Radiographic Assessment of Sagittal Spinal Alignment to Correlate Standards Classified by Age and Low Back Pain

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Abstract

In the present study, a favorable standing spinal alignment was assessed based on standing lateral spinal radiographs. Moreover, correlations between the establishment of standards classified by age and low back pain were assessed. In this study, 343 subjects were enrolled; 169 males and 174 females ranging from 12 to 89 years of age (mean: 53.4 years). Both the degree of cervical lordosis and thoracic kyphosis increased with age, while the degree of lumbar lordosis decreased with age, resulting in bowing of the trunk and slight anterior deviation of the C7 plumb line. Distance B (the distance between the C7 plumb line and the posterior superior vertebral body of the S1) correlated with age, and tended to be longer in patients with low back pain (LBP). Therefore, predicted values for distance B were calculated in the respective age groups using regression analysis. Distance B predicted in the respective age groups in this study may be useful for establishing a targeted alignment in surgical planning.

Introduction

In recent years, spinal surgery techniques have markedly advanced due to the introduction of instrumentation surgery. However, residual low back pain is a serious problem after spinal surgery because its etiology and treatment remain unclear. In a previous report, the authors evaluated the relationship between spinal sagittal balance and residual low back pain. However, standard values for Japanese classified by age have not yet been established. In the present study, a favorable standing spinal alignment was assessed based on standing lateral spinal radiographs. Moreover, correlations between the establishment of standards classified by age and low back pain were assessed.

Subjects

In this study, 343 subjects were enrolled; 169 men and 174 women between 12 and 89 years of age (mean: 53.4 years) in whom standing lateral spinal radiographs were acquired at the outpatient clinic of our department or during group medical health checks at their workplaces. These subjects were divided into the following two subgroups: a non-low back pain (non-LBP) group consisting of 109 subjects without a past history of LBP (50 men and 59 women between 14 and 86 years of age, mean: 52.4 years) and an LBP group consisting of 234 subjects (119 men and 115 women between 12 and 89 years of age, mean: 54.4 years). Radiographic data were compared between those two groups.

Methods

Standing lateral spinal radiographs were acquired in the most stable and relaxed position while the subjects were standing with their arms extended and their hands gently clasped in front of the trunk. According to Cobb's procedure, the cervical lordotic angle (an angle between the lower edge of the C2 vertebral body and the lower edge of the C7 vertebral body), the thoracic kyphotic angle (an angle between the upper edge of the
Th1 vertebral body and the lower edge of the Th12 vertebral body, and the lumbar lordotic angle (an angle between the upper edge of the L1 vertebral body and the lower edge of the L5 vertebral body) were measured. In addition, according to the procedure proposed by Jackson et al., the distance between the C7 plumb line and the posterior superior vertebral body of the S1 (distance B) was measured. Subsequently, the following issues were assessed: the correlation between distance B and the 3 sagittal angles described above; data differences between the non-LBP and LBP groups; severity of LBP in the LBP group; and data differences classified by the disease type. Furthermore, predicted values of distance B classified by the respective age groups were obtained in the non-LBP group as standard values for Japanese. We used Student’s t-test to assess the presence of significant differences between the groups and Kruskal-Wallis test to analyze changes in spinal curvature due to age.

Results

Tables 1, 2, and 3 show the respective radiographic data. Mean values for the respective parameters were 13.2° for the cervical lordotic angle, 35.3° for the thoracic kyphotic angle, 44.2° for the lumbar lordotic angle, and 15.9 mm for distance B. There were no differences relation to gender for any of these parameters. In addition, there were no positive correlations among these parameters reflecting the severity of spinal deformity. Subsequently, the subjects were subclassified into the following 3 groups based on their age. Changes in the respective parameters were compared among these 3 groups: subjects aged 39 or younger (n=98), those between 40 and 69 years of age (n=188), and those aged 70 years or over (n=57). Changes in the respective parameters were compared among these 3 groups. Mean values for the cervical lordotic angle were 5.2°, 14.6°, and 23.8°, respectively (Fig. 1), while mean values for the thoracic kyphotic angle were 32.7°, 35.8°, and 38.5°, respectively (Fig. 2). In addition, mean values for the lumbar lordotic angle were 44.3°, 44.7°, and 39.5°, respectively (Fig. 3), while mean values for distance B were 6.1 mm, 12.5 mm, and 44.2 mm, respectively (Fig. 4). Although both the cervical lordotic angle and thoracic kyphotic angle tended to increase with age, the lumbar lordotic angle was significantly smaller in subjects aged 70 years or over (p<0.05). In addition, distance B was significantly longer in subjects aged 70 years or over than in subjects below 70 years of age (p<0.005). There were no significant differences in the cervical lordotic angle, thoracic kyphotic angle, or lumbar lordotic angle between the non-LBP and LBP groups (Fig. 5). The mean value of distance B was significantly shorter in the non-LBP group than in the LBP group (7.4±28.4 mm vs. 19.8±29.5 mm, p<0.005) (Fig. 6). In addition, distance B increased and pos-
Changes in cervical lordotic angle by age. There were significant differences in cervical lordotic angle among the three age groups, indicating a significant increase in cervical lordotic angle due to aging (Kruskal-Wallis test, P<0.001). *P<0.005

Changes in thoracic kyphotic angle by age. There was a significant difference in thoracic kyphotic angle between the group 39 years old or younger and the group 70 years old or over, indicating a significant increase in the angle due to aging. (Kruskal-Wallis test, P=0.02) **P<0.05, NS: not significant.

Changes in lumbar lordotic angle by age. There were significant differences in lumbar lordotic angle between the group 39 years old or younger and the group 70 years old or over, and between the group 40-69 years old and the group 70 years old or over. However, no significant difference due to aging was seen. **P<0.05, NS: not significant

tively correlated with age in both groups (r=0.834, n=109, p<0.0001 in the non-LBP group, and r=0.596, n=234, p<0.0001 in the LBP group) (Fig. 7).

According to the pain scale proposed by Eric & James2) (Table 4), patients in the LBP group were subclassified as follows based on the severity of LBP: 109 as grade 1 (50 men and 59 women between 12 and 89 years of age, mean: 52.5 years); 74 as grade 2 (38,
Fig. 4 Changes in Distance B by age. There were significant differences in distance B between the group 39 years old or younger and the group 70 years old or over, and between the group 40–69 years old and the group 70 years old or over. A significant increase in distance B due to aging was observed. (Kruskal-Wallis test, \( P < 0.001 \)) \( *P < 0.005 \), NS: not significant.

Fig. 5 Relationship between cervical lordotic angle and low back pain (LBP). People with LBP had significantly smaller cervical lordotic angles than people without LBP.

Fig. 6 Relationship between Distance B and LBP. People with LBP had significantly greater distance B than those without LBP. \( *P < 0.005 \)

Men and 36 women between 21 and 89 years of age, mean: 57.4 years) ; 41 as grade 3 (24 men and 17 women between 22 and 81 years of age, mean: 58.5 years), and 10 as grade 4 (7 males and 3 females between 17 and 75 years of age, mean: 36.9 years). Subsequently, the respective parameters were compared among these patients subclassified by the severity of LBP. The thoracic kyphotic angle in patients with grade 2 LBP (39.1 ± 8.1°) was significantly larger than that in patients with grade 1 or 3 LBP. However, there were no significant
Fig. 7  Relationship between Distance B and age. The size of distance B was directly proportional to age in both groups with and without LBP.

Table 4  Pain Scale (Eric & James, 1998)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Pain Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No pain</td>
</tr>
<tr>
<td>1</td>
<td>Occasional minimal pain, no need for medication</td>
</tr>
<tr>
<td>2</td>
<td>Occasional moderate pain, occasional medication no interruption of work or ADL</td>
</tr>
<tr>
<td>3</td>
<td>Moderate pain with slight modification of work and ADL and frequent medication</td>
</tr>
<tr>
<td>4</td>
<td>Moderate to severe pain, chronic medication, significant change in work and ADL</td>
</tr>
<tr>
<td>5</td>
<td>Constant severe incapacitating pain</td>
</tr>
</tbody>
</table>

Table 5  Sagittal Alignment and Grade

<table>
<thead>
<tr>
<th>Grade</th>
<th>cervical lordotic angle</th>
<th>thoracic kyphotic angle</th>
<th>lumbar lordotic angle</th>
<th>distance B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.5±12.5°</td>
<td>33.9±8.6°</td>
<td>42.6±13.3°</td>
<td>20.4±29.3 mm</td>
</tr>
<tr>
<td>2</td>
<td>14.9±15.6°</td>
<td>39.1±8.1°</td>
<td>45.8±13.7°</td>
<td>20.1±26.9 mm</td>
</tr>
<tr>
<td>3</td>
<td>16.4±9.0°</td>
<td>32.2±10.2°</td>
<td>46.4±12.9°</td>
<td>16.6±33.8 mm</td>
</tr>
<tr>
<td>4</td>
<td>12.0±5.7°</td>
<td>33.0±18.4°</td>
<td>43.4±8.5°</td>
<td>25.0±34.6 mm</td>
</tr>
</tbody>
</table>

Table 6  Sagittal Alignment and Causal Disease

<table>
<thead>
<tr>
<th>Grade</th>
<th>cervical lordotic angle</th>
<th>thoracic kyphotic angle</th>
<th>lumbar lordotic angle</th>
<th>distance B</th>
</tr>
</thead>
<tbody>
<tr>
<td>lumbar disc lesion (n=117)</td>
<td>9.5±12.0°*</td>
<td>33.2±9.5°</td>
<td>45.6±12.5°</td>
<td>10.7±24.9 mm*</td>
</tr>
<tr>
<td>spondylolisthesis (n=29)</td>
<td>11.7±12.8°</td>
<td>35.0±9.2°</td>
<td>48.1±14.1°</td>
<td>32.3±33.1 mm</td>
</tr>
<tr>
<td>spondylosis deformance (n=80)</td>
<td>20.0±12.5°</td>
<td>37.9±7.9°</td>
<td>40.8±13.8°**</td>
<td>29.3±30.5 mm</td>
</tr>
</tbody>
</table>

differences in either the cervical lordotic angle or the lumbar lordotic angle among these patients. Although distance B was slightly longer in patients with grade 4 LBP, there was no significant difference in distance B among patients classified by the severity of LBP (Table 5).

Among patients in the LBP group, 226 given a diagnosis of organic LBP; lumbar disc lesion in 117 (57 males and 60 females between 12 and 68 years of age, mean: 42.3 years), spondylolisthesis in 29 (9 males and 20 females between 45 and 81 years of age, mean: 66.4 years), and spondylosis deformance in 80 (48 males and 32 females between 49 and 89 years of age, mean: 68.0 years). The cervical lordotic angle in patients with lumbar disc lesion (9.5±12.0°) was significantly smaller than that in patients with spondylolisthesis or spondylosis deformity (p<0.005). Moreover, the lumbar lordotic angle in patients with spondylosis deformance lesion was significantly smaller than that in patients with other types of organic LBP (p<0.05).
Mean values for distance B were 10.7±24.9 mm in patients with lumbar disc lesion, 32.3±33.1 mm in those with spondylolysis and spondylolisthesis, and 29.3±30.5 mm in those with spondylosis deformance. Therefore, distance B was significantly shorter in patients with lumbar disc lesion than in those with other types of organic LBP (p<0.005) (Table 6).

Discussion

The degree of spinal deformity in the upright position gradually varies with age. However, most cases of spinal deformity remain uncorrected. Currently, there is no useful index suggesting which sagittal alignment is appropriate for fixation of the lumbar spine when lumbar spinal fusion is indicated for a variety of low back lesion. In the present study, we analyzed standing lateral spinal radiographs in patients with and without LBP to assess and clarify the difference of the alignment between the non-LBP and LBP groups. We also attempted to establish standard values that was useful as an indicator for planning lumbar spine surgery.

When the results of this study were compared with those of previous studies on sagittal balance in Japanese, mean values for cervical lordotic angle, thoracic kyphotic angle, and lumbar lordotic angle were similar to those reported previously: Fuchioka et al. reported a mean cervical lordotic angle of 16.3±10.3°, while Taki et al. reported a mean thoracic kyphotic angle of 28.0±8.2°. In addition, Taki et al. reported a mean lumbar lordotic angle of 37.1±11.0° (between the lower edge of L1 and the lower edge of L5), and Toyama et al. reported a mean lumbar lordotic angle of 34.2° (between the upper edge of L1 and the lower edge of L5).

Subsequently, when the results of this study were compared with those of non-Japanese studies, Harrison et al. reported a similar mean cervical lordotic angle of 14.89±10.97°. However, the mean thoracic kyphotic angle obtained in this study was smaller than that reported by Jackson et al. (43–47°: between the lower edge of L1 and the lower edge of L5) and that reported by Korovessis et al. (41.8±13°). With regard to the lumbar lordotic angle, although the mean lumbar lordotic angle obtained in this study was smaller than that reported by Jackson et al. (56–62°) and that reported by Anderson et al. (59.8±2.9°), it was similar to that reported by Korovessis et al. (45.7±12°). No previous Japanese study has assessed distance B. Jackson et al. reported a mean distance B of 7–9 mm, which was slightly shorter than that obtained in this study (15.9±29.7 mm). Few studies have compared sagittal alignment between Japanese and Western people. In general, the degree of both thoracic kyphosis and lumbar lordosis was reported to be larger in Western people than in Japanese. Therefore, the plumb line in Western people may be located behind the plumb line in Japanese.

It was reported that the degree of lumbar lordosis is generally lower in patients with LBP. Hansson et al. assessed radiograms of the lumbar spine in 600 patients with and without acute or chronic LBP, and reported that there were no significant differences in the degree of lumbar lordosis among these patients. In the present study, there were no significant differences in the degree of cervical lordosis, thoracic kyphosis, or lumbar lordosis between the non-LBP and LBP groups, suggesting that changes in the degree of spinal deformity are not always associated with the occurrence of LBP, although distance B was significantly longer in the LBP group than in the non-LBP group. The anteversion of the trunk causes the moment of procurvation to be loaded on the trunk in a standing position or during walking, frequently leading to chronic low back pain. Takemitsu et al. reported that when the center of gravity of the upper half of the body is located anteriorly (distance B becomes greater), prolonged action of the extensor of the lumbar region is necessary to keep the posture, and consequently, fatigue of the extensor causes myogenic low back pain. Moreover, prolonged action of the lumbar-region extensor with the trunk in an anteversion position is accompanied by increased intramuscular pressure, and eventually by reduced blood circulation in the muscle, which is involved in the development of tissue injury and the accumulation of pain substance.

When age-related changes in the degree of spinal deformity were assessed by standing lateral spinal radiography, the degree of cervical lordosis and thoracic kyphosis increased with age, whereas the degree of lumbar lordosis decreased with age. Therefore, it was confirmed that the trunk tended to become gradually bowed with age. These findings were identical with those reported previously. To explain this, Arita et al. hypothesized that the degree of cervical lordosis secondarily increases to compensate for increased thoracic kyphosis and decreased lumbar lordosis in the elderly to maintain the total balance of the spinal column. Similarly, Suzuki reported that age-related changes in the spinal column are initiated by the progression of thoracic kyphosis, followed by the progression of cervical lordosis and decreased lumbar lordosis to compensate for increased thoracic kyphosis to maintain the total balance of the spinal column. Because such age-related changes influence the total balance of the spinal column, distance B was positively correlated with age both in the non-LBP and LBP groups (r=0.834, n=109, p<0.0001 in the non-LBP group, and r=0.596, n=234, p<0.0001 in the LBP group). Based on
the results of regression analysis, values for distance B were predicted in the respective age groups (Table 7). In our department, predicted values for distance B are currently used as an index for the indication of fusion. Therefore, the correlation between residual LBP and distance B was also assessed in patients undergoing spinal surgery to confirm the propriety of these predicted values. When distance B was measured in 39 surgically treated patients with degenerative spondylolisthesis (25 males and 14 females between 42 and 79 years of age, mean: 64.2 years) who complained of residual LBP postoperatively, the mean distance B was 43.0 ± 26.0 mm in those with grade 2 or less severe LBP (according to the pain scale proposed by Eric et al.). However, the mean distance B was 31.2 ± 24.7 mm in those with grade 1 or more severe LBP, which was similar to distance B predicted in 60-year-old patients. Therefore, the suitability of predicted values for distance B was confirmed.

When spinal alignment classified by the respective disease types was assessed, distance B was shorter in patients with lumbar disc lesion than in those with other types of organic LBP. In addition, the degree of cervical lordosis and thoracic kyphosis was larger, but the degree of lumbar lordosis was smaller in patients with spondylosis deformity than in those with other types of organic LBP. However, mean ages of these 3 disease groups were 42.3, 66.4, and 68.0 years, respectively. Therefore, these values for distance B were not disease specific, and might be specific to aging.

Conclusions

1. Standing lateral spinal radiographs were acquired in Japanese patients with and without LBP to obtain normal spinal alignment, as well as to assess the relationships among radiographic parameters, age, and LBP.
2. When 343 patients with and without LBP were investigated, the mean cervical lordotic angle was 13.2°, the mean thoracic kyphotic angle was 35.3°, the mean lumbar lordotic angle was 44.2°, and the mean distance B was 15.9 mm.
3. Both the degree of cervical lordosis and thoracic kyphosis increased with age, while the degree of lumbar lordosis decreased with age, resulting in bowing of the trunk and slight anterior deviation of the C7 plumb line.
4. Distance B correlated with age, and tended to be longer in patients with LBP. Therefore, predicted values for distance B were calculated in the respective age groups using regression analysis.
5. Further evaluations are necessary to use these values for distance B predicted in the respective age groups in this study. However, distance B may be useful for establishing a targeted alignment in surgical planning.

Acknowledgement

The author are indebted to Professor J. Patrick Barron of the International Medical Communication Center of Tokyo Medical University for his review of this manuscript.

References

9) Andersson GB, Murphy RW, Ortengren R, Na-

| Table 7 Predicted Values for Distance B |
| age (years) | non-LBP group | LBP group |
| n = 109 | n = 234 |
| 20 | -4.32 mm | 0.80 mm |
| 30 | 3.31 | 6.41 |
| 40 | 10.94 | 12.02 |
| 50 | 18.57 | 17.52 |
| 60 | 26.20 | 23.23 |
| 70 | 33.83 | 28.84 |
| 80 | 41.46 | 34.45 |
立位全脊柱 Sagittal alignment に関する X 線学的検討
—— 年代別基準値の設定および腰痛との相関について——

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【要旨】 我々は立位全脊椎側面 X 線像から立位の良好な spinal alignment を知る目的で多角的に X 線計測を行ない、年齢および腰痛との関連について比較検討した。

【対象】 集団検診、整形外科外来で、立位全脊椎側面 X 線撮影した 343 例を対象とした。男性 169 例、女性 174 例、平均 53.4 歳で、このうち非腰痛群 109 例、腰痛群 234 例の 2 群について X 線計測値を比較した。

【方法】 立位全脊椎側面 X 線にて、頚椎前弯角、胸椎前弯角、腰椎前弯角、C7 plumb line と S1 椎体後上隅との距離（以下距離 B）の 4 項目を計測し、各計測値の相関性を調べるとともに、年齢別および腰痛の有無による計測値を比較検討した。

【結果】 頚椎前弯角は 13.2±13.4°、胸椎前弯角は 35.3±9.2°、腰椎前弯角は 44.2±13.3° であり、加齢変化により体幹は前傾姿勢を呈する傾向がみられた。距離 B は全症例で 15.9±29.7 mm、非腰痛群 7.3±28.7 mm、腰痛群 19.8±29.5 mm と腰痛群が有意に高値であった (p=0.005)。また距離 B は高齢ほど高値を示し統計学的有意差を認めた (Kruskal-Wallis test)。

【考察】 立位での sagittal balance は加齢とともに徐々に前傾傾向を示すが、多くは矯正の対象とされることはない。腰椎除圧固定術が適応される際には、いかなる alignment に固定するのが適切であるか明確な指標がないのが現状である。今回の検討では腰痛と最も相関する X 線計測値は距離 B であり腰痛群と非腰痛群の間に明らかな有意差がみられた。また非腰痛群について年代別の予測値を算出することができた。この予測値を脊椎固定術の指標とすることは、若年者においては今後の生理学的変化との関連が解決されていないため問題があるが、中高年に関しては教室の西山が術後遺残腰痛の検討から距離 B が 28-32 mm のものが最も腰痛が少ないことを報告しており、今回の予測値とほぼ一致していた。この結果を術後 alignment の指標として手術計画をたて、短期では良好な成績が得られているが、今後さらに長期成績を検討する必要がある。

【結論】 中高年の腰椎除圧固定術の手術計画において、目標 alignment を設定する上で、立位全脊椎側面 X 線における距離 B は有用な指標と考えられる。

＜Key words＞ 矢状面配列、距離 B、立位全脊椎 X 線