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ORIGINAL ARTICLE

The cohort study for the determination of reference values for spinopelvic parameters (T1 pelvic angle and global tilt) in elderly volunteers

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Abstract

Purpose T1 pelvic angle (TPA) and global tilt (GT) are spinopelvic parameters that account for trunk anteversion and pelvic retroversion. To investigate spinopelvic parameters, especially TPA and GT, in Japanese adults and determine norms for each parameter related to health-related quality of life (HRQOL).

Materials and methods Six hundred and fifty-six volunteers (262 men and 394 women) aged 50–92 years (mean, 72.8 years) were enrolled in this study. The incidence of vertebral fracture, spondylolisthesis and coronal malalignment were measured. Five spinopelvic parameters (TPA, GT, sagittal vertical axis [SVA], pelvic tilt [PT], and pelvic incidence-lumbar lordosis [PI-LL]) were measured using whole spine standing radiographs. The mean values for each parameter were estimated by sex and decade of life. HRQOL measures, including the Oswestry Disability Index (ODI) and EuroQuol-5D (EQ-5D), were also obtained. Pearson's correlation coefficients were determined between each parameter and HRQOL measure. Moreover, the factors contributing to the QOL score were calculated using logistic regression with age, sex, the existence of vertebral fracture and spondylolisthesis, coronal malalignment (coronal curve >30°) and sagittal malalignment (SVA >95 mm) as explanatory variables and the presence of disability (ODI >40) as a free variable.

Results The mean values for the spinopelvic parameters were as follows: TPA, 17.9°; GT, 23.2°; SVA, 50.2 mm; PT, 18.6°; and PI-LL, 7.5°. TPA and GT strongly correlated with each other ($r = 0.990$) and with the other spinopelvic parameters. TPA and GT correlated with ODI ($r = 0.339$, $r = 0.348$, respectively) and EQ-5D ($r = -0.285$, $r = -0.288$, respectively), similar to those for SVA. TPA, GT, PT, and PI-LL were significantly higher in women than in men. PT and PI-LL gradually increased with age, while TPA, GT, and SVA tended to deteriorate after the 7th decade. Based on a logistic regression analysis, the deterioration of ODI was mostly affected by the sagittal malalignment. The TPA and GT cut-off values for severe disability (ODI >40) based on linear regression modeling were 26.0° and 33.7°, respectively.

Conclusions We determined reference values for spinopelvic parameters in elderly volunteers. Similar to SVA, TPA and GT correlated with HRQOL. TPA, GT, PT, and PI-LL were worse in women and progressed with age.

Keywords Cohort study · Adult spinal deformity · Spinopelvic parameter · T1-pelvic angle · Global tilt · Reference value

Introduction

Adults with spinal deformities comprise both asymptomatic individuals and those with severe clinical symptoms, such as back pain, muscle fatigue, and functional disability. Although spinal deformities progress over time, they are not necessarily accompanied by clinical symptoms; this is because spinopelvic parameters have a wide range of normal values; that is, there is a large asymptomatic range. Generally, lumbar lordosis decreases, and the body's trunk shifts anteriorly with age [1, 2]. To establish a better understanding of adult spinal deformity, it

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is crucial to determine age-related progression of spinal curvature and the normal range of each parameter by decade of life. While several reports have described normal values for spinopelvic parameters [2–7], the subjects were generally younger than those normally treated clinically, and most of the values were assessed for Caucasians. Although racial differences in spinopelvic parameters have been previously established in adolescent idiopathic scoliosis [8], there are few reports on racial differences in spinopelvic parameters between normal adults.

Lee et al. [6] investigated spinopelvic parameters in 86 healthy, young Korean volunteers and noted that pelvic incidence (PI), sacral slope (SS), and lumbar lordosis (LL) were smaller than those reported for Caucasians. Moreover, Asians may have a different presentation and prevalence of each type of sagittal alignment compared to Caucasians. Thus, it is crucial to determine the normal range of spinopelvic parameters among elderly Asian individuals to improve their treatment for spinal deformity.

Recently, T1-pelvic angle (TPA) [9, 10] and global tilt (GT) [11] were proposed as novel spinopelvic parameters that simultaneously account for both spinal inclination and pelvic retroversion [9–11]; these parameters cannot be modified by posture compensation. TPA is defined as the angle subtended by a line from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral end plate. GT is defined as the angle subtended by a line from the center of the superior sacral end plate to the center of the C7 vertebral body and a line from the femoral heads to the center of the superior sacral end plate (Fig. 1). Both novel parameters combine trunk anteversion and pelvic retroversion as one parameter to assess global spinal deformity.

The purposes of this study were to investigate spinopelvic parameters in adult Japanese volunteers and to determine reference values of each parameter, especially TPA and GT, as they relate to health-related quality of life (HRQOL) measures.

Materials and methods

Radiographic analysis of sagittal alignment was performed under institutional review board approval using 724 healthy, elderly Japanese volunteers over 50 years of age who received medical examinations under the auspices of a local school of medicine in 2012. The examinations were held in the rural town of Toei-cho, Kitashitara-gun, Aichi Prefecture, and consisted of a radiographic analysis as well as a physical examination (height, weight, and body mass index) and HRQOL measures.

Radiographic measurement

Standing whole spine and lateral pelvic radiographs were taken to assess spinopelvic alignment. Radiographic views

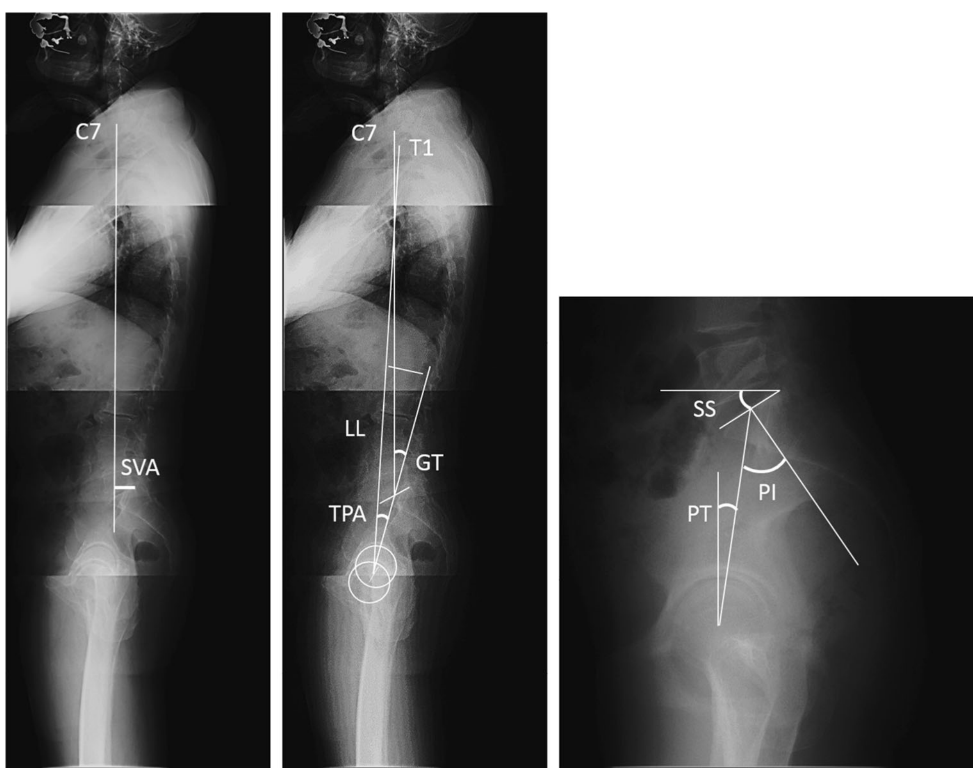

Fig. 1 Radiographic representation of spinopelvic parameters using whole spine and lateral pelvic radiograph. *Left* sagittal vertical axis (SVA). *Middle* lumbar lordosis (LL), T1 pelvic angle (TPA) and global tilt (GT). TPA is defined as the angle subtended by a line from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral end plate. GT is defined as the angle subtended by a line from the center of the superior sacral end plate to the center of the C7 vertebral body and a line from the femoral heads to the center of the superior sacral end plate. *Right* pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS)

were obtained with a 1.5-m distance between the X-ray tube and the radiograph for all subjects. The standing posture was standardized; subjects were asked to relax their heads while looking straight ahead without pulling in the chin and with their hands on the clavicles. We excluded subjects who had previous spine surgery, femoral neck fracture, artificial hip or knee replacement, or who had L6 or sacralization of L5, in which spinopelvic parameters could not be assessed accurately.

Using whole spine lateral radiographs, the incidence of vertebral fracture and spondylolisthesis was assessed. The incidence of vertebral fracture was assessed according to semi-quantitative criteria as reported by Genant [12]. Grade 1 and higher were interpreted as morphologic vertebral fractures. Regarding coronal malalignment, scoliosis was assessed based on the Scoliosis Research Society (SRS) Schwab classifications for coronal curves [13]. Coronal curves were classified into the following four types: T: thoracic only, L: lumbar only, D: double curve, and N: no major coronal deformity. Moreover, the following spinopelvic parameters were assessed: TPA, GT, sagittal vertical axis (SVA), pelvic tilt (PT), PI-LL from pelvic incidence (PI), and lumbar lordosis (LL) (Fig. 1). Two observers measured all parameters twice each using imaging software (Surgimap Spine; Nemaris Inc., New York, NY), and results were averaged.

HRQOL measurement

Two self-assessment HRQOL measurements, the Oswestry disability index (ODI) and the EuroQol-5D (EQ-5D), were obtained from each patient. We assessed the relationship between these HRQOL measures and radiographic spinopelvic parameters. All analyses were performed using SPSS version 13.0 (SPSS Inc., Chicago, IL). The Pearson correlation coefficient was calculated to evaluate the relationships among the spinopelvic parameters and between the spinopelvic parameters and HRQOL measures. Student's *t* test was used to evaluate sex differences among these parameters. Based on the SRS-Schwab classification [13], subjects with a coronal curve >30° were defined as having coronal malalignment, and those with SVA >95 mm as having sagittal malalignment. Furthermore, those with ODI >40 were defined as having disability. Factors contributing to the QOL score were calculated using logistic regression with age, sex, the existence of vertebral fracture and spondylolisthesis, coronal malalignment (coronal curve >30°), and sagittal malalignment (SVA >95 mm) as explanatory variables and the presence of disability (ODI >40) as a free variable. A p value less than 0.05 was considered significant. The intra- and inter-observer reliability were calculated by determining the intra-class correlation coefficient (ICC) for TPA, GT, SVA, PT, and PI of 100 randomly selected subjects in this study.

Results

Of the original 724 subjects, 656 subjects (262 men and 394 women) aged 50–92 years (mean, 72.8 years), met the inclusion criteria and were included. The mean height, weight, and body mass index were 154 cm, 54.6 kg, and 22.5 kg/m^2, respectively. Height and weight were higher among men, although there were no sex differences for age or BMI. Of 656 subjects, the incidence of vertebral fracture and spondylolisthesis was 18.2 and 31.1 %, respectively. Regarding the coronal curve, only six subjects (1 %) were categorized into type L, and the remainder was categorized into type N. No subjects were categorized into types T or D. The mean values for the spinopelvic parameters were as follows: TPA, 17.9°; GT, 23.2°; SVA, 50.2 mm; PT, 18.6°; and PI-LL, 7.5°. Sex differences were observed for TPA, GT, PT, and PI-LL, while there was no sex difference for SVA (Table 1). The mean values for TPA, GT, SVA, PT, and PI-LL according to the decade of life are shown in Table 2. While PT and PI-LL gradually increased with age, TPA and GT tended to worsen beginning in the 7th decade, in the same way as SVA (Fig. 2).

TPA was highly correlated with GT ($r = 0.990$), and TPA and GT were both highly correlated with PT ($r = 0.912$ and $r = 0.914$, respectively), SVA ($r = 0.737$ and $r = 0.751$, respectively), and PI-LL ($r = 0.768$ and $r = 0.768$, respectively), while the correlation between SVA and PT was $r = 0.446$.

All parameters were measured with good reproducibility. The intra-observer ICCs for TPA, GT, SVA, PT, and PI were 0.993, 0.996, 0.995, 0.996, and 0.918, respectively, and the inter-observer ICCs were 0.991, 0.990, 0.996, 0.990, and 0.966, respectively.

For the HRQOL measures, the mean scores for ODI and EQ-5D were 12.7 and 0.830, respectively. The ratios of ODI >20 (moderate disability) and ODI >40 (severe disability) were 21.6 and 3.4 %, respectively. TPA and GT were correlated with ODI ($r = 0.339$ and $r = 0.348$,

Table 1 Sex differences for spinopelvic parameters in 656 subjects

Parameters	Male ($n = 262$)		Female ($n = 394$)		P value
	Mean	SD	Mean	SD	
Age (years)	73.2	8.4	72.6	8.0	0.3559
TPA (°)	14.4	8.8	20.2	11.8	<0.0001
GT (°)	18.8	10.8	26.0	14.7	<0.0001
SVA (mm)	49.1	45.9	49.9	48.9	0.8368
PT (°)	14.6	7.6	21.3	10.1	<0.0001
PI-LL (°)	5.5	13.1	11.8	17.5	<0.0001

Table 2 Age-related changes in spinopelvic parameters in 656 subjects

Age (years)	50–59	60–69	70–79	Over 80
Number	36	175	304	141
Male/female	14/22	73/102	103/201	72/69
TPA (°)	12.0 ± 7.3	13.1 ± 8.1	18.5 ± 10.9	23.9 ± 12.1
GT (°)	15.4 ± 8.7	17.3 ± 10.3	24.0 ± 13.5	30.8 ± 14.8
SVA (mm)	26.9 ± 33.1	28.5 ± 32.2	49.2 ± 45.4	82.2 ± 53.7
PT (°)	13.8 ± 6.5	15.6 ± 7.9	19.4 ± 9.9	21.8 ± 10.5
PI-LL (°)	2.3 ± 9.3	4.7 ± 13.1	9.6 ± 16.7	15.9 ± 17.7

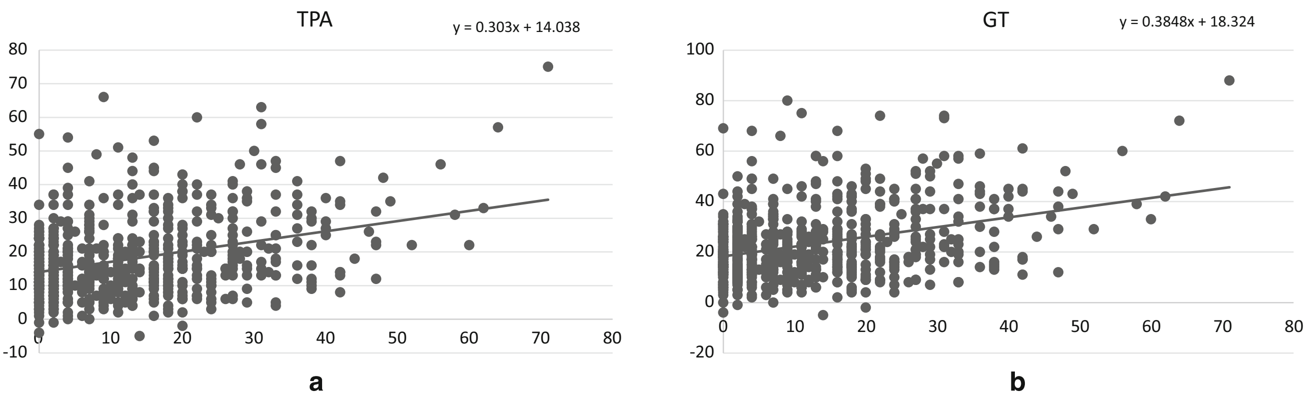

Fig. 2 Bar graphs of age-related changes in spinopelvic parameters

Table 3 Correlation coefficients between spinopelvic parameters and HRQOL measures

Correlation coefficient	Age	SVA	PT	PI-LL	TPA	GT
ODI	0.294	0.390	0.241	0.286	0.339	0.348
EQ-5D	−0.285	−0.287	−0.213	−0.229	−0.285	−0.288

$p < 0.01$

Table 4 Logistic regression assessing factors contributing to QOL deterioration

Model	Regression coefficient (B)	Standard error of (B)	*p* value	OR	95 %CI
Disability (ODI >40)					
Sex	−0.511	0.510	0.316	0.600	0.221–1.630
Age	0.046	0.035	0.191	1.047	0.977–1.122
Vertebral fracture	−0.377	0.500	0.450	0.686	0.258–1.826
Spondylolysthesis	0.271	0.482	0.573	1.312	0.511–3.371
Coronal malalignment (Cobb >30°)	−0.799	1.207	0.508	0.450	0.042–4.788
Sagittal malalignment (SVA >95 mm)	−2.129	0.524	<0.001	0.119	0.043–0.332

respectively) and EQ-5D ($r = -0.285$ and $r = -0.288$, respectively), similar to those for SVA (Table 3). Using a logistic regression analysis, sagittal malalignment had the greatest effect on the deterioration of ODI. In contrast, age, sex, coronal malalignment, vertebral fracture and spondylolisthesis were not statistically associated with the deterioration of ODI (Table 4).

The following regression models were obtained: for the linear relationship between TPA and ODI, TPA = 0.303 × ODI + 14.038 ($r = 0.339$), and for the linear relationship between GT and ODI, GT = 0.385 × ODI + 18.324 ($r = 0.348$; Fig. 3). Using these regression models, the TPA and GT cut-off values for severe disability (ODI >40) were 26.0° and 33.7°, respectively.

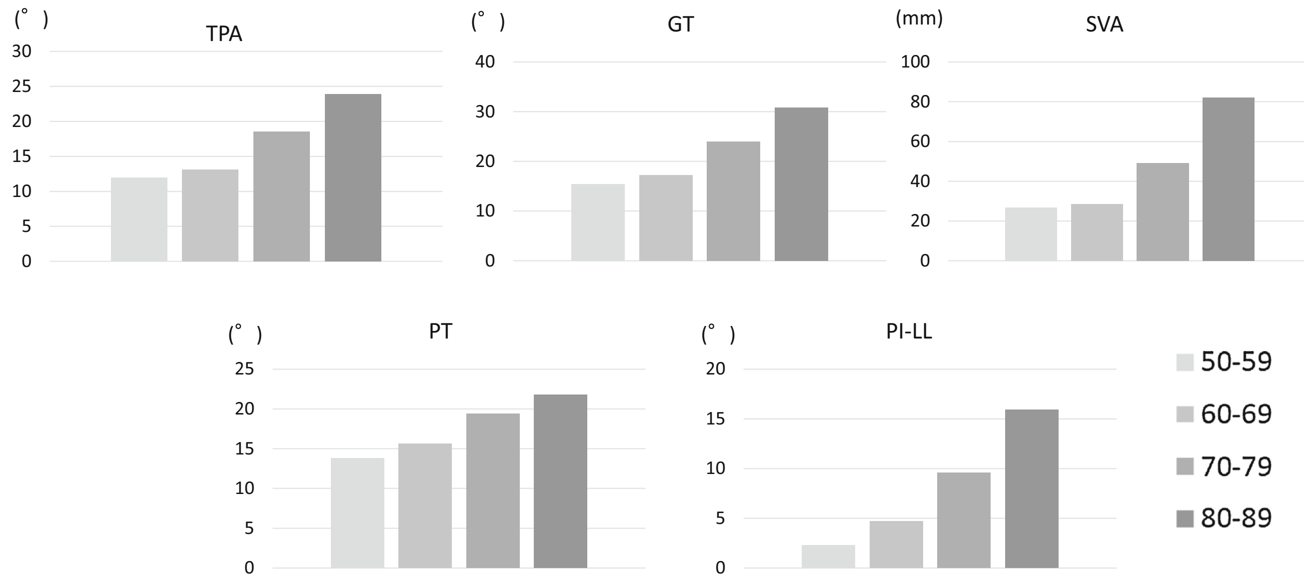

Fig. 3 Scatter diagram describing the relationship between **a** TPA and ODI and **b** GT and ODI. The correlation coefficients between ODI and TPA and ODI and GT were 0.339 and 0.348, respectively. The cut-off values of TPA and GT for severe disability (ODI >40) according to the linear regression analysis were 26.0° and 33.7°, respectively. Although PT and PI-LL values gradually increased with age, TPA, GT, and SVA values tended to increase from the seventh decade of life

Discussion

TPA and GT are novel spinopelvic parameters, and each accounts for both pelvic retroversion and trunk anteversion [9–11]. Because the concepts of TPA and GT are similar, we found a strong correlation between TPA and GT ($r = 0.990$). Consequently, either is sufficient for assessing global alignment and this is the first report regarding the reference values of TPA and GT in elderly volunteers.

Several studies have demonstrated adult scoliosis patients showed significantly poorer scores for clinical symptoms in association with deteriorating sagittal alignment, thus efforts should be made to achieve optimal sagittal alignment [5, 13–18]. However, especially in the elderly population, there were many subjects with vertebral fractures, spinal degenerative changes, and coronal deformity, which could affect the deterioration of HRQOL measures. Therefore, we assessed the risk factors that had a negative influence on HRQOL measures using a logistic regression. Indeed, although there were many subjects who had vertebral fracture, spondylolisthesis, coronal malalignment, and/or sagittal malalignment, sagittal malalignment showed the greatest association with the deterioration of ODI.

Many previously reported spinopelvic parameters have been shown to be correlated with HRQOL measures in adult spinal deformity patients. Schwab et al. [18] compared the spinopelvic parameters and HRQOL in adult spinal deformity patients who received non-operative and operative treatment. Those who received the operative treatment showed poor spinopelvic parameters and HRQOL compared to those who received non-operative treatment; moreover, spinopelvic parameters, especially SVA, PT, and PI-LL, were correlated with HRQOL. Actually, SVA and PT are important spinopelvic parameters that reflect the severity of adult spinal deformity; however, there are some problems with these parameters [14–16, 19]. First, SVA represents trunk inclination; therefore, the value is influenced by the subject's height or by radiographic calibrations [20]. Furthermore, SVA may be compensated by posture, such as knee flexion and pelvic retroversion, to maintain global standing alignment [21]. Thus, SVA and PT are interrelated; when SVA was greater, PT was smaller for an individual patient. In contrast, TPA and GT have many advantages for assessing global alignment in that they are largely unaffected by posture or radiographic calibrations. Furthermore, TPA and GT strongly correlated with conventional global parameters (SVA, PT, PI-LL). Regarding clinical evaluation, the correlations between TPA, GT, and HRQOL measures (ODI, EQ-5D) were similar to those of SVA and HRQOL measures. Therefore, TPA and GT are useful parameters for assessing global alignment in adult spinal deformity.

However, compared to previous reports describing the relationship between TPA and ODI, the correlation was lower in this study [9, 10, 22]. This discrepancy may be because previous studies examined adult spinal deformity patients, while the present study examined elderly volunteers who may have had vertebral fracture, spinal degenerative change, and lower limbs joint diseases that could affect ODI measures. Based on linear regression modeling, the TPA and GT cut-off values for ODI scores >40 were 26.0° and 33.7°, respectively. This TPA cut-off value was higher than the severe deformity threshold for TPA (20° for ODI scores >40) previously reported by Ryan et al. [10], and it may be that Japanese individuals are tolerant of TPA deterioration.

We found that there were sex differences for some of the spinopelvic parameters among our elderly volunteers in spite of there being no statistical age differences. TPA, GT, PT, and PI-LL were greater in women, although SVA was not significantly different between the two sexes. These results are in contrast to other reports describing sex differences for spinopelvic parameters. Vialle et al. [3] showed that LL, SS, and PI were greater in women (110) than in men (190); the average age was 35 years. On the contrary, Janssen et al. [23] and Mac-Thiong et al. [2] did not find any sex differences for SS, PI, or PT in young volunteers. Because our study consisted of elderly volunteers, we may have found sex differences because spinal deformity may progress more quickly with age in women than in men due to osteoporosis or declining back muscle strength. Though there were no sex differences for SVA, the trunk inclination due to the decrease of lumbar lordosis might be compensated for by pelvic retroversion (increase of PT). Therefore, it may be that sagittal deformity in elderly women is worse than in elderly men, unlike among younger people. TPA and GT are thought to be more sensitive values reflecting these compensatory mechanisms because they include the element of pelvic tilt.

Generally, it is obvious that PT increases with aging, indicating an increased retroversion of the pelvis to compensate for degenerative processes of the spine that tend to decrease lumbar lordosis and induce a positive spinal balance [1, 2]. To understand the natural history of spinal sagittal alignment, it is crucial to know the normal values for adult spinopelvic parameters; however, there has been no previous report of these normal values by each decade of life among asymptomatic subjects. In this report, PT and PI-LL gradually increased with age; on the other hand, TPA and GT tended to decrease starting in the 7th decade, similar to SVA. Through the 6th decade of life, lumbar lordosis gradually decreased, and when the trunk shifted anteriorly, the compensatory mechanism of pelvic retroversion occurred; therefore, SVA was not aggravated. Beginning in the 7th decade, lumbar kyphosis and trunk inclination could no longer be compensated; thus, SVA declined in this decompensated stage.

After Schwab et al. [15] proposed the ideal spinopelvic parameters as SVA <50 mm, PT <20°, and PI-LL <±9° to obtain good surgical outcomes, many surgeons correcting spinal deformities aimed to restore this ideal sagittal alignment. Although it is difficult to determine postoperative sagittal alignment at operative planning, TPA and GT are useful parameters, because these parameters are less affected by posture and assess the deformity as one parameter. Qiao et al. [22] reported that the pre- vs. post-operative change in TPA more strongly correlated with the degree of pedicle subtraction osteotomy than SVA or PT. To use TPA or GT, however, a formula for predicting postoperative sagittal alignment will be required.

This study has some limitations. First, the incidence of lower joint disease, such as osteoarthritis of the hip or knee, which might affect HRQOL, were not taken into account. Moreover, compensation by lower limbs was not assessed. Second, this study included subjects living in a rural area of Japan, and most of them were engaged in agriculture. Thus, these results may not be applicable to subjects living in cities. Third, there might be race differences in spinopelvic parameters; therefore, these data may not apply to other races. However, these data from a large sample of elderly Japanese volunteers could improve understanding of age- and gender-related changes in spinopelvic parameters.

Finally, many types of spinal alignment were included in this cohort study because the pathologies of spinal deformity with compensation are likely different depending on the type of deformity. Lamartina et al. [24] proposed a sagittal spinal deformity classification and revealed that spinopelvic parameters differed with the level of deformity and compensatory mechanism. In addition, Kim et al. [25] reported that elderly adults without disc degeneration had higher lumbar lordosis compared with young adults and insisted that deformities based on aging and disc degeneration were different. Therefore a longitudinal study is needed to reveal the progression of deformity and reference values of spinopelvic parameters based on the type of deformity.

Conclusion

Sagittal malalignment was correlated with the deterioration of HRQOL measures. TPA and GT were correlated with HRQOL measures and other conventional parameters (SVA, PT, PI-LL). Sex differences were observed for TPA, GT, PT, and PI-LL. In elderly people, spinal deformity gradually progressed with age, suggesting the clinical application of these parameters.

Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

Informed consent All study participants provided informed consent, and the study design was approved by the appropriate ethics review boards.

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