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Clinical Study

Sagittal spinal alignment deviation in the general elderly population: a Japanese cohort survey randomly sampled from a basic resident registry

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Abstract

BACKGROUND CONTEXT: It is widely recognized that sagittal spinal alignment changes with age. However, there are presently no clear benchmarks for such values or those for the cervical spine in the general population. Quality epidemiological studies are needed to establish standards for spinal alignment deviation.

OBJECTIVES: In this study of an aged Japanese population, we employed random sampling from the basic resident registry of a rural town for subject selection to determine reference values of sagittal spinal alignment including the cervical spine.

STUDY DESIGN: Japanese resident cohort study based on a municipal registry.

PATIENT SAMPLE: A total of 413 aged people randomly sampled from the resident registry of a rural Japanese town.

OUTCOME MEASURES: All subjects underwent a whole spine lateral radiograph for measurement of sagittal spinal alignment parameters.

METHODS: Registered citizens of 50 to 89 years old were targeted for this survey. We established eight groups based on age (50s, 60s, 70s, and 80s) and gender (male and female) after random sampling from the resident registry of Obuse town in 2014. A total of 413 people (203 males and 210 females) were enrolled. Radiographic parameters of sagittal spinal alignment of the cohort were measured and analyzed. Funding for this study was provided by the Japan Orthopaedics and Traumatology Research Foundation (10,000 USD), the Japanese Orthopaedic Association (5,000 USD), the Japanese Society for Musculoskeletal Medicine (40,000 USD), and the Nakatomi Foundation (15,000 USD).

RESULTS: Global spinal alignments became more misaligned with age for both genders. Sagittal vertical axis (SVA) forward shift was significantly more frequent in 80s males and 70s females, and SVA in 80s females was a mean of 66 mm forward of that of 50s females. Cervical protrusion was markedly greater in 60s males onwards. In women, lumbar lordosis and posterior pelvic

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inclination were noticeable from a younger age than in men. The amount of pelvic tilt misalignment in female subjects was approximately 10 years earlier than their male counterparts.
CONCLUSIONS: This first resident cohort of Japanese individuals determined average spinal alignment parameters by age and gender. Spinal balance generally shifts forward as age increases. A forward shift in the upper cervical spine occurs first in men, whereas lumbopelvic alignment shift occurs first in women.

Keywords: Adult spine; Age; Epidemiological study; Gender; Normative value; Resident cohort; Spinal alignment.

Introduction

A large shift in sagittal spinal alignment (adult spinal deformity; ASD) hinders standing and walking [1]. Sagittal spinal alignment is more strongly correlated than coronal spinal alignment in health-related quality of life (HRQOL) [2], even if the spinal deformity is not severe, which can be an important barometer of health status for ordinary citizens. Sagittal spinal alignment changes with age [3,4]. However, there are at present no clear ranges of sagittal spinal alignment for the general population. There has been a movement in Japan to establish age group-based benchmark values for sagittal spinal alignment through high quality epidemiological research [3,4]. As the elderly rate reached 27% of the population in 2016 (Ministry of Internal Affairs and Communications, Statistics Bureau, Population Census), interest is mounting about spinal alignment data.

In the establishment of a new population study of Japanese people, we employed random sampling from the basic resident registry of the rural town of Obuse to minimize selection bias and obtain a cohort representative of the general population. This epidemiological study was coined "the Obuse study," bearing the name of the cooperating local government. This study proposes reference values for sagittal spinal alignment for the Japanese using the Obuse study cohort.

Materials and methods

This study was approved by the investigational review board of our hospital (approval number: 2792).

Cohort construction by age and gender

With a population of 11,326 people (2014), the municipality of Obuse town is located in the Nagano prefecture, in the center of Japan. Survey subjects included Obuse residents of 50 to 89 years old. We defined eight groups by age (50s, 60s, 70s, and 80s) and gender (male and female). Each group was planned to consist of approximately 50 participants for a total of at least 400 subjects. We randomly sampled 1,297 individuals from 5,352 people aged between 50 and 89 years in basic resident registry of Obuse town in 2014 (Fig. 1). After providing written consent, 415 subjects were enrolled in the Obuse study. Two people with missing radiographic data were excluded, leaving a total of 413 (203 male and 210 female) subjects. An exclusion criterion in this study was a history of spinal instrumentation surgery.

Measurements of spinal alignment

All subjects underwent a single whole spine lateral radiographic examination in a standing position with the hands on the clavicles [5] for measurement of: (1) sagittal vertical axis (SVA) and global tilt (GT) as total spinal alignment, (2) cervical SVA (CSVA; the distance between a plumb line from the center of the C2 vertebral body and posterior superior corner of C7), cervical lordosis (CL; the lordotic angle between the C2 inferior endplate and C7 inferior endplate), T1 slope (T1S; the angle between the horizontal plane and T1 superior endplate), and thoracic kyphosis (TK; the kyphotic angle between the T5 superior endplate and T12 inferior endplate) as cervicothoracic alignment, and (3) lumbar lordosis (LL; the lordotic angle between the L1 superior endplate and sacral plate), sacral slope (SS; the angle between the horizontal plane and sacral plate), pelvic tilt (PT; the angle between the line connecting the midpoint of the sacral plate to the bicoxofemoral axis and the vertical line from the bicoxofemoral axis), and

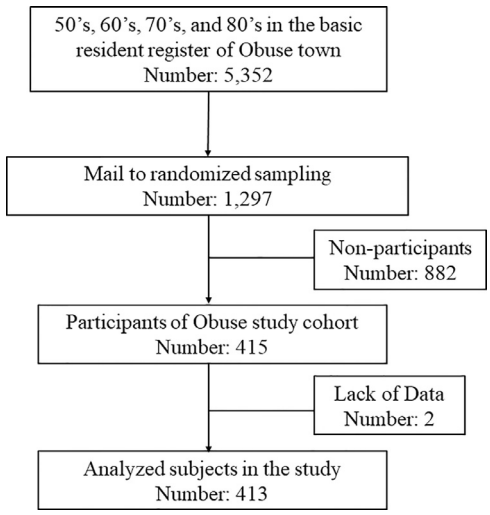

Fig. 1. Obuse town resident participant flowchart.
Note: 1,297 people were randomly sampled from 5,352 residents aged between 50 and 89 years in the basic resident registry of Obuse town. A total of 415 people joined the Obuse study cohort, but two were excluded due to a lack of radiographic data.

pelvic incidence (PI; the angle between the line perpendicular to the sacral plate and the line connecting the midpoint of the sacral plate to the bicoxofemoral axis) as lumbopelvic alignment (Fig. 2).

The average values of measurements by two spine surgeons (M.U. and S.I.) and a trained staff member (R.T. or H.N.) were recorded for each parameter. The inter-rater reliability of each parameter was as follows: 0.95 for SVA, 0.71 for GT, 0.96 for CSVA, 0.88 for CL, 0.88 for T1S, 0.92 for TK, 0.89 for PT, and 0.80 for PI. The inter-rater reliability for LL and SS was 0.65 and 0.48, respectively, likely due to variation in the S1 end plate.

Statistical analyses

The means and standard deviations of the spinal alignment parameters for each age and gender groups were calculated. The age of the Obuse study cohort was uniformly distributed by decade over the age of 50 years, with a population ratio different from that of the standard population pyramid in Japan. Therefore, these values were weighted by age based on the Japanese population composition of July 2017 (http://www.stat.go.jp/english/index.htm) and used to calculate the reference values of spinal alignment parameters in Japanese over 50 years of age.

For the purposes of examining to what extent deviation would occur and from which age, comparisons between age groups on the basis of 50s age group reference values were performed using multiple comparisons based on the Dunnett test. The mean deviations of spinal alignment parameters of each age group were calculated using 95% confidence intervals. Statistical analyses were carried out using the statistical package R, version 3.4.3 (available at: http://www.r-project.org). The level of significance was set at $p<.05$.

Results

The eight groups classified by age and gender contained of a mean of 52 people (range: 45 to 61). Table 1 summarizes the baseline characteristics of the Obuse study cohort. There were many subjects in their 50s employed in tertiary industries and many in their 60s engaged in primary industries. Unemployment increased with age.

Table 2 presents each spinal alignment parameter stratified by age and gender. Spinal alignment parameter values differed with age, with greater divergence as age progressed. “All” values were based on the uniformly distributed age group of the Obuse study cohort. “Weighted” values were based on the population composition ratio of Japan and represented the reference values for Japanese

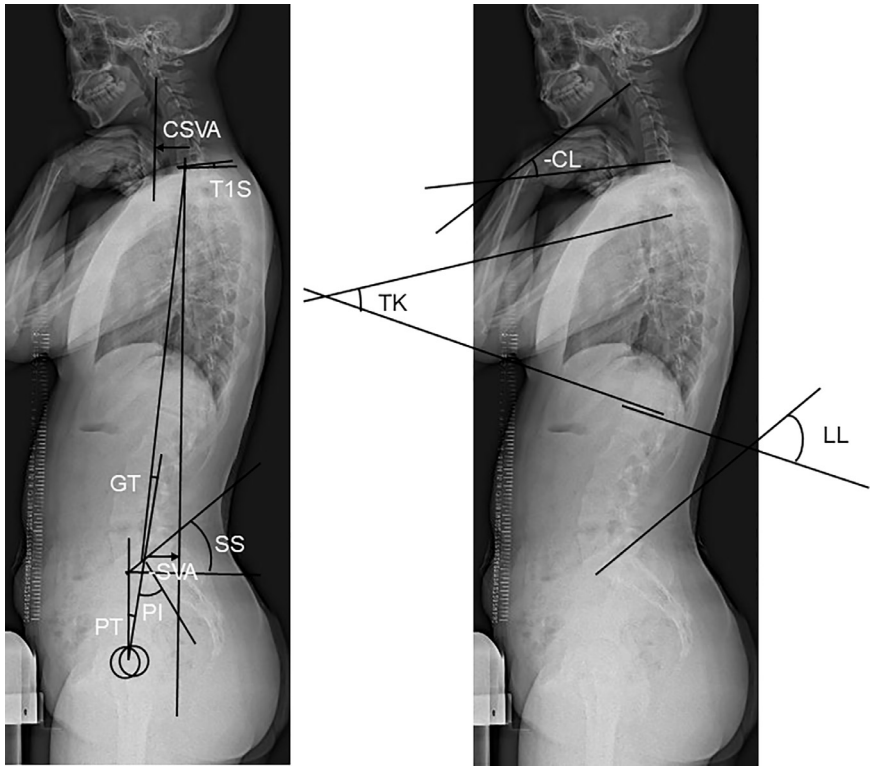

Fig. 2. Radiographic parameters of sagittal spinal alignment.

Note: Error bars represent 95% confidence intervals.

Abbreviations: SVA, sagittal vertical axis; GT, global tilt; CL, cervical lordosis; CSVA, cervical sagittal vertical axis; T1S, T1 slope; TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

Table 1
Baseline characteristics of the Obuse study cohort

Sex	Age (years)	Number	Height (cm)	Weight (kg)	BMI (kg/m$^{2)}$	Job (Pri; Sec; Ter; None)
Male	50s	50	171.8 (6.0)	67.1 (9.1)	22.7 (2.9)	3; 7; 40; 0
	60s	53	166.7 (4.7)	66.9 (7.7)	24.1 (2.7)	18; 5; 19; 11
	70s	55	163.2 (5.0)	60.0 (10.3)	22.5 (3.4)	22; 2; 8; 23
	80s	45	160.1 (5.7)	57.5 (8.5)	22.4 (2.8)	19; 0; 3; 23
	All	203	165.6 (6.8)	63.0 (9.8)	22.9 (3.0)	62; 14; 70; 57
Female	50s	47	158.1 (4.9)	55.4 (9.0)	22.2 (3.8)	5; 4; 29; 9
	60s	61	152.8 (5.4)	52.2 (7.6)	22.3 (2.8)	21; 4; 17; 19
	70s	54	149.7 (5.3)	50.6 (7.9)	22.6 (3.2)	16; 4; 8; 26
	80s	48	144.6 (5.9)	48.3 (7.9)	23.1 (3.3)	11; 0; 5; 32
	All	210	151.3 (7.1)	51.6 (8.4)	22.5 (3.2)	53; 12; 59; 86

Values represent the mean (standard deviation). Two subjects with missing radiographic measurements were excluded.
Abbreviations: BMI, body mass index; Pri, primary industry employment; Sec, secondary industry employment; Ter, tertiary industry employment.

over 50 years old. Whole spinal balance moved forward with age in both males and females, with remarkable increases in SVA and GT. Forward movement of the cervical spine was especially prominent in men. The CSVA was large at all ages in males, and T1S increased from their 60s. In contrast, women displayed large PT at all ages. Female LL was larger than that of men in their 50s but was almost equal in the 80s. Taken together, although spinal balance generally shifted forward with age, the specific position and degree of deviation from perfect balance differed between genders. A forward shift of the head occurred first in men, whereas a lumbopelvic alignment change was seen first in women.

Global spinal alignment deviated linearly with age for both genders (Fig. 3). A GT became larger as SVA moved forward. Mean SVA at the ages of 50s, 60s, 70s, and 80s was 6, 9, 22, and 57 mm in men and −5, 5, 30, and 61 mm in women, respectively (Table 2). The SVA protrusion was statistically significant in 80s males and 70s females. A GT increase was significant from the 70s onwards for both genders. The mean SVA in 80s females was a mean of 66 mm ahead of that of 50s females.

There was a clear difference regarding gender in cervicothoracic alignment parameters by age. Advanced age preferentially moved the upper cervical vertebrae forward in men and increased CL in women (Fig. 4). Contrary to the cervical spine, parameter differences were moderate in the thoracic spine. T1S was significantly larger in 80s subjects than 50s subjects for both genders. Although the deviation of TK was significant only for men in their 70s or older, its total was approximately 4° to 6° for both genders.

Lumbopelvic alignment became more misaligned from perfect sagittal balance with age for both genders, with a notable decrease in LL for women (Fig. 5). The LL was comparable between men in their 60s or 70s and those in their 50s, and was 7° smaller in 80s males. On the other hand, LL was significantly smaller by 9° in 70s females and 14° in 80s females. This trend was similar for SS. PT was significantly larger in 70s subjects than in 50s subjects for

Table 2
Spinal alignment parameters of the Obuse study cohort

Sex	Age (years)	Number	SVA (mm)	GT (degrees)	CL (degrees)	CSVA (mm)	T1S (degrees)	TK (degrees)	LL (degrees)	SS (degrees)	PT (degrees)	PI (degrees)
Male	50s	50	6 (26)	13 (7)	10 (10)	23 (14)	25 (6)	25 (8)	44 (11)	33 (8)	12 (6)	45 (9)
	60s	53	9 (38)	17 (11)	9 (11)	28 (15)	27 (8)	29 (8)	45 (13)	31 (9)	14 (8)	45 (10)
	70s	55	22 (30)	19 (8)	13 (12)	29 (12)	29 (9)	31 (10)	45 (13)	33 (9)	16 (6)	49 (10)
	80s	45	57 (49)	29 (12)	14 (15)	31 (17)	31 (10)	31 (13)	38 (12)	28 (6)	21 (7)	49 (9)
	All	203	22 (41)	19 (11)	12 (12)	28 (15)	28 (8)	29 (10)	43 (12)	31 (8)	16 (7)	47 (10)
	Weighted		17 (38)	18 (11)	11 (12)	27 (15)	28 (8)	29 (9)	44 (12)	32 (8)	15 (7)	46 (10)
Female	50s	47	-5 (26)	14 (8)	9 (10)	18 (11)	23 (7)	27 (9)	51 (11)	36 (8)	14 (6)	49 (9)
	60s	61	5 (30)	19 (11)	9 (9)	16 (8)	22 (7)	31 (10)	47 (14)	31 (10)	17 (8)	48 (11)
	70s	54	30 (36)	26 (11)	13 (11)	17 (11)	25 (10)	30 (11)	42 (14)	29 (9)	23 (10)	53 (11)
	80s	48	61 (60)	36 (16)	19 (12)	19 (16)	30 (14)	33 (19)	38 (20)	25 (11)	27 (11)	51 (11)
	All	210	22 (46)	23 (14)	12 (11)	17 (11)	25 (10)	30 (12)	45 (16)	30 (10)	20 (10)	50 (11)
	Weighted		19 (45)	22 (14)	12 (11)	17 (11)	24 (10)	30 (12)	45 (16)	31 (10)	20 (10)	50 (11)

Values represent the mean (standard deviation).
Abbreviations: SVA, sagittal vertical axis; GT, global tilt; CL, cervical lordosis; CSVA, cervical sagittal vertical axis; T1S, T1 slope; TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

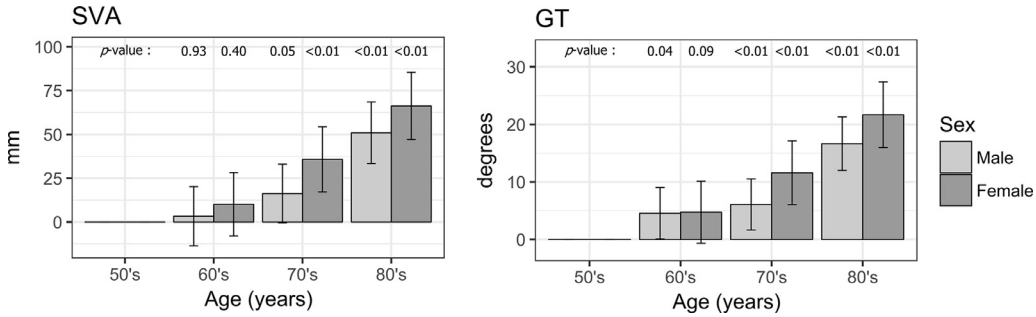

Fig. 3. Deviation in the whole spine from 50 years of age.
Note: Error bars represent 95% confidence intervals.
Abbreviations: SVA, sagittal vertical axis; GT, global tilt.

both genders. This deviation was particularly large in women, reaching 9° in their 70s and 13° in their 80s. The LL deviation was 9° in 80s males. The amount of PT deviation in women advanced roughly 10 years earlier than in men. Regarding PI, values remained comparable with those of subjects in their 50s for both genders.

Discussion

In the present cohort study of over 400 subjects randomly selected from a rural Japanese town registry, we were able to calculate average spinal alignment parameters by age and gender of seniors over 50 years old according to the Japanese population ratio.

In recent years, the number of patients consulting a medical institution with the main complaint of back pain and daily life disorders from ASD is increasing, likely due to population aging and growing healthy life expectancy. Because Glassman et al. reported that sagittal spinal alignment was more strongly correlated than coronal spinal alignment for HRQOL [2], sagittal spinal alignment including the pelvis has attracted considerable attention. Schwab et al. reported PI minus LL = ±9 as a harmonized alignment from studies of healthy US citizens [6,7]. Thereafter, the SRS-Schwab classification was established in 2012 by reviewing factors related to HRQOL in ASD cases and thresholds for Oswestry Disability Index >40% [8]. Several other studies have examined average spinal parameters in various populations [3,4,9–12], as summarized in Table 3. Previous surveys in France, Canada, and China targeted younger people than the present one, which might have been a limitation since the elderly tend to more frequently have spinal alignment problems. As for PI, which is

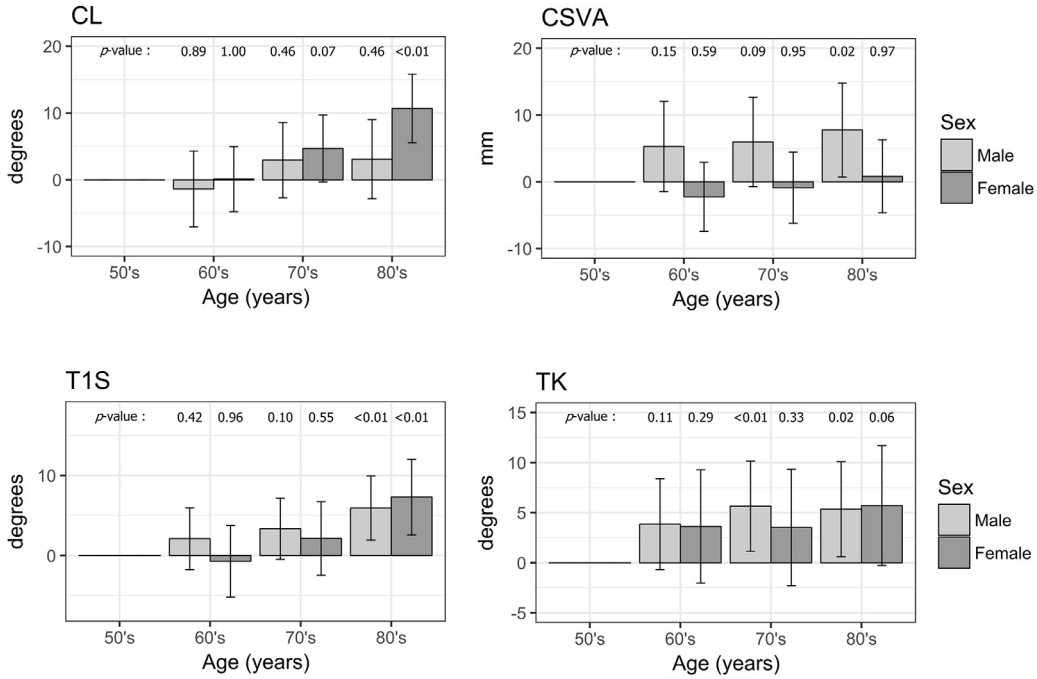

Fig. 4. Deviation in the cervical and thoracic spine from 50 years of age.
Note: Error bars represent 95% confidence intervals.
Abbreviations: CL, cervical lordosis; CSVA, cervical sagittal vertical axis; T1S, T1 slope; TK, thoracic kyphosis.

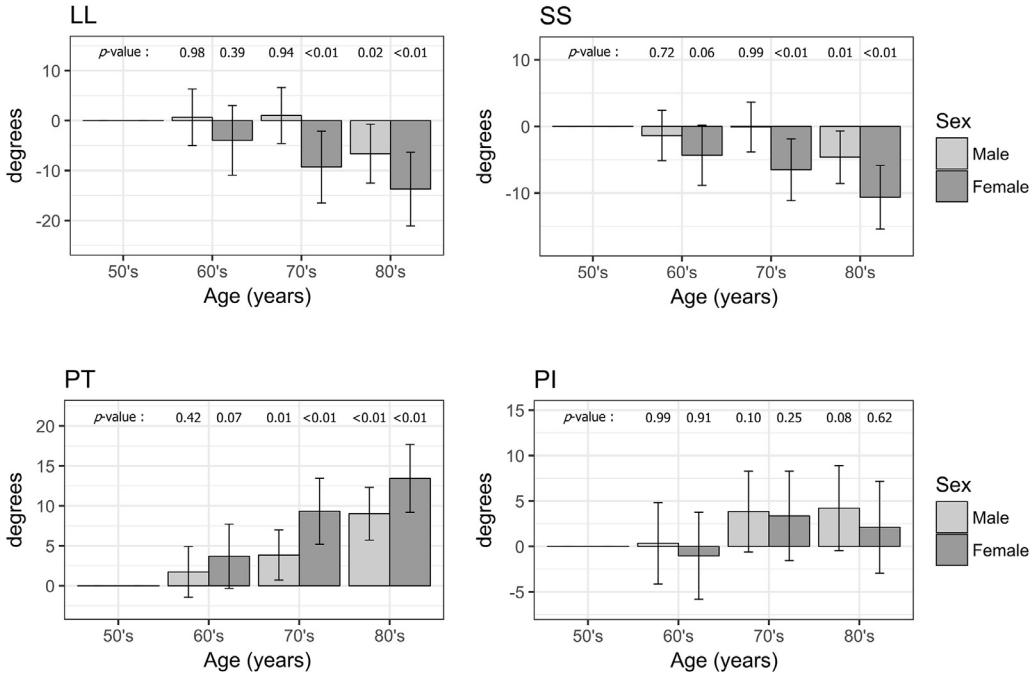

Fig. 5. Deviation in the lumbopelvic region from 50 years of age.
Note: Error bars represent 95% confidence intervals.
Abbreviations: LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.

regarded as a value unique to the individual, those of Westerners tend to be larger than those of the Japanese.

The HRQOL may be affected by lifestyle and nationality, with reported differences between Japan and the United States for ASD cases [13]. Two studies have addressed sagittal spinal alignment in the Japanese general population [3,4]. The TOEI study [3] and Wakayama Spine Study [4] were epidemiological surveys carried out through active participant recruitment in a designated area. Compared with earlier reports on Japanese volunteers, our results showed that TK was slightly smaller but other pelvic parameters were equivalent. The Obuse study has two key advantages over its predecessors: participant selection was random and more representative of the general population and age and gender were uniformly distributed.

Spinal alignment was found to worsen with age in Japanese volunteer cohorts [3,4]. Oe et al. stated that alignment changes started from a decrease in LL in women because of pregnancy and childbirth [3]. In our study, spinal alignment parameters also differed with age; the higher the age group, the more divergent were values from those in the 50s group. Specifically, the degree of SVA protrusion was statistically significant in 80s males and 70s females, and a GT increase was significant over the age of 70 for both genders. Among

Table 3
Mean parameters of spinal alignment in previous reports

Study	Country	Sex	Number	Age (years)	TK (degrees)	LL (degrees)	SS (degrees)	PT (degrees)	PI (degrees)
Vialle 2005 [9]	France	Male	190	35	42 (10)	41 (11)	41 (9)	13 (6)	53 (11)
		Female	110		39 (10)	46 (11)	43 (8)	14 (6)	56 (10)
Roussouly 2006 [11]	France	Both	M 79/ F 74	26 (6)	46 (10)	61 (9)	40 (8)	11 (6)	51 (10)
Mac-Thiong 2010 [8]	Canada	Male	354	38 (15)			40 (8)	13 (7)	52 (11)
		Female	355	36 (14)			40 (8)	13 (7)	53 (10)
Zhu 2014 [10]	China	Male	104	34 (12)	28 (9)	43 (10)	32 (6)	11 (7)	43 (8)
		Female	156	35 (11)	28 (11)	49 (9)	33 (7)	11 (8)	45 (11)
Oe 2015 [3]	Japan	Male	263	73 (8)	35 (12)	40 (14)	31 (9)	15 (8)	46 (9)
		Female	393	72 (8)	36 (15)	40 (17)	29 (11)	22 (10)	51 (13)
Asai 2017 [4]	Japan	Male	466	66 (14)	39 (11)	45 (13)		16 (8)	48 (10)
		Female	995	65 (13)	37 (13)	46 (14)		25 (20)	51 (11)
Our study	Japan	Male	203	70 (11)	29 (10)	43 (12)	31 (8)	16 (7)	47 (10)
		Female	210	70 (11)	30 (12)	45 (16)	30 (10)	20 (10)	50 (11)

Values represent the mean (standard deviation).
Since the age groups were distributed uniformly in the present study, we presented the mean and standard deviation for comparison with other reports.
Abbreviations: TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; M, male; F, female.

Table 4
Cervical alignment in previous reports

Author		Ames 2013 [14]			Oe 2015 [3]				Our study			
Country		USA			Japan				Japan			
Number		55			656				413			
Age (years)		20−39	40−59	≥60	50−59	60−69	70−79	80−89	50−59	60−69	70−79	80−89
T1S (degrees)	Male Female	22 (7)	21 (8)	32 (9)	32 (6) 28 (9)	31 (6) 29 (7)	33 (7) 32 (7)	36 (7) 37 (10)	25 (6) 23 (7)	27 (8) 22 (7)	29 (9) 25(10)	31 (10) 30 (14)
CL (degrees)	Male Female	9 (9)	7 (9)	22 (9)	11 (7) 13 (11)	14 (9) 12 (9)	11 (8) 15 (11)	13 (9) 17 (11)	10 (10) 9 (10)	9 (11) 9 (9)	13 (11) 13 (12)	14 (15) 19 (12)
CSVA (mm)	Male Female				25 (7) 20 (9)	28 (13) 21 (10)	34 (16) 22 (12)	35 (14) 28 (14)	23 (14) 18 (11)	28 (15) 16 (8)	29 (12) 17 (11)	31 (17) 19 (16)

Values represent the mean (standard deviation).
Abbreviations: T1S, T1 slope; CL, cervical lordosis; CSVA, cervical sagittal vertical axis.

women in their 80s, SVA was an average of 66 mm ahead of those in their 50s. We also observed spinal alignment deterioration at an earlier age in female subjects. Lumbopelvic alignment deviated with age for both genders, with a remarkable decrease in women. This was the case as well for SS. The PT deviation was large in women and roughly 10 years more advanced than in males.

With regards to the cervical spine, a relationship between the sagittal alignment of the cervical spine and cervical pain has been reported [14−16]. In measurements of patients undergoing cervical spine surgery, the Neck Disability Index increased as lordosis decreased, and neck pain increased as T1 slope decreased [14]. Moreover, the disappearance of CL and occurrence of cervical kyphosis are greatly related to CSVA and T1 slope, and the onset of cervical spondylosis is strongly influenced by the sagittal alignment of the adjacent vertebrae [15,16]. It is also important to establish normal values for cervical alignment. However, few such reports on healthy adults exist, as summarized in Table 4. Although an American cohort was small and relatively young [14], the T1S of the Japanese was similar, but CL was smaller. We also observed a clear difference for gender for cervicothoracic alignment with aging in the Obuse cohort. In higher age groups, upper cervical vertebrae were more forward in men and CL was increased in women.

The limitations of the current investigation include its cross-sectional design and possibilities of regional and interobserver bias. We are planning further longitudinal studies to investigate deviation changes over time. As this was a noncompulsory survey, the proportion of people randomly sampled who ultimately participated in the survey was less than half, so that selection bias could still exist. Nevertheless, the Obuse study cohort very closely resembled the average Japanese population due to its survey design.

Conclusion

We conducted a random sample Japanese cohort based on a resident registry and determined mean spinal alignment parameters by age and gender. We also calculated the population average of individuals over 50 years of age according to the Japanese population ratio. Although spinal alignment generally shifts forward with age, the details of position and degree of misalignment differ between genders: a forward shift of the upper cervical spine occurs first in men, whereas lumbopelvic alignment displacement occurs first in women.

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