Novel Method for Evaluation of Sagittal Spinal Alignment Using Cluster Analysis of Slope of Each Vertebra.

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Abstract

Background: The parameters of sagittal spinal alignment proposed to date measure only the specific sectional angle or the specific sectional distance of the entire spine. To evaluate the alignment of the entire spine without segmentation, we sought to measure and analyze the slope of each vertebral body from skull to pelvis. The purpose of this study was to confirm the effectiveness of this novel analytic method for the evaluation of spinal alignment that considers the slope of each spinal vertebra using graph and cluster analysis.

Methods: Every spinal slope from McGregor's slope to the sacral slope of 88 patients who underwent standing whole spine radiography was measured. Subsequently, we conducted cluster analysis of each spinal slope to understand the characteristics of sagittal alignment.

Results: Cluster analysis of whole spinal slopes did not provide useful results in this study because the number of cases per cluster was small due to the large number of parameters. Therefore, we focused the cluster analysis on only the cervical spine slopes. Then, we categorized cervical alignment into four groups (named Normal, Mismatch, Straight, and Sigmoid) based on the results of the cluster analysis. Patients in the Normal and Mismatch groups were older and had lower lumbar apex (L4), apparent lordo-kyphosis around the thoracolumbar junction, and high thoracic kyphosis (TK). Patients in the straight and sigmoid groups were younger, had a higher lumbar apex (L3), flat thoracolumbar junction, and low TK. There was no significant difference between the four groups with respect to pelvic incidence (PI) or pelvic tilt (PT).

Conclusion: We proposed a novel method for visually understanding sagittal alignment. Using this analysis method, differences and similarities of sagittal alignment between each group can be easily identified. More detailed analysis of the whole spine may be possible by increasing the number of cases.

Background

Evaluation of radiographs from various aspects is essential to understand spinal alignment and to improve clinical treatment. In particular, evaluation of the sagittal plane has been emphasized; in addition, many sagittal parameters have been proposed for the evaluation of spinal alignment to achieve better treatment outcomes. [1, 2, 3, 4] Schwab et al. reported a correlation between quality of life and radiographic sagittal parameters in patients treated for adult spinal deformity. [5] They indicated the importance of harmony among spinopelvic parameters and patient-specific realignment using sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence (PI) − lumbar lordosis (LL). In the area of the cervical spine, Ames et al. classified cervical deformity with five modifiers, such as C2–C7 SVA, chin brow vertical axis, and T1 slope (T1S) − cervical lordosis (CL). [6] However, these proposed parameters measure the specific sectional angle or specific sectional distance of the entire spine and evaluate the correlations between them. To characterize the alignment of the entire spine using each spinal element without segmentation, we measured and analyzed the slope of each vertebral body from skull to pelvis. Then, the patients were evaluated using cluster analysis of spinal slopes.

Methods

A total of 88 patients (50 males and 38 females; mean age: 64.4 years) who underwent standing whole spine radiography at our hospital were included in this study. Patients with spinal deformity (scoliosis, kyphosis, or compression fracture) and those who had unclear radiographic images were excluded from this study. Fifty-three patients had cervical spondylotic myelopathy, 20 patients had lumbar spinal canal stenosis, 12 patients had spondylosis, and 3 patients had intradural tumors. Most of the radiographs were taken as the preoperative evaluation for each disease. Every spinal slope from McGregor's slope to the sacral slope was measured, and the values were plotted on a diagram (Fig. 1). In the diagram, 0 degrees indicates the apex of lordosis or kyphosis, the top and bottom of the curve indicate the inflection point of kypho-lordosis, the downward slope indicates kyphosis, and the upward slope indicates lordosis.

McGregor's slope is the angle between the horizontal line and McGregor's line. The C1 slope is the angle between the horizontal line and the line from the anterior tubercle to the posterior tubercle. The C2 slope is the angle between the horizontal line and the line parallel to the lower endplate of the C2 body. From the C3 slope to the sacral (S1) slope were angles between the horizontal line and the line parallel to the upper endplate of each vertebral body. Of these, we conducted cluster analysis of slopes for categorizing sagittal alignment (Fig. 2 and Fig. 3). The mean value of each spinal slope was compared between each group (Table 1). The mean values of each spinal slope from McGregor's slope to the sacral slope for each group were plotted on the diagram, and the shape of the graph was compared (Fig. 4). CL was calculated from the difference between the C2 slope and the C7 slope. Thoracic kyphosis (TK) was calculated from the difference between the T5 slope and the T12 slope. The thoracolumbar angle (TL) was calculated from the difference between the T10 slope and the L2 slope. LL was calculated from the difference between the L1 slope and the sacral slope.

Radiographic analysis and data collection

All subjects had 36-inch spinal radiographs, made with patients standing and free of any external support. All radiographic measurements were performed using picture archiving and communication systems (PACS) and Centricity enterprise web v3.0 software.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS version 27.0, SPSS Inc, Chicago, IL, USA) software was used for all statistical analyses. We performed one-way analysis of variance and the chi-squared test to compare values between groups. Cluster analysis was performed to categorize sagittal alignment using every spinal slope. Statistical analyses were two sided, and p values ≤ 0.05 were considered indicative of statistical significance.

Results

First, cluster analysis was performed using the slope of all vertebrae. However, the analysis for all spinal slopes was not effective due to the many variations of clusters and the small number of cases per cluster in this study (Fig. 2). Therefore, we attempted a cluster analysis focusing only on the cervical (C2 - C7) spine. Based on the results of cluster analysis of cervical slopes, the patients were categorized into five groups (Fig. 3). Fig. 4 shows the mean value for every spinal slope in each cervical group. Based on the values of the parameters of each group, these groups are referred to as the Normal group, Mismatch group, Straight group, Sigmoid group, and Upward group. The upward group (7 patients) had extremely low C1, C2, and McGregor slopes, which implies inappropriate head position (looking upward) at the time of obtaining the radiograph. Therefore, we excluded this group from the analysis. The Normal group (17 patients) had moderate T1S (32°) and moderate CL (19°). The Mismatch group (11 patients) had a high T1S (40°) and low CL (12°). These two groups had lordotic cervical alignment, and the remaining two groups (Straight group and Sigmoid group) had relatively low T1S and exhibited both lordosis and kyphosis in the subaxial cervical spine. The Straight group (25 patients) had 2° lordosis and 3° kyphosis, and the Sigmoid group (28 patients) had 9° lordosis and 4° kyphosis in the subaxial cervical lesion. We arranged these four groups into two groups, based on Fig. 4, to facilitate understanding. We named them the LORDOSIS group (Normal and Mismatch group) and the KYPHOSIS group (Straight and Sigmoid group, which included kyphotic segments in subaxial cervical lesions). First, we compared these two groups in Fig. 4 and Table 1. Patients in the LORDOSIS group were significantly older, had a lower lumbar apex (L4), apparent lordo-kyphosis around the thoracolumbar junction, and had a high TK. Patients in the KYPHOSIS group were significantly younger, had a higher lumbar apex (L3) and flat thoracolumbar junction, and had a low TK. Although there was no significant difference between the LL and TL of the two groups, there seemed to be a clear difference between the two groups with respect to the shape of the graph at the thoracolumbar lesion and the lumbar apex level. This may have resulted from the characteristics of the conventional sectional measurement method. LL is the angle between the L1 endplate and the S1 endplate, and there was no significant difference between the two groups in this section. However, when the slope of each vertebral body was evaluated, the apex level and the inflection point were clearly different. A similar situation was observed with respect to the TL alignment. When comparing the four groups with one-way ANOVA, the pelvic parameters (PI, PT and SS) were not significantly different between the groups. There was a significant difference with respect to the L3 and L4 slopes between the Normal group and the Sigmoid group. In the cervical spine lesion (C2–C7), there were no significant differences between the Normal group and Sigmoid group with respect to the C2 slope and C3 slope, between the Normal group and Straight group with respect to the C4 slope, or between the Straight group and Sigmoid group with respect to the C7 slope after Bonferroni correction. All other groups showed significant differences at each cervical level. However, all these differences were not observed at C1 and McGregor's slopes. This indicates that the craniovertebral junction (Occipito-C1-C2 joint) can adjust a variety of cervical angles (mismatches) and plays an essential role in maintaining horizontal gaze.

Discussion

We proposed a new method for the analysis of spinal alignment. Measuring the slope of each vertebral body and plotting it on a diagram enables a clear understanding of the characteristics of the individual whole spinal alignment visually, which includes the magnitude of lordo-kyphosis, apex of curvature, and inflection point. Furthermore, since the measurement is not for a specific section (such as T5-T12 or L1-S1), it is easy to find a portion or degree different from the standard pattern. It also has the potential to classify sagittal alignment by using cluster analysis for the measured spinal slope values of specific sections. This study clarified the difference in spinal alignment between the LORDOSIS and KYPHOSIS groups. This seemed attributable to the difference in T1S associated with the TK difference. No significant between-group difference was observed with respect to LL, TL, or pelvic parameters (PI, PT and SS); however, the lumbar apex level (L3 and L4) was significantly different between groups. These results are also clearly discernible from the shape of the graph. The LORDOSIS group contained older patients with a lower lumbar apex (L4), apparent lordo-kyphosis around the thoracolumbar junction, and a higher TK than the KYPHOSIS group. LL is the sectional angle between the L1 endplate and the S1 endplate, and there was no significant difference between the two groups in this section. However, when the slope of each vertebral body was evaluated, as in this method, the apex level and the inflection point were clearly different. A similar situation was observed with respect to TL alignment. These discrepancies might result from the characteristics of the conventional sectional measurement method. Although there were no significant differences between the TL values of the four groups, the shape of the graph showed clear differences (apparent kypho-lordosis or flat alignment). This is an advantage of this method in that it allows visual evaluation of the entire spine, including each vertebral body element. Roussouly et al. classified lumbar spine alignment of healthy volumteers into four types using apex level, inflection point, number of vertebral bodies in each curvature, total kyphosis and lordosis in degrees, lordosis tilt angle, and the angle of sacral slope [7]. They indicated the difference in apex level and inflection point of each group. Although this study focused on cervical alignment, we observed significant differences in lumbar apex level and lumbar inflection point between the groups, as in their study. This indicates the importance of these parameters in evaluating spinal alignment. The shape of the graph helps clarify individual spinal alignment, including the apex, inflection point, and magnitude of lordosis and kyphosis. Comparing normal spinal alignment patterns and patient patterns makes it easy to understand the alignment of each patient and how much it differs from the normal spine.

Some limitations of our study should be acknowledged. Although this is the first study that analyzed whole spinal alignment with each spinal element, this analysis did not include distance values, such as SVA, or sectional angle values, such as the T1 pelvic angle. Appropriate selection and analysis of spinal elements may allow precise evaluation of spinal alignment and ensure better surgical results. Since the subject of this study was patients who visited our spine clinic and the number of patients in each group may not be sufficient for categorizing or comparing values between the groups in this study, the details of categorization and its characteristics will require a larger study of healthy volunteers in the future. Last, selection bias may have influenced the results because all 88 patients were patients of our hospital, and deformity cases were excluded from this study. The impact of this analysis on the quality of life of patients is unknown.

Conclusion

In this study, we proposed a novel method for understanding sagittal alignment visually. We categorized cervical alignment into four groups using cluster analysis of every cervical spinal slope. There were differences between the cervical LORDOSIS group and the KYPHOSIS group with respect to the thoracolumbar alignment and the lumbar apex level, which could not be found with the conventional Cobb method. Additional larger studies will be required to better understand this analysis in the future.

Abbreviations

TK: thoracic kyphosis

PI: pelvic incidence

PT: pelvic tilt

SVA: sagittal vertical axis

LL: lumbar lordosis

T1S: T1 slope

CL: cervical lordosis

TL: thoracolumbar

SS: sacral slope

Declarations

- Ethics approval: All methods were performed in accordance with the Declaration of Helsinki. The institutional review board of the clinical research support center of the University of Tokyo Hospital approved this study.
- Consent to participate: Written informed consent was obtained from the patients.
- Consent for publication: Written informed consent was obtained from the patients.
- Availability of data and material: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.
- Conflicts of interest/Competing interests: Not applicable
- Funding: Not applicable

- Authors' contributions: Y.M. performed the design of the work, interpreted the data and drafted the work. Y.O. and Y.T. and T.D. and S.K. performed interpretation of data. H.N. performed data acquisition. S.T. performed revised this work. All authors read and approved the final manuscript
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Table

Table 1. Comparison of the demographic characteristics and the radiographic parameters among the four groups.

	Total n = 81	Normal n = 17	Mismatch n = 11	Straight n = 25	Sigmoid n = 28	*P value* *(ANOVA)*
Age	64.4 (13.9)	72.6 (6.6)	73.9 (6.1)	57.8 (14.9)	61.6 (14.4)	0.0002
Male/Female	49/32	12/5	8/3	16/9	13/15	0.28(chi-squared)
Pathology (C/L/D/T)	53/20/5/3	12/4/0/1	4/4/3/0	17/6/1/1	20/6/1/1	0.40(chi-squared)
McG Slope	−0.2 (6.7)	1.6 (6.5)	0.64 (6.6)	−1.1 (8.1)	−0.64 (5.3)	0.57
C2 Slope	16.7 (8.0)	10.8 (5.6)	26.9 (7.6)	20.4(4.7)	12.9 (6.0)	<0.0001
T1 Slope	25.8 (10.6)	32.5 (4.5)	40.3 (13.6)	22.5 (5.2)	28.1 (13.4)	<0.0001
L3 Slope	−4.3(8.5)	−9.0 (11.1)	−8.2 (5.8)	−2.6 (7.3)	−1.8 (7.2)	0.009
L4 Slope	3.8 (10.3)	0.2 (11.3)	-2.0 (9.4)	5.0 (8.1)	7.2 (10.6)	0.026
Sscral Slope	34.7 (9.5)	32.9 (10.8)	30.8 (11.6)	34.8 (7.7)	37.2 (8.9)	0.23
CL	5.9 (13.5)	18.6 (8.8)	12.4 (19.4)	−1.6 (7.6)	2.3 (10.8)	<0.0001
TK	22.7 (9.1)	28.7 (8.4)	31.0 (7.7)	21.4 (8.3)	17.2 (6.3)	<0.0001
TL	−0.9 (6.9)	−2.9 (9.2)	−4.5 (6.9)	−0.9 (6.5)	0.0 (5.1)	0.090
LL	43.9 (13.3)	45.3 (12.2)	42.7 (21.8)	43.2 (11.3)	44.1 (11.9)	0.95
PI	54.0 (10.4)	52.0 (10.6)	51.4 (11.3)	54.5 (8.8)	55.9 (11.1)	0.52
PT	19.2 (8.9)	19.1 (11.8)	20.5 (10.8)	19.7 (5.7)	18.5 (8.9)	0.92
T1S-CL	19.9 (8.1)	13.9 (6.3)	27.9 (8.5)	23.8 (6.3)	17.1 (6.2)	<0.0001
PI-LL	10.1 (14.6)	6.7 (15.1)	8.6 (22.6)	11.3 (11.6)	11.7 (13.4)	0.68

C: cervical myelopathy; L: lumbar canal stenosis; D: degenerative disease; T: spinal tumor; McG: McGregor's; CL: cervical lordosis; TK: thoracic kyphosis; TL: thoracolumbar angle; LL: lumbar lordosis; PI: pelvic incidence; PT: pelvic tilt; T1S: T1 slope

Figures

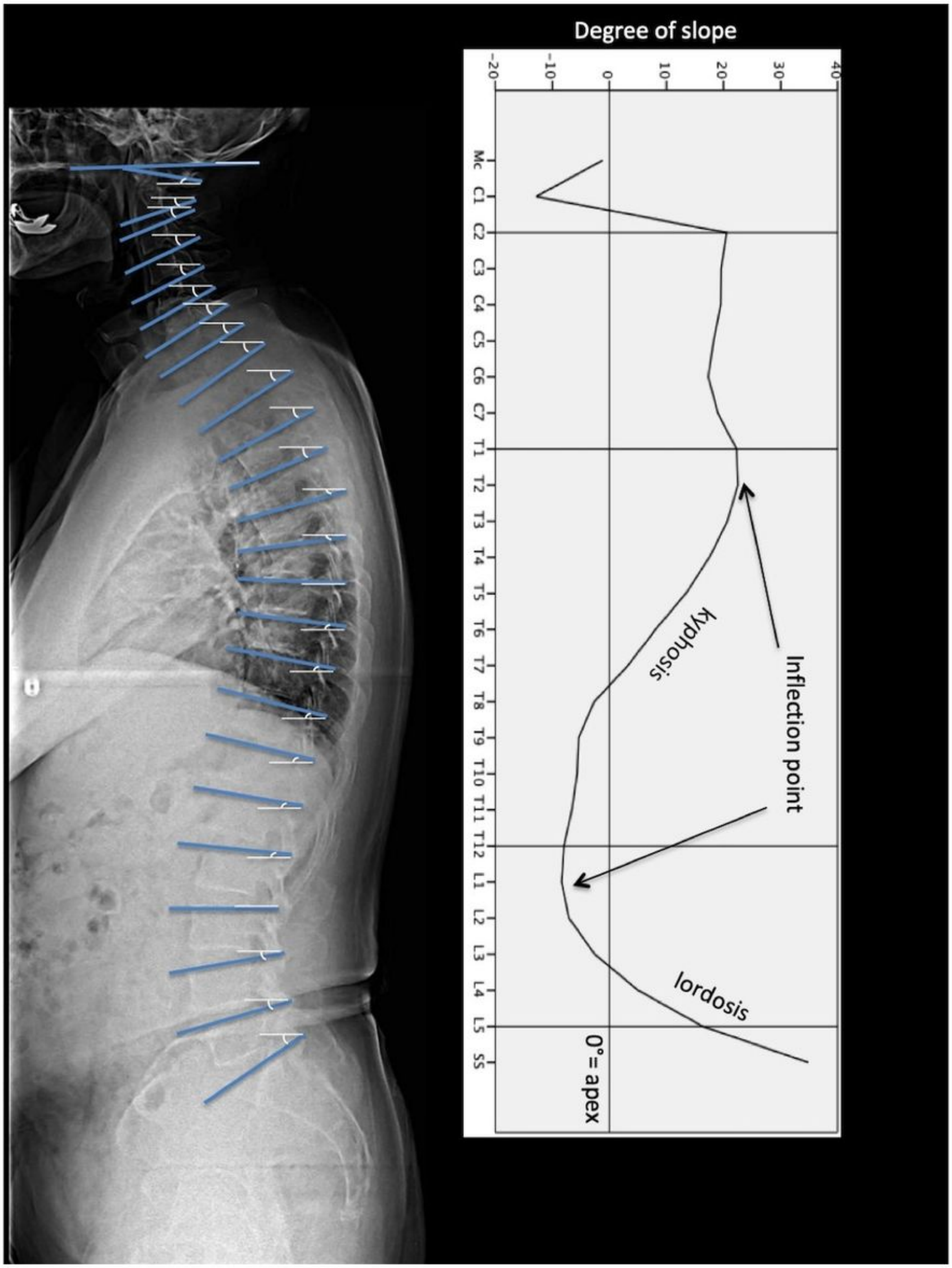

Figure 1

Method for measurement of every spinal slope and the graph of a sample case. Every spinal slope from McGregor's slope to the sacral slope was measured, and the values were plotted on a diagram. 0 degrees indicates the apex of lordosis or kyphosis, the top and bottom of the curve indicate the inflection point of kypho-lordosis, the downward slope indicates kyphosis, and the upward slope indicates lordosis.

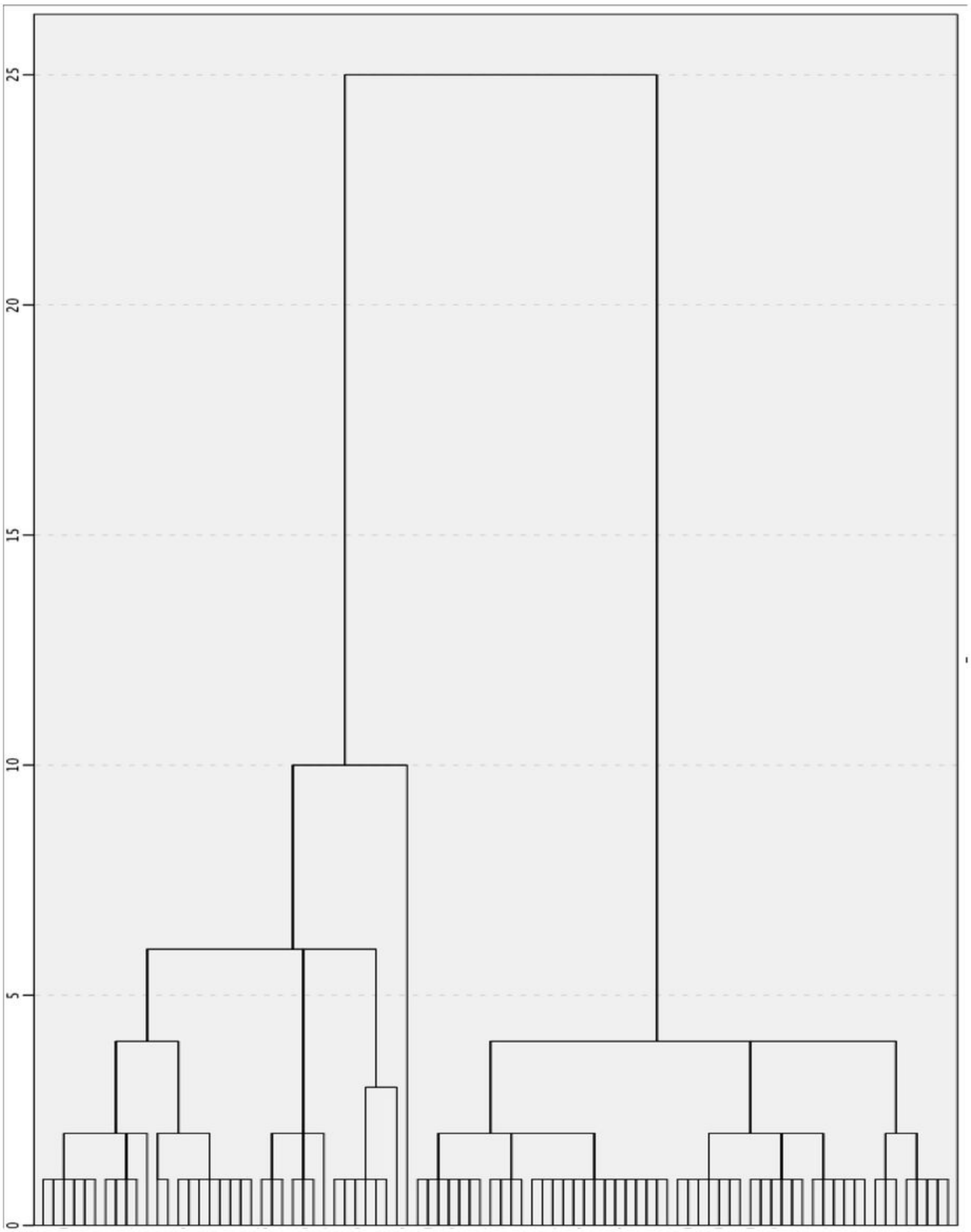

Figure 2

Dendrogram of cluster analysis for all spinal slopes was not effective due to the many variations of clusters and the small number of cases per cluster in this study.

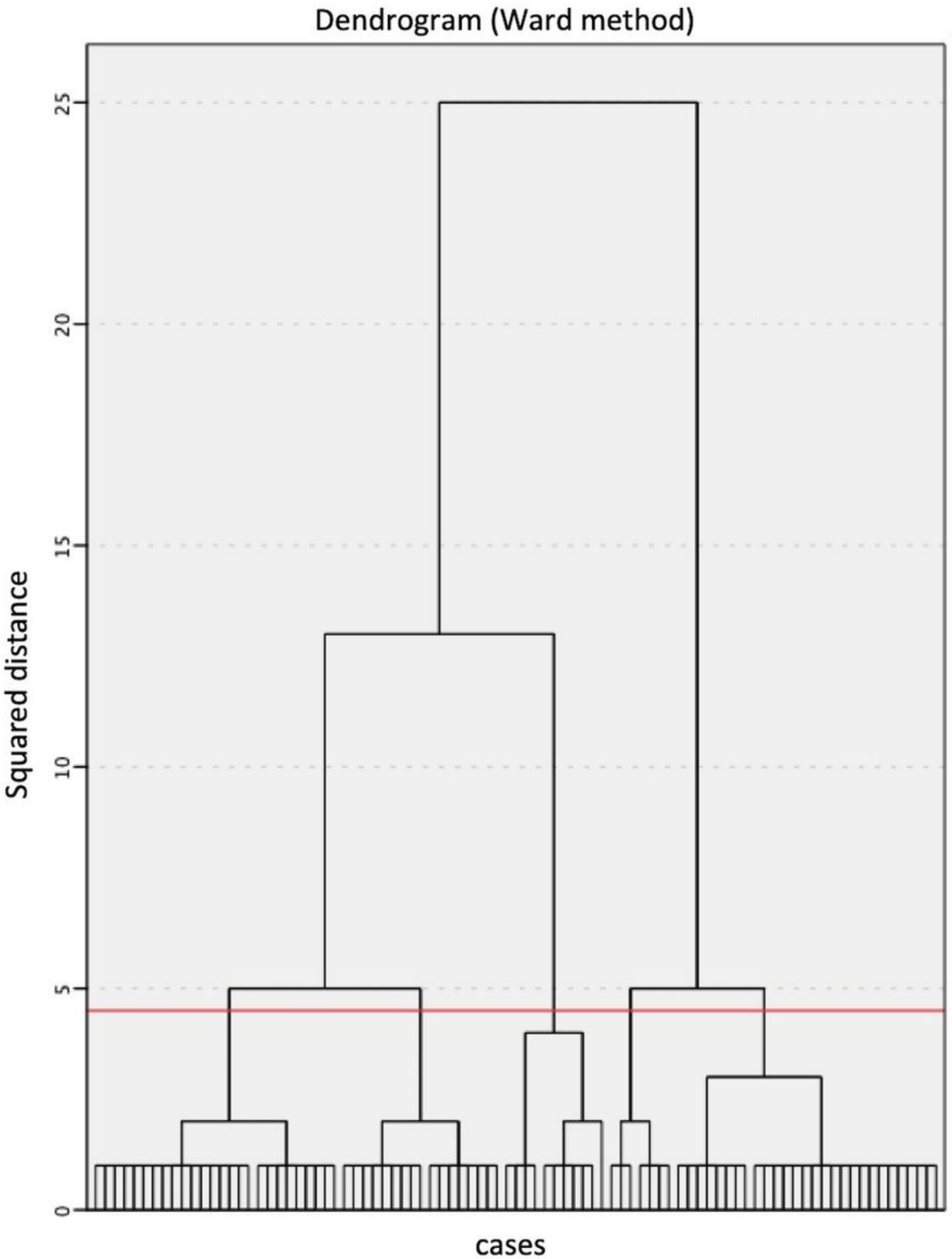

Figure 3

Dendrogram of cluster analysis for subaxial cervical spinal slopes. Patients were categorized based on the red line level.

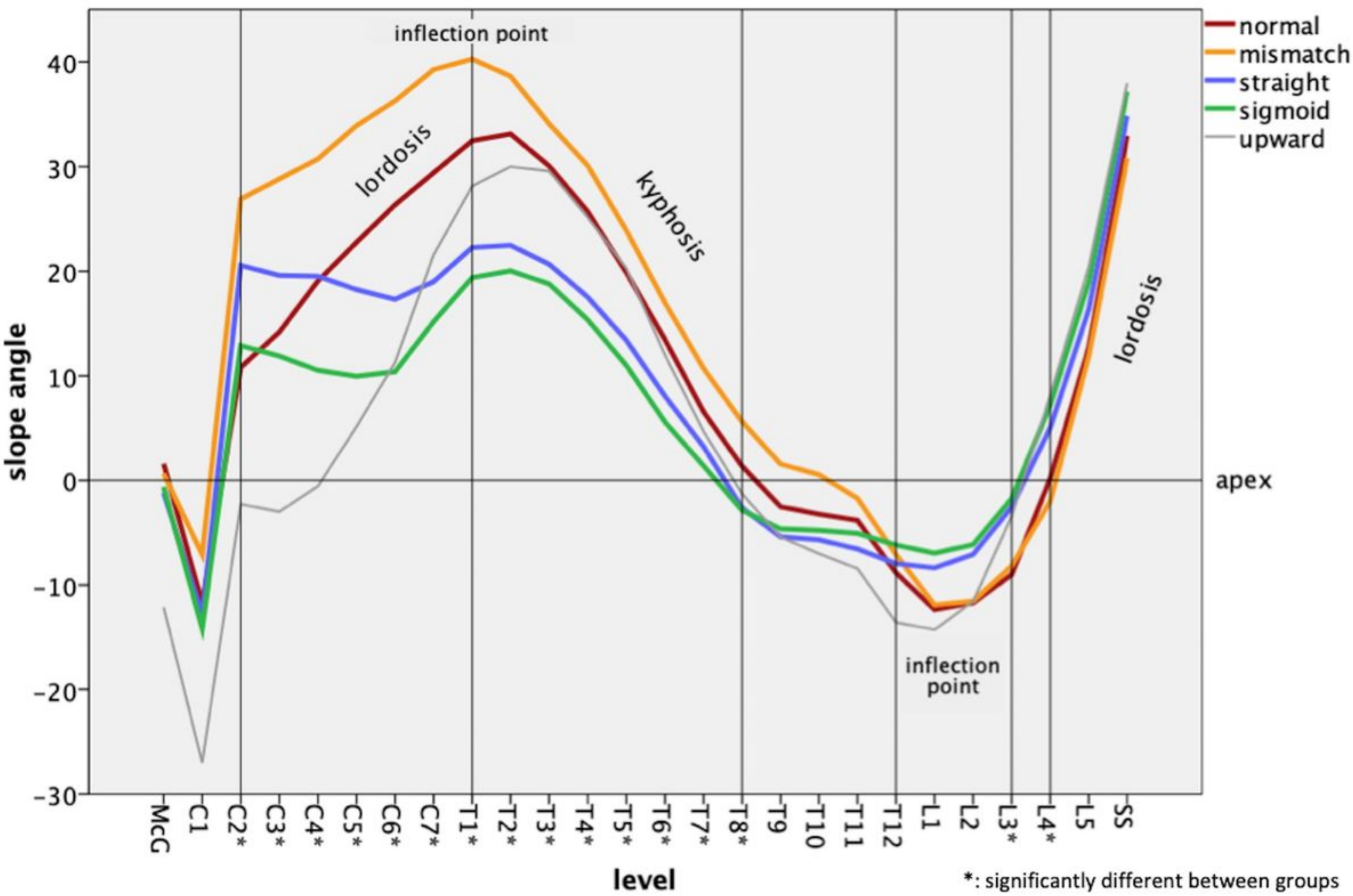

Figure 4

The mean values of each spinal slope from McGregor's slope to the sacral slope for each group were plotted on the diagram.