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ORIGINAL ARTICLE - SPINE

Sagittal spinal alignment in asymptomatic patients over 30 years old in the Korean population

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Abstract
Background We aim to provide sagittal and pelvic parameters according to different age groups in an asymptomatic population all over 30 years old and to investigate the possible causes of changes in these parameters.
Methods Whole-spine, standing lateral radiographs were taken in 128 asymptomatic Korean people over 30 years old. The spinal parameters (the total thoracic kyphosis (TTK), maximal lumbar lordosis (MLL), total lumbar lordosis (TLL), lower lumbar lordosis (LLL), thoracolumbar junctional angle (TLJA), and lumbar inclination (LI)), pelvic parameters (pelvic incidence (PI), sacral slope (SS), and pelvic tilt (PT)), and spinal balance parameters (spinal balance, sacropelvic balance, and spinopelvic balance) were measured. The body mass index, body protein mass, waist line, skeletal muscle mass, and body fat mass were also measured for potential causes.
Results TTK and TLJA were significantly increased in the group over 70 years of age compared to the other age groups ($p =$ 0.0002, <0.001). TLL was significantly decreased in the group over 70 years of age ($p = 0.002$), whereas the PI values were similar to PI even in over 70-year age group. LLL did not differ in the group over 70 years of age ($p = 0.29$), gradually increasing with an increase in age. SS was significantly decreased and PT was significantly increased in the group over 70 years of age as compared to the other age groups ($p = 0.049$, 0.049, respectively). PI was similar in all age groups ($p = 0.75$). Spinal balance was significantly decreased in the group over 70 years of age ($p = <0.0001$). PT was significantly associated with body protein mass and skeletal muscle mass ($p = 0.01$, 0.001, respectively). Body protein mass and skeletal muscle mass were significantly lower in the group over 70 years of age ($p = 0.02$, 0.02) and were possible causes.
Conclusions Several sagittal and pelvic parameters are different in asymptomatic adults over 70 years of age. Decreased body protein mass and skeletal muscle mass are possible causes of these changes.

Keywords Sagittal balance · Spinal alignment · Sacral slope · Adult spine · Normal patterns

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Introduction

Proper knowledge of the physiologic sagittal balance and associated pelvic parameters is essential for spine surgeons to achieve successful outcomes of spinal surgery [12, 15, 22]. Many authors have reported the importance of the sagittal plane contour in the normal function of the spine and in various disease states [1, 3, 7–11, 17, 18, 22, 24, 27–29, 32–35]. Normal parameters have been investigated in several studies, however the participants were typically adolescents or young adults [6, 23, 30]. Other studies have attempted to determine sagittal and pelvic parameters in older people [15, 20]. However, their investigations included patients in addition to asymptomatic subjects [20] or did not include middle-aged subjects [15].

In this study, we aim to elucidate sagittal and pelvic parameters in an asymptomatic Korean population depending on age in subject groups all exceeding 30 years of age and to investigate the possible causes of changes in these parameters.

Materials and methods

Study participants

From March 2007 to February 2013, a total of 219 people underwent whole-spine standing radiographs as part of a premium routine health screening program at the Healthcare System Gangnam Center of Seoul National University. Among these 219 people, those with two or more radiographs ($n = 14$), foreigners ($n = 6$), those for whom the quality of the measurements was inadequate ($n = 22$), and those with low back pain ($n = 31$) were excluded. People under 30 years of age were also excluded. In total, 128 cases were included (Fig. 1). All of the participants provided informed consents. The mean age, height, and weight of the participants were 54.1 years (range, 30–79 years), 164.6 cm (range, 142–183 cm), and 63.0 kg (range, 39–92 kg), respectively. This study was approved by the SNUH institutional review board (H-1308-124-517).

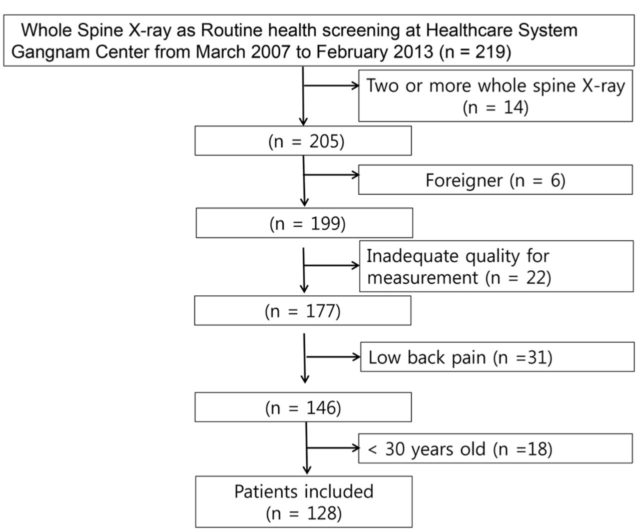

Fig. 1 Numbers of cases of whole-spine X-rays as part of the routine health screening and case numbers included in this study

Radiographic and body composition measurement

Whole-spine lateral radiographs were taken in a standing position with standard 37-in film. The hip joint and cervical spine were also included. The participants were instructed to stand straight and relaxed, with their knees fully extended. The elbows were flexed, with both hands resting at the level of their shoulders. The film-to-focus distance was 2 m.

Six reference points were used: These were the hip axis (the midpoint of the line between the geometric center of both femoral heads), the center of the C7 vertebral body, the horizontal thoracic level (HTL, the thoracic vertebra or disc space closest to the horizontal line), the junctional level (JL, the most tilted thoracolumbar vertebra), the horizontal lumbar level (HLL, the lumbar vertebra or disc space closest to the horizontal line), and the midsacral point (the midpoint of the superior endplate of S1). As spinal parameters, the total thoracic kyphosis (TTK), maximal lumbar lordosis (MLL), total lumbar lordosis (TLL), lower lumbar lordosis (LLL), thoracolumbar junctional angle (TLJA), and lumbar inclination (LI) were measured (Fig. 2). As

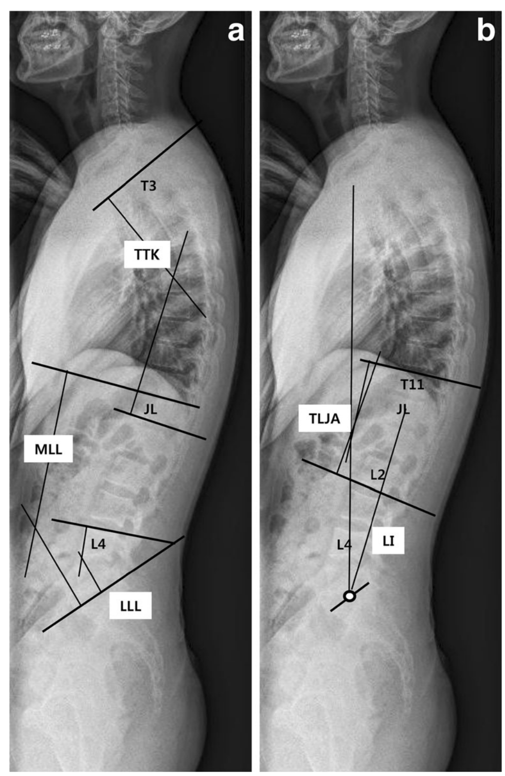

Fig. 2 Spinal parameters. **a** Total thoracic kyphosis (TTK) is defined as the angle between the upper end plate of T3 and the lower end plate of the most tilted thoracolumbar vertebra (JL); maximal lumbar lordosis (*MLL*), JL and S1; total lumbar lordosis (*TLL*), the T12 low end plate and S1; and lower lumbar lordosis (*LLL*), L4 and S1. **b** The thoracolumbar junctional angle (*TLJA*) is defined as the angle between T11 and L2; and lumbar inclination (*LI*) is a *vertical line* and a *line* connecting JL and the midsacral point (*MSP*)

pelvic parameters, the pelvic incidence (PI), sacral slope (SS), and pelvic tilt (PT) were measured (Fig. 3). The sagittal balance was measured by assessing the spinal balance, spinopelvic balance, and sacropelvic balance (Fig. 4). The offsets had negative values when the C7 plumb line was backward relative to the reference point (the hip axis and the midsacral point) [23].

All images in our clinic were digitized and all parameters were measured using a computerized method in PACS (Marosis, version 5483, Infinitt Healthcare), as reported in our previous study [13].

One spine surgeon (S. Sohn) measured all of the parameters once. One registered nurse (H. Kim) measured all of the parameters independently again. For measurement reliability, the registered nurse (H. Kim) measured all parameters once again with a 7-day interval. Reliability levels between and within observers were assessed based on an inter-rater correlation coefficient (ICC) [31]. The ICC values were 0.94 between observers and 0.99 within observer and are considered to be in "strong agreement".

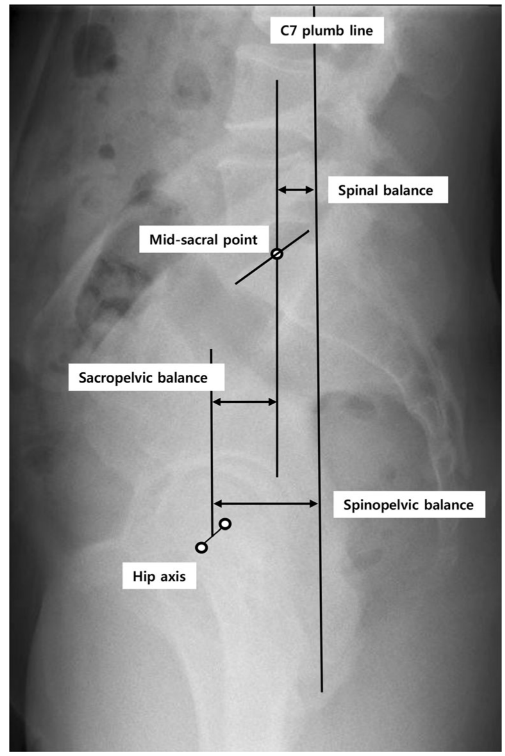

Fig. 4 Parameters of the sagittal balance of the spine and pelvis. Spinal balance is defined as the horizontal offset between the midsacral point and the C7 plumb line; spinopelvic balance, between the hip axis and the C7 plumb line; and sacropelvic balance, between the hip axis and the midsacral point

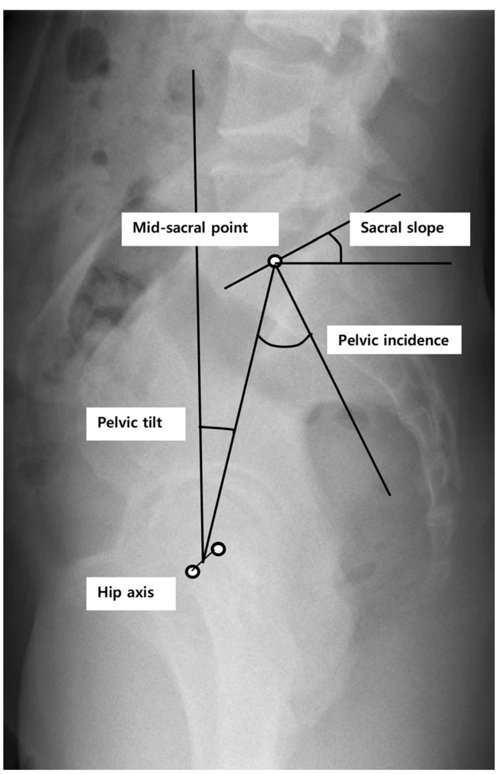

Fig. 3 Pelvic parameters. Pelvic incidence (*PI*) is defined as the angle between the perpendicular to the sacral plate at its midpoint and a line connecting the same point to the hip axis (the center of the bicoxofemoral axis). The sacral slope (*SS*) is defined as the angle between the horizontal and sacral plate. The pelvic tilt (*PT*) is defined as the angle between a vertical line originating at the hip axis and a line drawn between the same point and middle of the superior endplate of S1

The body composition variables of the body protein mass, skeletal muscle mass, percentage of body fat, and body fat mass were measured by using a bioimpedance analysis device (InBody720; Biospace CO. Ltd., Seoul, Korea) [4, 19].

Statistical analysis

Radiographic parameters for each age group are presented as the mean and standard deviation. Gender differences were compared by using Wilcoxon rank sum test. ANOVA and the contrast of regression analysis were used to analyze differences among age groups. Associations between radiological parameters and body composition variables were assessed by using Spearman's rank correlations. Regression analysis between radiological parameters and body composition variables were assessed. A two-tailed p value of <0.05 was considered indicative of a significant difference. The software SPSS for Windows (version 19.0; IBM Corp., Armonk, NY, USA) was used for a statistical analysis of the data. Counseling regarding the statistics in this study was provided by the Seoul National University Medical Research Collaborating Center (2015-0113).

Table 1 Mean, minimum, maximum, and standard deviations of the parameters

Parameters	Total ($n = 128$)				Male ($n = 63$)				Female ($n = 65$)				
	Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD	*p* value
Age (year)	54.1	30.0	79.0	10.4	54.0	35.0	76.0	9.6	54.1	30.0	79.0	11.2	0.92
Total thoracic kyphosis (°)	36.4	16.9	66.2	9.2	37.6	16.9	66.2	9.5	35.3	18.9	65.5	8.7	0.14
Thoracolumbar junctional angle (°)	3.3	−15.3	38.7	8.2	5.4	−11.9	38.7	8.2	1.2	−15.3	24.9	7.7	0.0009
Total lumbar lordosis (°)	−53.8	−84.6	−5.3	10.8	−52.1	−84.6	−5.3	12.1	−55.4	−76.5	−22.5	9.2	0.03
Maximal lumbar lordosis (°)	−50.0	−80.2	50.6	13.0	−47.7	−80.2	50.6	15.8	−52.1	−70.0	−26.5	9.3	0.01
Lower lumbar lordosis (°)	−33.1	−54.3	−9.5	7.5	−33.9	−51.9	−14.6	7.4	−32.2	−54.3	−9.5	7.5	0.14
Lumbar inclination (°)	8.0	−12.6	28.9	5.5	9.2	−1.4	25.6	4.9	6.7	−12.6	28.9	5.9	0.002
Sacral slope (°)	34.7	2.3	58.5	8.1	33.8	2.3	58.5	9.0	35.5	13.9	51.1	7.2	0.14
Pelvic tilt (°)	12.8	−1.1	42.6	7.5	10.7	−1.1	42.6	6.8	14.8	3.4	40.8	7.6	0.002
Pelvic incidence (°)	47.5	23.8	79.9	9.9	44.5	29.7	70.6	8.3	50.3	23.8	79.9	10.6	0.0002
Spinal balance (cm)	27.2	−65.0	92.5	29.2	28.1	−34.5	92.5	27.1	26.3	−65.0	86	31.2	0.94
Sacropelvic balance (cm)	25.2	−2.0	69.5	12.8	22.1	−2.0	69.5	11.9	28.1	4.6	60.5	13.0	0.009
Spinopelvic balance (cm)	52.2	−46.4	130.0	29.7	50.2	−5.0	130.0	27.4	54.1	−46.4	130.0	31.8	0.29
Body mass index (kg/m^2)	23.2	18.1	31.7	2.5	24.2	20.8	31.7	2.1	21.8	18.1	30.4	2.5	<.0001
Percentage of body fat (%)	26.0	13.2	43.2	6.3	22.9	13.2	36.2	4.4	30.5	20.6	43.2	5.9	<.0001
Body protein mass (kg)	9.3	6	13.1	2.0	10.7	8.8	13.1	1.1	7.3	6	9	0.8	<.0001
Waist line (cm)	83.9	66.5	106.0	7.7	87.0	75	105.9	6.0	79.3	66.5	97	7.6	<.0001
Skeletal muscle mass (kg)	26.1	16	39.2	6.3	30.5	24.4	39.2	3.6	19.7	16	25.2	2.6	<.0001
Body fat mass (kg)	16.4	8	33.7	4.4	16.2	8	33.1	4.1	16.7	8	33.7	4.4	0.92

SD standard deviation

Results

Parameters in all age groups

Table 1 lists the mean, minimum, maximum, and standard deviation of the parameters. The most common HTL, JL, and HLL parameters were the T6 body, the T12 body, and the L4 body, respectively.

When we compared the parameters between male and female participants, TLJA, TLL, MLL, LI, PT, PI, and the sacropelvic balance were found to differ significantly ($p = 0.0009$, 0.03, 0.01, 0.002, 0.002, 0.0002, and 0.009, respectively, Table 1).

Spinal parameters according to each age group

TTK and TLJA was significantly higher in the group over 70 years of age compared to the other age groups ($p = 0.0002$, <0.001). TLL was significantly lower in the group over 70 years of age ($p = 0.002$) (Fig. 5), whereas PI for this age group remained similar. LI was also significantly different in the group over 70 years of age as compared to the other age groups ($p = 0.008$). LLL did not differ in the group over 70 years of age ($p = 0.29$), and this parameter gradually increased with age groups (Fig. 5). MLL as well did not differ in the group over 70 years of age ($p = 0.23$). In multiple regression analysis,

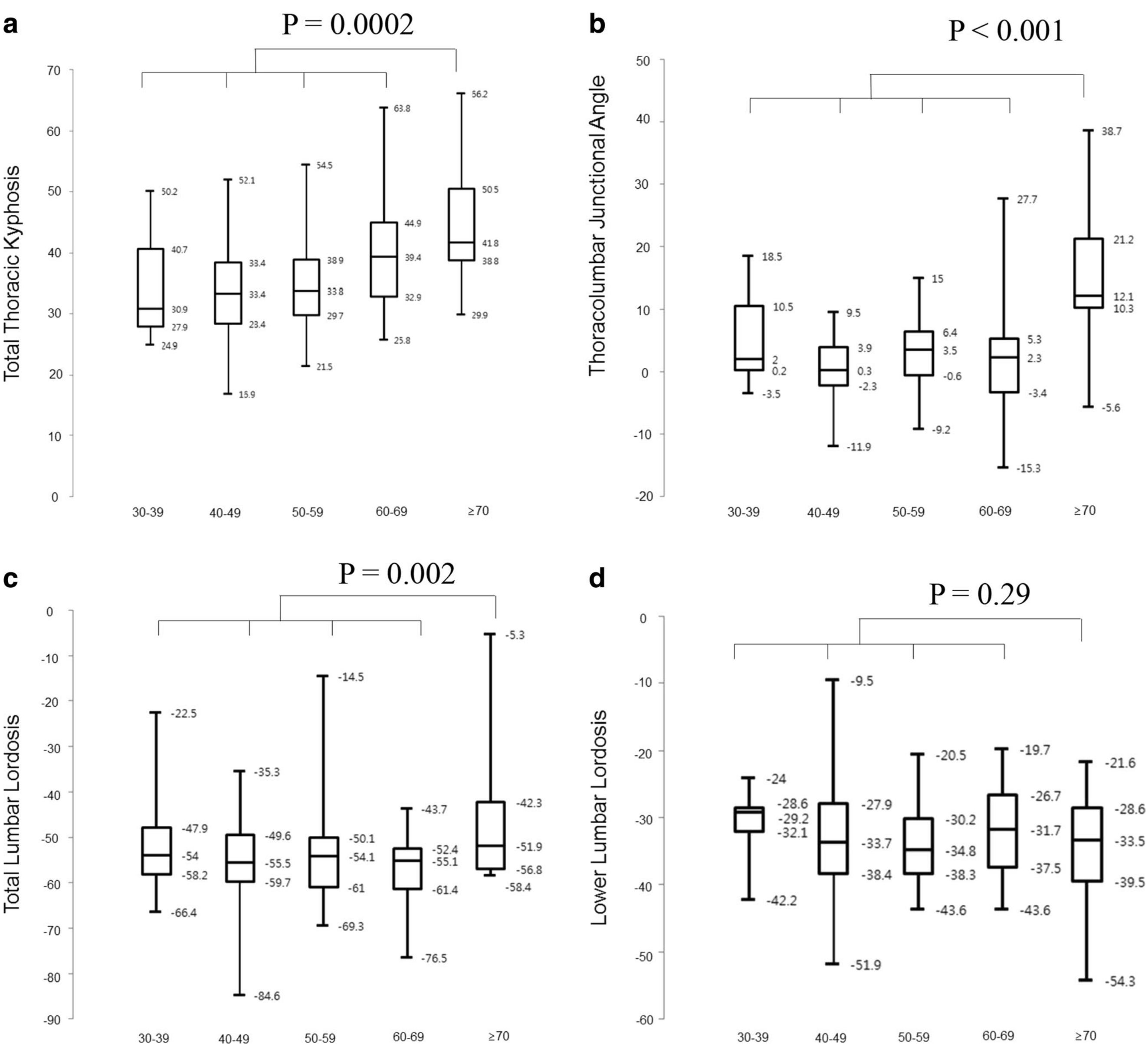

Fig. 5 Spinal parameters according to each age group. **a**, **b** TTK and TLJA in the group over 70 years of age were significantly higher than those in the other age groups. **c** TLL in the group over 70 years of age was significantly lower than those in the other age groups. **d** LLL gradually increased with age

TTK and TLJA and LI was significantly associated with increasing age (p = <0.0001, 0.002, 0.02, respectively) (Table 2).

Pelvic parameters according to each age group

SS was significantly lower and PT was significantly higher in the group over 70 years of age as compared to the other age groups (p = 0.049, 0.049, respectively, Fig. 6a–b). PI was similar in all age groups (p = 0.75, Fig. 6c). In multiple regression analysis, PT was significantly associated with increasing age (p = 0.002).

Spinal balance parameters for each age group

Spinal balance was significantly lower in the group over 70 years of age compared to the other age groups (p = <0.0001). The value for this parameter was −5.2 mm in

Table 2 Regression analysis between the parameters and age

Parameters		Univariate		Multivariate	
		Regression coefficient	p value	Regression coefficient	p value
Total thoracic kyphosis (°)	Age	0.2991	**<.0001**	0.2996	**<.0001**
	Female (ref. Male)	−2.368	0.15	−2.3954	0.12
Thoracolumbar junctional angle (°)	Age	0.2018	**0.004**	0.2027	**0.002**
	Female (ref. Male)	−4.2531	**0.003**	−4.2717	**0.002**
Total lumbar lordosis (°)	Age	0.0876	0.34	0.0883	0.34
	Female (ref. Male)	−3.2362	0.09	−3.2443	0.09
Maximal lumbar lordosis (°)	Age	0.0601	0.59	0.0611	0.58
	Female (ref. Male)	−4.4101	0.06	−4.4157	0.06
Lower lumbar lordosis (°)	Age	−0.0607	0.34	−0.0611	0.34
	Female (ref. Male)	1.7364	0.19	1.742	0.19
Lumbar inclination (°)	Age	0.1069	**0.02**	0.1074	**0.02**
	Female (ref. Male)	−2.5254	**0.01**	−2.5352	**0.008**
Sacral slope (°)	Age	−0.0853	0.23	−0.0832	0.24
	Female (ref. Male)	1.7074	0.24	1.663	0.25
Pelvic tilt (°)	Age	0.1848	**0.005**	0.1901	**0.002**
	Female (ref. Male)	4.0423	**0.002**	4.1437	**0.001**
Pelvic incidence (°)	Age	0.0995	0.25	0.1069	0.20
	Female (ref. Male)	5.7496	**0.001**	5.8066	**0.0009**
Spinal balance (°)	Age	−0.7028	**0.005**	−0.7055	**0.005**
	Female (ref. Male)	−1.7628	0.74	−2.1391	0.68
Sacropelvic balance (°)	Age	0.2852	**0.01**	0.293	**0.007**
	Female (ref. Male)	6.0286	**0.008**	6.1848	**0.005**
Spinopelvic balance (°)	Age	−0.4333	0.09	−0.4285	0.10
	Female (ref. Male)	3.9704	0.46	3.7419	0.48
Body mass index (kg/m^2)	Age	0.0203	0.46	0.0283	0.25
	Female (ref. Male)	−2.3736	**<0.0001**	−2.4201	**<.0001**
Percentage of body fat (%)	Age	0.1548	**0.02**	0.1304	**0.02**
	Female (ref. Male)	7.5889	**<0.0001**	7.3749	**<.0001**
Body protein mass (kg)	Age	−0.051	**0.01**	−0.0401	**<.0001**
	Female (ref. Male)	−3.3778	**<0.0001**	−3.3121	**<.0001**
Waist line (cm)	Age	0.1187	0.15	0.1448	**0.04**
	Female (ref. Male)	−7.6497	**<0.0001**	−7.8873	**<.0001**
Skeletal muscle mass (kg)	Age	−0.158	**0.02**	−0.1229	**0.0002**
	Female (ref. Male)	−10.8129	**<0.0001**	−10.6113	**<.0001**
Body fat mass (kg)	Age	0.0408	0.39	0.0395	0.41
	Female (ref. Male)	0.4571	0.67	0.3923	0.71

Bold style indicates statistical significance

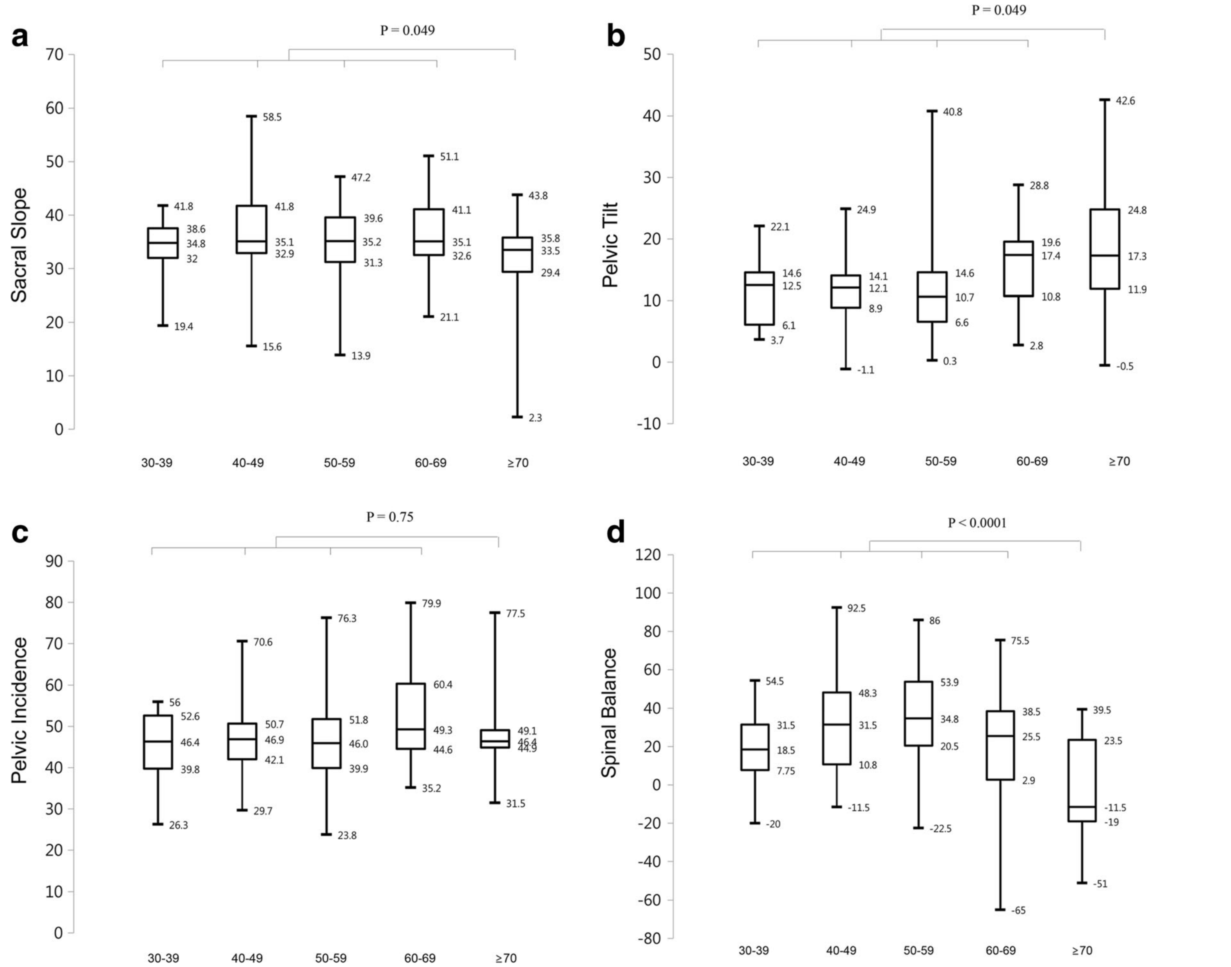

Fig. 6 Pelvic and sagittal balance parameters according to each age group. **a**, **b** SS and PT in the group over 70 year old age were significantly higher than those in the other age groups. **c** PI was similar in all age groups. **d** Spinal balance in the group over 70 years of age was significantly lower than those values in the other age groups

the group over 70 years of age (Fig. 6d). Spinopelvic balance was also significantly different in the group over 70 year of age compared with the other age groups ($p = 0.004$). Sacropelvic balance was not significantly different in the group over 70 years of age compared with other age groups ($p = 0.06$). In multiple regression analysis, spinal balance and sacropelvic balance were significantly associated with increasing age ($p = 0.005$, 0.007, respectively).

Possible causes for spinal and pelvic parameters

Body protein mass and skeletal muscle mass were significantly lower in the group over 70 years of age than in the other age groups ($p = 0.02$, 0.02, respectively, Fig. 7). Body mass index, the percentage of body fat, the waist line, and the body fat mass were not different in the group over 70 years of age compared with the other age groups ($p = 0.76$, 0.052, 0.37, 0.62). Pelvic tilt was significantly associated with body protein mass and skeletal muscle mass ($p = 0.01$, 0.001, respectively).

In multiple regression analysis, Body protein mass and skeletal muscle mass were significantly associated with increasing age ($p = <0.0001$, 0.0002, respectively). Percentage of body fat and the waist line were also significantly associated with increasing age ($p = 0.02$, 0.04, respectively).

Discussion

In our study, several sagittal and pelvic parameters in the group over 70 years of age were significantly different compared with the other age groups. This implies that normal radiographic variables in a young population cannot be applied to people over 70 years of age. Thus, while radiographic parameters are in accordance with adult deformity criteria, we may not regard people in this age cohort as abnormal if they do not have related symptoms such as pain or disability.

The change in the lumbar lordosis parameter is very important among the many sagittal parameters because lumbar lordosis plays a key role in achieving global sagittal balance [2]. The tendency of changes in the lumbar lordosis parameter in

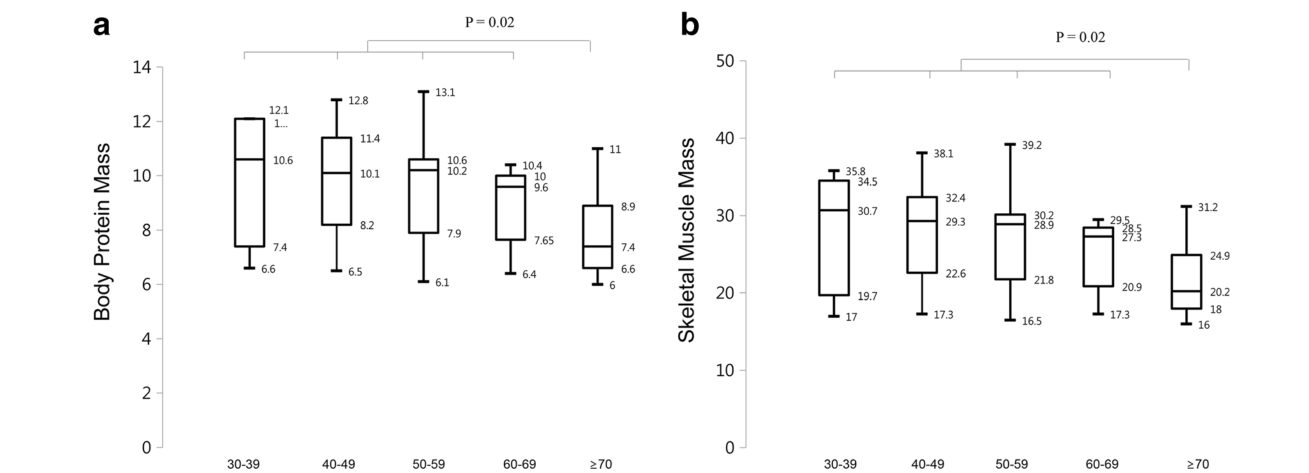

Fig. 7 Body protein mass and skeletal mass according to each age group. **a**, **b** Body protein mass and skeletal mass in the group over 70 years of age were significantly lower than those in the other age groups

relation to aging is controversial. Two reports have shown that lumbar lordosis values are lower in older people [7, 16]. One study showed that lumbar lordosis did not differ between adolescents and adults [35]. A recent study reported that lumbar lordosis values were significantly higher in an old age group as compared to a younger group [15]. In the present study, total lumbar lordosis values were found to be steady up to 70 years old, whereas they were lower after 70. However, the results for total lumbar lordosis were identical to those for pelvic incidence even in the group over 70 years of age (Figs. 5c and 6c). With regard to adult spinal deformity surgery, the first key parameter for correction is PI minus LL. Even in the group over 70 years of age, PI minus LL was well maintained in our asymptomatic study group.

LLL is known to be the most important determinant of global lordosis [1, 30]. The change in LLL is also still controversial. One report found that increasing age led to a more forward SVA with a loss of distal lumbar lordosis [7]. However, a recent report showed that LLL increases with age [15]. In the present study, LLL increased gradually according to age, even in the group over 70 years of age. Considering that degenerative losses of lumbar lordosis usually start in the lower lumbar spine, one should consider a proper amount of reconstruction with regard to lower lumbar lordosis for a better sagittal balance postoperatively.

Legaye et al. [24] determined that PI is affected by individual characteristics of anatomy and that it will not change for life after maturation, whereas but Mendoza-Lattes et al. [26] reported that PI increases gradually throughout the lifespan. In our study, PI was not changed even in the group over 70 years of age. Further studies are warranted to clarify this PI change.

Several authors have insisted that thoracic kyphosis increase with age [5, 18], but other studies did not support this condition [7, 35]. The present study showed that TTK and TLJA values remained steady up to 70 years old, but that TTK and TLJA were significantly higher in the group over 70 years of age. We hypothesized that the increases in TTK and TLJA in the group over 70 years of age represented fundamental changes, leading to reciprocal changes of TLL and the pelvic parameters.

In our study, spinal balance was significantly lower in the group over 70 years of age as compared with the other age groups. However, spinal balance remained at −5.3 mm even in the group over 70 years of age. Overcorrection or large sagittal vertical axis correction have been reported as possible causes of proximal junctional problems in adult deformity surgery [14, 21, 25]. When we correct adult deformity, consideration of the natural sagittal balance in the aged, especially in those over 70 years of age, should be considered according to the findings here. Further studies are warranted to elucidate correction strategies for those over 70 years of age.

According to the findings, decreased body protein mass and skeletal muscle mass were associated with increased pelvic tilt in the group over 70 years of age. TTK, TLJA, TLL, and SS were not significantly associated with body protein mass or skeletal muscle mass; however, a lack of statistical power due to the small series cannot be excluded. We also found that body protein mass and skeletal muscle mass were significantly lower in the group over 70 years of age. These results suggest that changes in body protein mass and skeletal muscle mass are possible factors in the changed parameters in the group over 70 years of age (Fig. 7). Strategies to increase skeletal muscle mass such as nutritional support and core exercise could be good ways to maintain various parameters for those over 70 years of age. Further studies are thus warranted to find definite causes of the changes in the sagittal and pelvic parameters in people over 70 years old.

Limitations

Several limitations of this study should be noted. First, this is a cross-sectional study and not a longitudinal study. Therefore, we cannot compare each parameter according to the aging process in each person. Second, we presumed that all individuals in their respective groups had similar sagittal patterns. Previous studies find that there are several sagittal patterns in normal subjects [23, 30]. Regardless of these limitations, to the best of our knowledge, this is the first study to introduce sagittal and pelvic parameters in comprehensive age groups of an asymptomatic adult population.

Conclusions

TTK and TLJA are higher and TLL is lower in a group over 70 years of age as compared to other age groups. LLL gradually increase with age. However, TLL remains similar to PI even in the group over 70 years of age. Decreased body protein mass and skeletal muscle mass are possible causes of the changes in parameters in the group over 70 years of age.

Compliance with ethical standards

Disclosure The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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