Relationship of Sagittal Spinal Alignment With Low Back Pain And Physical Performance In A Population-Based Japanese Cohort: The Wakayama Spine Study

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Abstract

Studies have suggested a relationship between sagittal malalignment of the spine and low back pain (LBP). The Wakayama Spine Study investigated the relationship between spinal alignment, LBP, and physical performance in 1491 individuals who attended a second follow-up visit as part of the ROAD Study and for whom standing lateral spinal radiographs were available. The sagittal vertical axis at C7 (C7 SVA) was measured by a spinal surgeon. LBP in the previous month was determined by the Oswestry Disability Index (ODI), and indicators of physical performance were measured. The mean C7 SVA was 11.0 ± 42.7 mm and significantly greater in older subjects ($p<0.001$). Based on their C7 SVA, the subjects were divided into small (<40 mm), intermediate (40≤SVA<95 mm), and large (≥95 mm) groups. LBP was more prevalent in subjects with a larger C7 SVA (small, 35.7%; intermediate, 47.3%; large, 59.4%; $p<0.001$) and those with a higher ODI score (10.0%, 17.5%, and 29.4%, respectively; $p<0.001$). Physical performance was significantly decreased in subjects with a larger C7 SVA ($p<0.001$). Multiple linear regression analysis revealed that LBP and physical performance were significantly associated with C7 SVA ($p<0.001$). Thus, sagittal malalignment of the spine may lead to LBP and decreased physical performance.

Introduction

Sagittal spinopelvic malalignment is one of the most prevalent disorders of the aging spine.

The sagittal curvature of the spine and pelvis balance each other to maintain a stable posture and horizontal gaze. Glassman et al. reported that positive sagittal balance was significantly related to clinical symptoms and health-related quality of life in patients with adult spinal deformity.[1] When the sagittal alignment is abnormal, more energy is required to maintain balance without external support.[2] Considering the progressive nature of spinal deformity and the ongoing escalation in numbers of elderly people in most developed countries, there is an urgent need for prevention strategies. Nonetheless, the impact of spinal deformity on physical performance, which is the basic information needed for prevention of spinal deformity, has not been well characterized. The impact of spinal deformity on physical performance cannot be estimated by hospital surveys because many people already have severely impaired functional status by the time they visit a hospital. Therefore, a population-based study is needed for clarification of the relationship between sagittal spinal alignment and physical performance. Whole-spine radiographs are important in the diagnosis of spinal deformity, but few population-based studies of spinal deformity using whole-spine radiography have been performed. Decreased physical performance is considered a symptom of spinal deformity and can lead to decreased quality of life, especially in elderly patients with kyphotic deformity. Although spinal deformity is commonly seen in asymptomatic elderly subjects, it is unclear whether or not physical performance deteriorates in patients with adult spinal deformity. Therefore, the objective of this study was to examine the association between sagittal spinal alignment parameters and physical performance.

Results

The baseline characteristics of the 1461 study participants, including anthropometric measurements and visual analog scale (VAS) scores for low back pain/neck pain, are shown in Table 1. There was no sex-related significant difference in age, the Oswestry Disability Index (ODI), or the VAS scores for low back pain and neck pain. Height, weight, body mass index (BMI), and grip strength were significantly greater in men than in women.

Table 1. Characteristics of men and women.

	Men	Women
N	466	995
Age (years)	66.3 ± 13.8	65.3 ± 12.5
Height (cm)	164.7 ± 7.3***	151.8 ± 6.7
Weight (kg)	64.2 ± 11.4***	52.4 ± 8.7
Body mass index	23.6 ± 3.4**	22.7 ± 3.5
Grip strength (kg)	39.1 ± 8.8***	24.5 ± 5.6
Oswestry Disability Index (%)	10.9 ± 11.9	12.6 ± 13.6
Low back pain (VAS)	13.4 ± 21.6	15.2 ± 13.4
Neck pain (VAS)	4.4 ± 13.3	4.6 ± 14.9

The data are shown as the mean ± standard deviation.

*p<0.05, **p<0.01, ***p<0.001: Significantly different from the values for women (Student's *t*-test)

VAS, visual analog scale

Table 2 compares the mean values for sagittal spinal alignment in each age strata in this cohort. The mean sagittal vertical axis at C7 (C7 SVA) was 11.0 ± 42.7 mm, and older subjects had a larger C7 SVA (p<0.001). The association between sagittal spinal alignment on radiographs and pain/physical performance is shown in Table 3. Univariate analysis indicated that low back pain was more prevalent in subjects with a larger C7 SVA (small, 35.7%; intermediate, 47.3%; large, 59.4%; p<0.001), and these subjects also had a higher ODI score (small, 10.0%; intermediate, 17.5%; large, 29.4%; p<0.001). Indicators of physical performance decreased significantly in subjects with a larger C7 SVA (p<0.001).

Table 2. Comparison of mean sagittal spinal alignment values among different age strata in the cohort

	<50 (n=170)	50–60 (n=256)	60–70 (n=418)	70–80 (n=407)	≥80 (n=210)	Overall (n=1461)
Overall						
Th5-12 angle (°)	21.6 ± 7.7	23.5 ± 9.4	25.8 ± 10.2	30.1 ± 11.7	33.8 ± 14.2	27.2 ± 10.9
Lumbar lordosis (°)	-50.7 ± 10.1	-47.8 ± 10.3	-46.4 ± 12.5	-44.2 ± 14.0	-38.9 ± 17.8	-45.4 ± 13.2
Pelvic tilt (°)	13.5 ± 6.9	15.3 ± 7.6	17.3 ± 8.1	20.9 ± 10.1	22.9 ± 10.0	18.3 ± 8.8
Sacral slope (°)	35.8 ± 7.8	33.8 ± 7.6	32.6 ± 8.8	30.3 ± 9.1	27.2 ± 10.7	31.8 ± 8.9
C7-SVA (mm)	-16.2 ± 24.3	-4.4 ± 27.7	3.7 ± 33.5	21.1 ± 42.2	46.4 ± 56.6	10.9 ± 38.5
Men	N=56	N=75	N=124	N=123	N=88	N=466
Th5-12 angle (°)	21.5 ± 7.2	23.0 ± 9.0	25.3 ± 9.4	28.9 ± 10.8	30.1 ± 10.0	26.3 ± 9.6
Lumbar lordosis (°)	-47.9 ± 9.1	-45.2 ± 9.5	-45.2 ± 11.8	-45.7 ± 13.4	-39.3 ± 15.9	-44.5± 12.5
Pelvic tilt (°)	11.5 ± 6.9	14.4 ± 6.6	15.5 ± 6.8	16.0 ± 7.5	19.7 ± 8.4	15.8 ± 7.2
Sacral slope (°)	34.5 ± 6.9	33.3 ± 7.7	32.9 ± 8.8	31.5 ± 7.9	28.3 ± 10.2	31.9 ± 8.5
C7-SVA (mm)	-10.9 ± 22.9	4.7 ± 30.7	8.2 ± 35.0	13.9 ± 39.2	39.1 ± 54.3	12.7 ± 38.8
Women	N=114	N=181	N=294	N=284	N=122	N=995
Th5-12 angle (°)	21.7 ± 8.0	23.7 ± 9.5	26.0 ± 10.6	30.6 ± 12.0	36.4 ± 16.2	27.7 ± 11.4
Lumbar lordosis (°)	-52.0 ± 10.3	-48.9 ± 10.4	-46.9 ± 12.8	-43.6 ± 14.2	-38.6 ± 19.1	-45.9 ± 13.5
Pelvic tilt (°)	14.5 ± 6.7	15.8 ± 8.0	18.1 ± 8.5	23.0 ± 10.3	25.2 ± 10.4	19.5 ± 9.0
Sacral slope (°)	36.5 ± 8.2	34.0 ± 7.6	32.5 ± 8.9	29.7 ± 9.6	26.4 ± 11.1	31.7 ± 9.1
C7-SVA (mm)	-18.8 ± 24.6	-8.2 ± 25.6	1.8 ± 32.7	24.2 ± 43.1	51.6 ± 57.9	10.1 ± 38.0

The data are shown as the mean ± standard deviation.

C7 SVA, sagittal vertical axis at C7

Table 3. Association between sagittal spinal alignment and pain/physical performance on radiographs

	Low: ≤40 mm (n=1192)	Intermediate: 40 < SVA < 95 mm (n=205)	High: >95 mm (n=64)	p-value
Age (years)	63.3 ± 12.7	74.3 ± 8.9	79.2 ± 7.0	<0.001
Sex (male/female)	387/805	60/145	19/45	
BMI	22.9 ± 3.5	23.3 ± 3.4	23.7 ± 3.6	0.14
Neck pain VAS (mm)	4.5 ± 14.2	4.4 ± 16.0	4.1 ± 11.0	0.97
Presence of low back pain (%)	35.7	47.3	59.4	<0.001
Low back pain VAS (mm)	13.0 ± 21.5	19.3 ± 26.0	29.6 ± 29.4	<0.001
ODI (%)	10.0 ± 11.3	17.5 ± 15.0	29.4 ± 17.4	<0.001
Physical performance				
Grip strength (kg)	30.1 ± 9.5	25.6 ± 9.0	21.9 ± 6.8	<0.001
Chair-stand time (s)	8.1 ± 2.7	10.1 ± 4.3	12.0 ± 4.2	<0.001
6-m walking time (m/s)	1.1 ± 0.3	1.0 ± 0.3	0.7 ± 0.3	<0.001
One leg standing test (s)	44.8 ± 20.6	24.5 ± 21.1	9.8 ± 11.3	<0.001

The data are shown as the mean ± standard deviation.

Significant difference between the three groups (Cochran-Armitage trend test)

BMI, body mass index; ODI, Oswestry Disability Index; VAS, visual analog scale

Table 4. Association between sagittal spinal alignment and physical performance

	B-coefficient (95% CI)	VIF	p-value
Grip strength			
Age, years	-0.40	1.23	<.0001*
Sex	0.72	1.01	<.0001*
Body mass index	0.09	1.03	<.0001*
C7 SVA (mm)	-0.07	1.23	<.0001*
Chair-stand time			
Age, years	0.37	1.22	<.0001*
Sex	-0.01	1.02	0.74
Body mass index	0.06	1.03	0.015*
C7 SVA (mm)	0.17	1.23	<.0001*
6-m walking time			
Age, years	-0.39	1.23	<.0001*
Sex	-0.01	1.01	0.65
Body mass index	-0.05	1.03	0.018*
C7 SVA (mm)	-0.21	1.23	<.0001*
One-leg standing test			
Age, years	-0.58	1.22	<.0001*
Sex	0.05	1.02	0.0082*
Body mass index	-0.13	1.03	<.0001*
C7 SVA (mm)	-0.18	1.22	<.0001*

Beta values are shown using multiple regression analysis after adjustment for age, sex, and the body mass index.

CI, confidence interval; VIF, variance inflation factor; C7 SVA, sagittal vertical axis at C7

Finally, after adjusting for sex, age, and BMI, multiple linear regression analysis was performed with individual measures of physical performance as response variables. The association between sagittal spinal alignment and physical performance is shown in Table 4. These measures of physical performance were significantly associated with C7 SVA ($p<0.001$).

Discussion

To our knowledge, the Wakayama Spine Study is the first population-based study to use whole-spine radiographs to clarify the age-related difference in sagittal spine parameters and the association with low back pain and physical performance measures in a large cohort. The mean C7 SVA was 11.0 ± 42.7 mm, and older subjects had a larger C7 SVA. Univariate analysis indicated that low back pain was more prevalent in subjects with a larger C7 SVA, and these subjects also had a higher ODI score. Physical performance measures, namely grip strength, chair stand time, 6-m walking time, and the one-leg standing test, were significantly associated with C7 SVA.

In this study, thoracic kyphosis (TK), pelvic tilt, and C7 SVA increased with age, whereas LL and the sacral slope decreased with age. Furthermore, the rate of increase in TK and C7 SVA was greater in women than in men, although the mean values of these parameters were within the generally accepted normal ranges.[3] Fon et al. reported that the degree of kyphosis increased with age, with a greater rate of increase in women than in men.[4] Interestingly, we found a marked change in C7 SVA in the 70s and 80s in both men and women. This finding is common because increased TK is often associated with osteoporotic compression wedging of the vertebrae, degenerative change in the intervertebral discs, and decreased strength of the back extensor muscles in the aged spine.[5–8] This degenerative change can also contribute to decreased LL.[9] Gelb et al. investigated 100 asymptomatic middle-aged and older volunteers and found a correlation between C7 SVA, LL, and age.[10] The above-mentioned correlation between spinopelvic parameters and age may explain the physiological aging of the spine.

The impact of sex on spinopelvic parameters remains controversial. Vialle et al. reported significant differences in LL and PI between male and female subjects.[11] Furthermore, Zhu et al. found a significant sex-related difference in LL.[12] However, other researchers found no significant sex-related difference in any spinopelvic parameter.[13–15] Although there were statistically significant differences in TK, LL, pelvic tilt, and C7 SVA between men and women in the present study, the sex-related difference in the mean value for each parameter was quite small. Moreover, the individual variations were much larger than the sex-related differences. When considering clinically important differences, further studies should be performed to corroborate this finding.

In this study, we demonstrated an association of sagittal malalignment with low back pain and physical performance measures in a large cohort. Our multiple regression analysis also demonstrated a significant relationship between C7 SVA and grip strength, chair stand time, 6-m walking time, and the one-leg standing test.

The center-of-gravity line moves forward with increasing age.[16] The pelvis should be tilted backwards to correct this position, which interferes with the social standard of maintaining a horizontal gaze.[17] The physiologic curvature of the spine in the sagittal plane, a straight spine in the coronal plane, balanced tension of the spinal ligaments, and activation of intrinsic anterior and posterior muscle groups should permit an extended pain-free erect posture with minimal muscle energy expenditure. This concept is reflected in the “cone of economy” principle conceptualized by Dubousset.[2] Within the center of the cone, the individual may remain in an ergonomically favorable erect position. However, larger deviations in the anterior-posterior or lateral plane and the resulting progression of imbalance require greater energy expenditure to maintain a standing position, eventually causing low back pain. Finally, progression outside of the “stable cone” results in loss of postural control and the need for external support. Our epidemiological findings support this theory.

We also demonstrated an association between C7 SVA and decreased physical performance, including grip strength. Clinicians should be vigilant for muscle weakness, which may result in poor outcomes, commonly seen as proximal junctional kyphosis after adult spinal deformity surgery. Therefore, we believe that the findings of this study may help to improve the treatment of patients with adult spinal deformity.

This study has several limitations. First, although more than 1000 participants were included, the sample may not be representative of the general population because the subjects were recruited from only two areas of Japan. However, when anthropometric measurements were compared between the participants in this study and the general Japanese population, there were no significant differences in the mean BMI of men (23.71 ± 3.41 vs 23.95 ± 2.64; $p = 0.33$) as well as women (23.06 ± 3.42 vs 23.50 ± 3.69; $p = 0.07$). Second, a longitudinal study is required to determine the causal relationship between sagittal spinopelvic parameters and physical performance. Evaluation of the alignment of the cervical spine and/or lower extremities should be included because they also show age-related changes and affect spinopelvic alignment.

In conclusion, to our knowledge, this population-based study is the first to use whole-spine radiographs to investigate age-related differences in sagittal spine parameters and their association with low back pain and physical performance measures in a large cohort. A larger C7 SVA was more prevalent in subjects with low back pain and decreased physical performance.

Methods

Compliance with ethical standards.

This study was conducted in accordance with the Declaration of Helsinki, and the study design was approved by the Ethics Committee of the Wakayama Medical University. All volunteers provided written informed consent for participation.

Participants

With the approval of our institutional review board, the present study, entitled the Wakayama Spine Study, was performed in a sub-cohort of patients who presented for a second follow-up visit in the Research on Osteoarthritis/Osteoporosis Against Disability (ROAD) study, which was initiated in 2011 as a nationwide prospective study of bone and joint diseases in population-based cohorts and was completed in 2012.[18–20] In addition to the participants enrolled at the outset of the study, inhabitants of the mountainous and coastal areas in the Wakayama prefecture who were willing to participate in the ROAD survey were also included in the second follow-up visit. A total of 1575 individuals (513 men, 1062 women) presented for this visit. One hundred and fourteen individuals who could not maintain a standing position while undergoing total lateral whole-spine radiography or had other disqualifiers were excluded. Finally, lateral whole-spine radiographs were available for 1461 subjects (466 men, 995 women), who were divided based on their birth year into five groups: (1) younger than 50 years, (2) 50–59 years, (3) 60–69 years, (4) 70–79 years, and (5) 80 years or older.

Evaluation of physical performance

Medical information on low back pain and physical performance was collected by an experienced orthopedic surgeon. The following tests were conducted to evaluate physical performance: grip strength, 6-m walking time, step length, chair-stand time, and one-leg standing time. Grip strength was measured for each hand using a handgrip dynamometer (Toei Light Co., Ltd, Saitama, Japan). To measure walking speed, the time taken to walk 6 m at a usual pace in a hallway was recorded. Similarly, the 6-m walking time at maximal pace was measured. The time taken for five consecutive chair rises without use of hands was also recorded. One-leg standing time was measured for each leg using a stopwatch (upper limit, 60 s), and the mean value for both legs was recorded.[21]

The ODI was used to evaluate problems in daily living due to low back pain. The severity of low back pain in the previous week was evaluated using the VAS score.

Radiographic evaluation

Standing lateral radiographs of the whole spine and pelvis were obtained for each subject using a 40-inch film. Each radiograph was aligned such that the edge of the film was used as a reference for vertical alignment. The subject was instructed to stand in a comfortable position with the hips and knees fully extended. The arms were flexed with the hands resting on the supports at the level of the shoulders. Measured radiographic parameters included the following: TK (the Cobb angle from the upper endplate of T5 to the lower endplate of T12), LL (the Cobb angle from the upper endplate of L1 to the lower endplate of S1), pelvic tilt (the angle between the line connecting the midpoint of the sacral plate to the axis of the femoral heads and the vertical axis), pelvic incidence (the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads), and SVA (sagittal vertical axis; the horizontal distance from the C7 plumb line originating at the middle of the C7 vertebral body to the posterior superior endplate of S1) (Fig. 1). Based on Schwab's classification,[22] the subjects were divided into groups based on whether their C7 SVA was small (< 40 mm), intermediate (40 ≤ SVA < 95 mm), or large (≥ 95 mm).

Statistical analysis

All values are expressed as the mean ± standard deviation. The Student's *t*-test was used to analyze differences in spinal and pelvic parameters between men and women. Correlations between sagittal spinal alignment variables were examined using the Spearman rank correlation coefficient (r), which is interpreted as follows: <0.3, none; 0.31–0.5, weak; 0.51–0.7, strong; 0.71–0.9, very strong; and > 0.9, excellent. Finally, we analyzed the relationship between sagittal spinal alignment and physical performance measures using the Cochran–Armitage trend test. Age, sex, and BMI were entered into a multiple regression model to adjust for potential confounding factors. The variance inflation factor was used to check for multicollinearity in the model. All statistical analyses were performed using JMP version 8 (SAS Institute Inc., Cary, NC, USA). A p-value of < 0.05 was considered statistically significant.

Declarations

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Author contributions

K.M., K.N., H.H., H.O., S.M., Y.I., M.Y., S.T., A.M., Y.N., N.Y., and H.Y. conceived and designed this study. K.M. and K.N. wrote the manuscript. K.M., K.N., H.H., H.O., Y.I., S.M., and N.Y. collected the data. K.M., K.N., H.H., H.O., and N.Y. analyzed the data. All authors have seen the original study data, reviewed the data analysis, and approved the final manuscript.

ADDITIONAL INFORMATION

Competing interests

The authors declare no competing interests.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional review board and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate

Informed consent was obtained from all study participants.

Consent for publication

Not applicable

Data availability

All data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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Figures

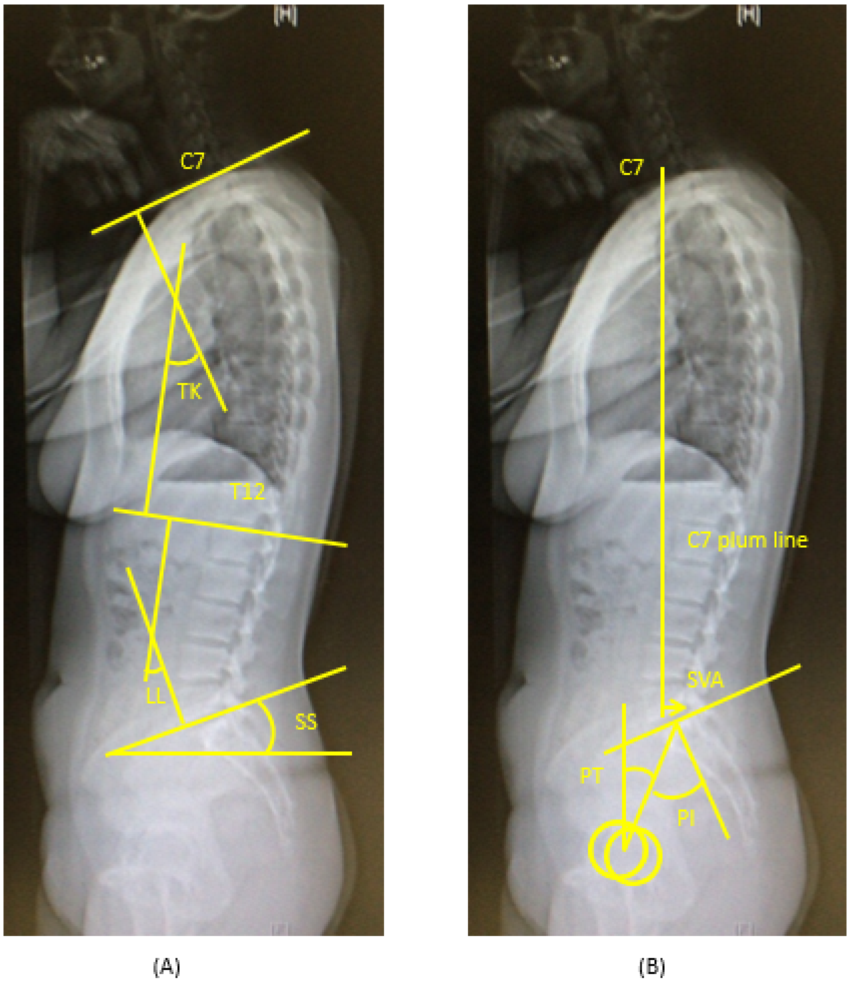

Figure 1

Whole spine radiographic measurements. (a) Measurement of thoracic kyphosis (TK), lumbar lordosis (LL) and sacral slope. (b) Measurement of diameter of sagittal vertical axis at C7.