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Fig. 6: 3D reformatted CT image. The angle between line a and line b indicates the Inter-iliac angle; the angle between line c and line d indicates the inter-sacro-iliac joint angle.

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Fig. 7: 3D reformatted CT image. The alpha angle indicates the pelvic angle of incidence.

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Fig. 8: 3D reformatted CT image. Line a indicates the height of the Iliac crest.
Fig. 9: Sagittal reformatted CT image passing through midsagittal level. (a) The angle between line a and line b indicates the lumbar angle; and the alpha angle indicates the sacral slope. (b) Line a indicates the sagittal length of the L5 vertebra upper endplate; line b indicates the sagittal length of the S1 vertebra upper endplate; the alpha angle indicates sacral kyphosis. (c) The alpha angle indicates the sacral table angle and the beta angle indicates the posterior angle of the L5 vertebra.

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Results

There was an association between spondylolisthesis and decreased thickness of the transverse process ($p = 0.01$), the height of the iliac crest ($p = 0.028$), lumbar angle ($p = 0.041$), sacral table angle ($p = 0.033$), sacral table index ($p = 0.0001$), sacral kyphosis ($p = 0.025$), sacral slope ($p = 0.007$), and width of the transverse process ($p = 0.038$), and increased transverse articular dimension of the facet joint ($p = 0.003$), axial angle of the facet joint ($p = 0.002$), sagittal angle of the facet joint ($p = 0.012$), S1 vertebra interfacet index ($p = 0.003$), the distance between the L5 vertebral transverse process and the iliac crest ($p = 0.003$), pelvic incidence ($p = 0.016$), L5 vertebra posterior angle ($p = 0.001$), and intersacroiliac joint angle ($p = 0.024$).
Conclusion

In the present study, numerous parameters of the lumbosacropelvic morphology in patients with DS and in normal individuals were evaluated and statistically significant differences were detected between the group with slip and the normal individuals in terms of pelvic incidence, lumbar lordosis angle, sacral slope, sacral surface angle, sacral kyphosis angle, STI, L5 vertebra posterior angle, axial and sagittal angles of the facet joint, transverse articular dimension of the facet joint, S1 vertebra IFI, the angle between the sacroiliac joints, the height of the iliac crest, the distance between the iliac crest and L5 vertebra transverse process, and the thickness and the width of the transverse process.

The orientation and shape of the pelvis determines the organization of lumbothoracic spine and plays an important role in spinal stability. However, there are no reports in the literature that evaluate the anatomy of sacrum and iliac wings in patients with DS. In the present study, the morphology of sacrum and iliac wings was analysed using different parameters and the angle between sacroiliac joints was found to be higher in the group with slip than in the normal individuals (p =0.024). The present results indicate that there is a relationship between DS and more coronally oriented inter-sacro-iliac joint angles.

The present study had some limitations. First of all, mobile or low-grade DS cases were evaluated as normal because of the fact that the examination was undertaken in the supine position. 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. Finally, although all measurements were performed with the joint decision of both experts, it was not possible to assess intra- and interobserver variability.

In conclusion, the lumbosacropelvic morphology in DS individuals is quite different from that of normal individuals. Imaging methods should be used to investigate the presence of these morphological abnormalities as they can be defining for pseudospondylolisthesis development and
have important effects on therapy planning.
References


