Deterioration of sagittal spinal alignment with age originates from the pelvis not the lumbar spine: A 4-year longitudinal cohort study

Title

Deterioration of sagittal spinal alignment with age originates from the pelvis not the lumbar spine: A 4-year longitudinal cohort study

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Title

Deterioration of sagittal spinal alignment with age originates from the pelvis not the lumbar spine: A 4-year longitudinal cohort study

Abstract

Purpose: There is controversy regarding age-related deterioration of spinal sagittal alignment in cross-sectional study. Although we reported that deterioration in spinal alignment originated at the cervical spine in males and the pelvis in females, others studies have indicated that the lumbar spine is initially implicated in both sexes. The purpose of this study was to clarify these differences in a longitudinal cohort study.

Methods: Our analysis was based on 237 individuals aged 60-89 years who participated in our health screening study in 2014 and 2018. They were classified into 6 groups by birth-year and sex: 60-69 years (26 males, 49 females); 70-79 years (35 males, 88 females); and 80-89 years (19 males, 20 females). The following parameters were measured from standing radiographs: pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), thoracic kyphosis (TK), T1 slope (TS), cervical lordosis (CL), C7 sagittal vertical axis (C7 SVA), and C2-7 SVA.

Results: In males, the first significant change was an increase in the PT angle (19°, in 2014, to 21°, in 2018) in the 80-89 years age group ($P<0.05$), with no significant deterioration in cervical parameters. In females, spinal deterioration included a change in the SS (32° to 30°), PT (18° to 20°), and SVA (-8 mm to 6 mm) in the 60-69 years age group (P<0.05), with no change in the LL.

Conclusions: Contrary to prior studies, our longitudinal data indicated that deterioration in spinal alignment originate in the pelvis for both sex but develop earlier in females than males.

Key words: spinal alignment, longitudinal cohort study, sex difference, spinal deformity, age-related change

Introduction

It is well recognized that sagittal spinal malalignment influences health-related quality of life (HRQOL) [1.2]. Several large-scale cohort studies have been conducted to investigate normative values of spinal alignment and age-related changes [3-8]. However, as these studies used a cross-sectional design to compare changes across age groups, there remains controversy about the origin of age-related changes in spinal alignment. Legaya et al. [9] argued that the pelvic incidence (PI) represents individual anatomical characteristics and, as such, does not change after maturation. By contrast, Mendoza-Lattes et al. [10] reported that the PI indeed does increase gradually, even after the end of growth. There is also controversy as to the origin and timing of age-related spinal deformity. It has been hypothesized that these changes are initiated by a kyphotic change of the lumbar [11] or thoracic spine [12-14]. Based on health screening data of the TOEI study [3], we previously reported that spinal deformity developed from the cervical spine in males and the pelvis in females. However, a longitudinal analysis is required to identify the origin and timing of age-related changes in sagittal spinal alignment. To our knowledge, this type of analysis has not previously been conducted.

The health screening in the TOEI study has been conducted every 2 years since 2012. Spinal radiographs were obtained in a standardized standing position from 2014, with hands placed on the clavicles and the head oriented to maintain horizontal gaze, with a mirror placed in front of participants (Figure 1). In our original report of this study data [15], we described a change, from 2012 to 2014, in specific spinal parameters: a large backward shift in the plumb line of C7, a decrease in the sagittal vertical axis (SVA) of 20 mm, an increase of 4° in both the pelvic tilt (PT) and T1 slope, an increase in cervical lordosis (CL) of 10°, a decrease in the C2-7 SVA of 10 mm, and a decrease in the thoracic spine kyphosis to cervical spine lordosis (TS-CL) of 10° (all $P<0.0001$). There was no change noted in the lumbar spine. The purpose of our current study was to conduct a longitudinal assessment of the change in sagittal spinal alignment over a 4-year period, by sex and age, to confirm these findings and to characterize the origin and timing of age-related changes in spinal alignment in females and males.

Material and Methods

This study was approved by the institutional Review Board of our university hospital (IRB No. 201201)

Study Cohort

The eligible participants were 399 individuals living in the city of Toei, in the Aichi prefecture, Japan, for whom a spinal radiograph was obtained as part of the TOEI study in 2018. The inclusion criteria were as follows: aged 60-89 years; availability of standing spinal radiographs; and provision of informed consent. The exclusion criteria were as follows: Cobb angle ≥25°; symptomatic osteoporotic vertebral fracture(s) with severe grade 3 wedged-shaped deformity of the vertebral body [16]; total joint arthroplasty and instrumented spinal surgery; and inability to stand independently.

Demographic characteristics

The following data were collected from participants' charts in the TOEI study: age; height; weight; body mass index (BMI); hand-grip strength; bone mineral density (BMD), expressed as a percentage of the young adult mean (%YAM), in the total proximal femur using dual-energy X-ray absorptiometry; and body composition, including the body fat percentage, muscle volume, and base metabolism, assessed using bioelectrical impedance analysis (BIA) with a (Multi Frequency Segmental Body Composition Analyzer MC-780A-N). We also obtained the following demographic data by questionnaire: parity in females; current habit of alcohol intake, regardless of any past drinking history; current smoking habit, again regardless of any previous history of smoking; occupation, classified as light of hard manual work, desk job, and homemaker; and sport habit.

Radiological assessment

Standardization of spinal radiographs was as follows (Figure 1): standing with hands on clavicles; 1.5 m distance of the X-ray tube; a 15×20 cm mirror placed at eye-level of each participant, at a distance of 1.0 m in front of participants. Digitized radiographs were imported in Digital Imaging and Communications in Medicine (DICOM) format for offline measurements performed using the Surgimap Spine software (Nemaris Inc., New York City, NY, USA).

Measured radiographic parameters

The following spinal measures were obtained: pelvic tilt (PT); sacral slope (SS); pelvic incidence (PI); pelvic incidence minus lumbar lordosis (PI-LL); LL (Cobb angle between the superior endplate of L1 and S1); thoracic kyphosis (TK, measured as the Cobb angle between the superior endplate of T5 and inferior endplate of T12); T1 slope (T1S, the angle between the horizontal plane and T1 superior endplate); cervical lordosis (CL, Cobb angle between the inferior end plate of C2 and C7); C7 SVA (measures as the distance between a plumb line from the center of the C7 vertebral body and posterior superior corner of the sacrum); C2 SVA (measured as the distance between a plumb line from the center of the C2 vertebral body and posterior superior corner of the sacrum); C2-7 SVA (measured as the distance between a plumb line from the center of the C2 vertebral body and posterior superior corner of C7); and T1S-CL. Positive hip and knee osteoarthritis (OA) was defined by a ≥grade 2 on the Kellgren and Lawrence.

Clinical evaluation

The following patient-reported outcomes (PROs) were obtained: the Oswestry Disability Index (ODI) and the EuroQOL (EQ-5D) short-form health survey.

Statistical analysis

Longitudinal changes in spinal parameters and PROs between 2014 and 2018 were evaluated by age, sub-classified into six groups by birth-year decade in 2014 (60-69 years, 70-79 years and 80-89 years, and sex. Age-related differences were evaluated using the paired t-test, with between-sex differences evaluated using unpaired t-tests. The contingency table was calculated using the chi-squared test. A probability (p) value <0.05 was considered statistically significant. All analyses were performed using SPSS (version 25; IBM-SPSS, Inc., Chicago, IL, USA).

Results

Characteristics of the study cohort

Of the 399 individuals eligible for the study, the following were excluded: 132 due to absence of radiographs in 2014 and 30 due to unclear images preventing accurate measurements of spinal parameters (Figure 2). The characteristics of the 237 individuals forming the study group are summarized in Table 1. The sex distribution by age group was as follows: 60-69 years (26 males, 49 females); 70-79 years (35 males, 88 females); and 80-89 years (19 males, 20 females). There was no difference in the age distribution of males and females across all age groups.

Over the 4-year period of observation, the following differences in participant characteristics were noted: decreased height in males in the age range of 80-89 years ($P=0.019$); decrease in height in females across all three age ranges ($P \leq 0.001$); tendency to increasing weight in males and females in the age range of 60-69 years, with a subsequent decrease in weight in the 70-79 years and 80-89 years age range; and a deterioration in grip strength in males in both the 70-79 years and 80-89 years age range ($P<0.001$) and in females across all age ranges ($P<0.001$). Of note, there was no significant change in BMD in both males and females across all age ranges, although the BMD was significantly lower in females than males in the 70-79 years and 80-89 years age range in both 2014 and 2018.

Change in spinal alignment

The change in lumbar spine and pelvic parameters over the 4-year period of observation, and the between-sex differences, are reported in Table 2. In males, only the PT deteriorated from 18.5° to 21.1° in the 80-89 years age group (Figure 3). In females, both the SS and PT deteriorated in the 60-69 years age range, from 32.4° to 29.8° ($P=0.006$) and from 18.4° to 20.1°, respectively, (P=0.011; Figure 4). Significant deterioration was also observed in the following parameters for females in the 70-79 years age group: SS, from 28.6° to 25.6° (P=0.000); PT, from 23.5 to 26.4° (P=0.000); LL, from 42.5° to 37.8° (P=0.003); and PI-LL, from 9.5° to 14.4° (P=0.004). In the females in the 80-89 years age group, only a deterioration in the PI-LL parameter was identified, from 18.6° to 22.9° (P=0.049).

With regard to between-sex differences, the PT tended to be higher in males than in females in the 60-69 years age range in the 2018 data, while the PI tended to be higher in females than in males in the same age range in the 2014 data. There was no difference in the LL between males and females across all age ranges, and no difference in the PI-LL, except in the 80-89 years age range in the 2018 data.

Measures for the thoracic spine, cervical spine, global alignment, and PROs are reported in Table 3. As shown in Figure 3, there were no significant change in all radiographic parameters (TK, TS, CL, TS-CL, C2-7 SVA, and SVA) in males over the 4-year period of observation. With regard to the PROs, a significant deterioration in the ODI (from 13.0% to 20.5%) was noted in the 80-89 years age range. The same measures for females are reported in Table 3 and Figure 4. The SVA in females showed a significant deterioration across all age ranges: 60-69 years, from -7.5 mm to 6.2 mm (P=0.020); 70-79 years, from 18.3 mm to 43.4 mm (P=0.000); and 80-89 years (50.5 mm to 83.1 mm (P=0.000). There was also an increase in the following parameters in the 70-79 years age range: TS, from 26.4° to 31.1° (P=0.000); CL, from 23.8° to 27.1° (P=0.033); and TS-CL, from 7.8° to 10.5° (P=0.009). Only the SVA deteriorated in females in the 80-89 years age range. With regard to PROs, the EQ-5D deteriorated in females in the 60-69 years age range, from 0.914 to 0.863 (P=0.006), with no other changes in the PROs noted.

The evaluation of risk factor of increased PT in females

We compared characteristics between females with a ≥5° increase in PT and those with <5° increase between 2014 and 2018. This analysis included 138 females, with 19 excluded because of missing data regarding childbirth (Table 4). Over the 4-year period of observation, the PT increased by ≥5° in 32 of the 138 females included in the analysis. However, no significant difference was identified for all demographic characteristics measured.

Discussion

We conducted a longitudinal study of age-related changes in sagittal spinal alignment over a 4-year period of observation by age and sex. In this way, our study is different from the longitudinal study by Kobayashi et al. who reported the change in spinal alignment over a 10-year period of observation [17]. In that study, Kobayashi et al. reported an age-related decrease in LL and SS and an increase in TK and SVA. However, specific information about the origin and timing of these changes in spinal alignment could not be identified in that study. With regard to the origin of age-related changes in spinal alignment, several cross-sectional studies have presented conflicting information. Kim et al.[12] reported an increase in TK as the possible origin, while Takemitsu et al.[11] argued that the origin was a decrease in LL, while we reported the posterior tilt of the pelvis (namely, an increase in PT and a decrease in SS) as the origin [3]. The Statistics Bureau of the Ministry of Internal Affairs and Communications of Japan publishes the average height and weight of Japanese individuals by birth year [18]. This information provides the context for understanding the limitations of using cross-sectional studies to evaluate age-related changes in spinal alignment. We show the average height and weight at the age of 18 by birth year in Figure 5. We note that the average height of both males and females has increased by 10 cm, on average, over the last century: females, increase from 147 cm in 1900 to 158.6 cm in 2000; and males, increase from 160 cm in 1900 to 171.7 cm. Similarly, the average body weight has increased from 52 kg to 61.7 kg in males over the same period, and from 47 kg to 51.5 kg in females. Because of these population trends, use of a cross-sectional design to evaluate age-related changes in spinal alignment would not be reliable.

Our study has the advantage that it is the first large-scale longitudinal study evaluating the change in sagittal spinal alignment by sex and age over a 4-year period of observation. Males experienced a lesser extent of age-related changes in spinal alignment than females. Although we have previously reported the cervical spine as being the origin of deterioration in spinal alignment in males [3], in this study we identified that change in the parameters of cervical and thoracic spine alignment (TS, TS-CL, C2-7 SVA) was actually lower in males than in females (Table 3). In fact, the posterior tilt of the pelvis (specifically, an increase in PT) in the 80-89 years age range was at the origin of a deterioration in spinal alignment in males (Figure 3). Females exhibited a more rapid deterioration in spinal alignment than males, with a significant increase in the SVA identified in the 60-69 years age range (Figure 4). As in males, an increase in the posterior tilt of the pelvis (namely, an increase in PT and a decrease in SS) in the 60-69 years age range was at the origin of the deterioration in spinal alignment in females. This deterioration increased with advancing age, with a significant decrease in LL and increase in PI-LL, TS, CL, and TS-CL in the 70-79 years age range (Table 2 and 3), which might reflect a compensatory mechanism to the increase in posterior pelvic tilt that progressively involves the lumbar, thoracic, and cervical spine. Therefore, deterioration in spinal alignment originates from an increase in the posterior tilt of the pelvis in both males and females. The representative cases were shown in figure 6. Figure 6-a and b were X-ray in 2014 and 2018, respectively. He was 83 years old in 2014. The radiographic parameters that changed significantly between 2014 and 2018 were PT (16 to 21°) and SVA (23 to 42mm). On the other hand, no significant change was observed in LL(19 to 21°). The radiographs shown in Figure 6-c (2014) and d (2018) were for a 68-year-old female. In this female, a significant change was observed only in PT (17 to 22°) during 4 years, and LL (45 to 46°) showed no significant change.

We were unable to clarify the factors associated with the age-related increase in PT in females in our study group (Table 4). Bailey et al. [19] reported that the number of parity was associated with an age-related deterioration in the PI-LL parameter, a findings which we corroborated in our previous study [3]. However, we did not identify an effect of parity on an increase in PT of ≥5° over our 4-year period of observation. We do note that only two of the 132 females included in this sub-analysis were non-parous. Considering the heavy load placed on the pubic bones and movement of the sacroiliac joints during childbirth, it is conceivable that the change in age-related spinal alignment might be different between parous and non-parous females, with non-parous females likely to exhibit a pattern of deterioration of spinal alignment which might be closer to that of males. A comparison between non-parous females and parous females would be warranted to clarify the effect of parity on age-related change in spinal alignment.

We note the following three main limitations in our study. First, the number of cases was particularly small among males, which could bias on analyses. Moreover, at the onset of the TOEI study in 2012, spinal radiographs were obtained for 656 participants. However, by 2018, spinal radiographs were available for only 399 of the original 656 participants, and of these, radiographs for 2014 were only available in 267 participants. This reflects the issue of retention in longitudinal studies, due to various factors, such as moving away from the area or health-related issues. Further large-scale longitudinal research is necessary. Second, although we describe that age-related change in spinal alignment in females originates from an increase in the posterior tilt of the pelvis in the seventh decade, we do note that we did not evaluate females in their sixth decade. For this reason, the possibility that the pelvic tilt and SVA will increase prior to the age to 60 years cannot be denied. Thirdly, all participants in this study live in a mountainous region of Japan, which might have introduced biases. To solve these problems, it is necessary to further increase the number of samples. Since the majority of the participants in the TOEI study are elderly people, it is necessary to evaluate them in the future, including young people living in urban areas.

In conclusion, this is the first longitudinal study to have evaluated age-related change in the sagittal spinal alignment by sex and age. Age-related deterioration in spinal alignment develops in the ninth decade in males and in the seventh decade in females. Despite this between-sex difference in the onset of deterioration of spinal alignment, pelvic retroversion is at the origin of this deterioration in both males and females.

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Figure Legends

Figure 1. Standardization of spinal radiographs. Participants stood with hands on clavicles, at a 1.5 m distance from the X-ray tube. A 15×20 cm mirror was placed at eye-level for each participant, at a distance of 1.0 m in front of participants.

Figure 2. The flow chart of participant recruitment.

Figure 3. The change in spinal alignment from 2014 to 2018 in males. The PT increased significantly in the eighth decade, with no other significant change in alignment parameters noted over the 4-year period of observation.

Figure 4. The change in spinal alignment from 2014 to 2018, in females. A significant increase in the posterior tilt of the pelvis occurred by the sixth decade, with a further increase in TS and CL in the seventh decade.

Figure 5. The change of average height and weight in 18-year-old males and females obtained

from the Statistics Bureau, Ministry of Internal Affairs and Communications in Japan. The average height and weight of both males and females have gradually increased over the past 100 years.

Figure 6. The representative cases.

Figure 6-a and b were X-ray in 2014 and 2018, respectively. He was 83 years old in 2014. The radiographic parameters that changed significantly were PT and SVA. On the other hand, no significant change was observed in LL. The radiographs shown in Figure 6-c (2014) and d (2018) were for a 68-year-old female. In this female, a significant change was observed only in PT during 4 years, and LL showed no significant change.

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TABLE 1. Characteristics of the study group

	Total N=237		Aged 60-69 years			Aged 70-79 years			Aged 80-89 years		
Number	Male	Female	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value
	80	157	26	49	---	35	88	---	19	20	---
Age in 2014 (years)	---	---	65.3 (±2.3)	64.2 (±2.6)	0.074	74.8 (±2.9)	74.5 (±2.5)	0.541	82.6 (±3.0)	82.0 (±2.8)	0.534
Height (cm)	2014		165.1 (±5.4)	153.1 (±6.1)	<0.001 ***	161.4 (±6.2)	149.4 (±5.2)	<0.001 ***	159.5 (±6.0)	145.2 (±6.2)	<0.001 ***
	2018		164.5 (±6.8)	152.2 (±6.2)	<0.001 ***	160.9 (±6.6)	148.1 (±5.6)	<0.001 ***	158.4 (±6.1)	143.3 (±7.1)	<0.001 ***
	P		0.767	<0.001 ***	---	0.289	<0.001 ***	---	0.019 *	0.002 **	---

Weight (kg)	2014	63.0 (±8.1)	51.6 (±8.5)	<0.001 ***	60.4 (±9.5)	49.3 (±7.0)	<0.001 ***	56.8 (±8.6)	47.1 (±7.6)	0.001 **
	2018	65.2 (±7.6)	51.9 (±7.8)	<0.001 ***	59.6 (±8.7)	48.4 (±7.6)	<0.001 ***	55.5 (±8.7)	44.6 (±6.8)	<0.001 ***
	P	0.354	0.376	---	0.117	0.001**	---	0.057	0.005**	---
BMI (kg/m^2)	2014	23.2 (±3.2)	22.0 (±3.4)	0.143	23.1 (±2.6)	22.1 (±2.9)	0.068	22.3 (±3.2)	22.3 (±3.2)	0.986
	2018	24.1 (±3.1)	22.4 (±3.2)	0.147	23.0 (±2.4)	22.1 (±3.2)	0.097	22.1 (±3.3)	21.8 (±3.0)	0.716
	P	0.317	0.013*	---	0.457	0.824	---	0.478	0.135	---
Grip strength (kg)	2014	41.3 (±6.5)	27.5 (±4.8)	<0.001 ***	37.1 (±5.7)	25.4 (±3.9)	<0.001 ***	31.9 (±5.7)	21.4 (±4.7)	<0.001 ***
	2018	37.5 (±6.7)	23.6 (±4.5)	<0.001 ***	32.2 (±4.5)	21.4 (±3.6)	<0.001 ***	26.5 (±5.3)	17.8 (±3.9)	<0.001 ***

	P	0.062	<0.001 ***	---	<0.001 ***	<0.001 ***	---	<0.001 ***	<0.001 ***	---
BMD (%YAM)	2014	81.7 (±12.2)	77.7 (±14.5)	0.233	79.7 (±14.9)	71.1 (±10.7)	0.003**	74.5 (±16.8)	65.1 (±11.0)	0.031*
	2018	82.8 (±11.6)	76.4 (±13.2)	0.074	81.0 (±14.9)	70.8 (±14.0)	<0.001 ***	76.2 (±18.3)	63.8 (±14.1)	0.023*
	P	0.768	0.100	---	0.089	0.826	---	0.109	0.279	---

BMI; body mass index, BMD; bone mineral density, YAM; young adult mean.

*; P<0.05, **; P<0.01, ***; P<0.001

TABLE 2. Lumbar and pelvic parameters											
Number	Total N=237		60-69 years			70-79 years			80-89 years		
Number	Male	Female	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value
	80	157	26	49	---	35	88	---	19	20	---
SS	2014		28.3 (±7.8)	32.4 (±7.7)	0.065	31.8 (±8.9)	28.6 (±10.9)	0.137	26.9 (±10.9)	19.0 (±12.6)	0.047*
	2018		31.3 (±10.0)	29.8 (±8.6)	0.780	32.0 (±10.8)	25.6 (±11.4)	0.008**	26.7 (±9.7)	20.0 (±12.1)	0.064
	P-value		0.287	0.006**	---	0.894	<0.001 ***	---	0.872	0.619	---
PT	2014		13.7 (±7.0)	18.4 (±7.6)	0.032*	18.1 (±7.1)	23.5 (±8.0)	0.001**	18.5 (±10.1)	31.9 (±12.7)	0.001**

	2018	16.1 (±7.7)	20.1 (±7.4)	0.075	19.0 (±7.2)	26.4 (±8.8)	<0.001 ***	21.1 (±11.8)	31.9 (±10.6)	0.005 **
	P-value	0.113	0.011*	---	0.329	<0.001 ***	---	0.011*	0.975	---
PI	2014	44.6 (±12.0)	51.0 (±10.0)	0.003**	50.2 (±8.8)	52.2 (±11.6)	0.392	45.6 (±7.5)	51.3 (±10.4)	0.063
	2018	46.4 (±10.9)	49.9 (±10.0)	0.081	50.9 (±10.2)	51.9 (±10.9)	0.627	47.8 (±10.1)	52.0 (±9.9)	0.209
	P-value	0.098	0.256	---	0.636	0.710	---	0.171	0.776	---
LL	2014	41.9 (±13.8)	45.2 (±10.3)	0.329	42.7 (±11.0)	42.5 (±17.3)	0.950	34.2 (±12.1)	28.5 (±20.2)	0.309
	2018	44.7 (±15.1)	44.4 (±10.7)	0.700	42.9 (±14.5)	37.8 (±21.7)	0.175	39.0 (±12.0)	27.6 (±20.0)	0.053
	P-value	0.560	0.470	---	0.919	0.003**	---	0.124	0.584	---

PI-LL	2014	3.1 (±17.0)	7.5 (±13.5)	0.329	7.8 (±10.3)	9.5 (±16.0)	0.464	12.8 (±14.4)	18.6 (±19.8)	0.124
	2018	3.8 (±18.1)	5.7 (±10.6)	0.405	7.9 (±13.0)	14.4 (±19.2)	0.080	9.6 (±13.5)	22.9 (±17.4)	0.017*
	P-value	0.889	0.309	---	0.950	0.004**	---	0.345	0.049*	---

SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence, LL: lumbar lordosis

*; P<0.05, **; P<0.01, ***; P<0.001

TABLE 3. Thoracic, cervical, global alignment, and patient's reported outcome											
	Total N=237		Aged 60-69 years			Aged 70-79 years			Aged 80-89 years		
Number	Male	Female	Male	Female	P-value	Male	Female	P-value	Male	Female	P-value
	80	157	26	49	---	35	88	---	19	20	---
TK	2014		31.3 (±11.1)	28.9 (±12.6)	0.495	32.0 (±9.8)	34.9 (±14.5)	0.277	31.4 (±13.4)	40.3 (±22.2)	0.149
	2018		26.9 (±9.1)	28.2 (±12.6)	0.945	30.8 (±10.6)	34.0 (±16.6)	0.186	28.0 (±12.3)	37.9 (±20.7)	0.052
	P-value		0.200	0.596	---	0.537	0.289	---	0.302	0.276	---
TS	2014		25.5 (±6.9)	24.1 (±8.8)	0.504	27.7 (±7.7)	26.4 (±9.7)	0.667	31.3 (±12.8)	31.3 (±14.5)	0.691
	2018		26.2	22.2	0.003**	28.5	31.1	0.433	28.7	31.5	0.374

		(±5.0)	(±8.0)		(±8.5)	(±11.2)		(±8.8)	(±12.3)	
	P-value	0.751	0.173	---	0.637	<0.001 ***	---	0.333	0.929	---
CL	2014	17.7 (±6.9)	18.0 (±11.5)	0.943	20.4 (±10.8)	23.8 (±10.9)	0.136	20.3 (±9.3)	25.8 (±14.2)	0.141
	2018	17.0 (±11.4)	17.9 (±14.0)	0.674	24.5 (±14.2)	27.1 (±14.6)	0.705	19.4 (±6.2)	29.1--- (±15.5)	0.002**
	P-value	0.882	0.957	---	0.067	0.033*	---	0.717	0.408	---
TS-CL	2014	11.7 (±11.3)	8.1 (±5.8)	0.220	9.0 (±9.7)	7.8 (±5.5)	0.595	12.8 (±10.0)	7.3 (±6.5)	0.121
	2018	13.6 (±7.1)	9.2 (±6.5)	0.008**	11.1 (±9.3)	10.5 (±7.7)	0.945	13.0 (±10.9)	9.6 (±5.9)	0.246
	P-value	0.975	0.452	---	0.261	0.009**	---	0.240	0.385	---
	2014	11.6	9.1	0.561	18.8	14.0	0.376	16.0	14.0	0.827

		(±17.0)	(±9.2)		(±12.3)	(±29.7)		(±13.6)	(±10.9)	
C2-7 SVA	2018	16.9 (±11.4)	9.1 (±8.7)	0.027*	19.2 (±16.4)	12.7 (±12.6)	0.026*	17.9 (±18.8)	11.2 (±10.8)	0.056
	P-value	0.242	0.973	---	0.892	0.725	---	0.581	0.400	---
SVA	2014	9.6 (±35.4)	-7.5 (±21.3)	0.103	21.4 (±33.9)	18.3 (±48.8)	0.746	25.4 (±47.6)	50.5 (±48.9)	0.127
	2018	8.4 (±34.2)	6.2 (±34.6)	0.858	26.7 (±37.2)	43.4 (±68.0)	0.070	38.7 (±57.8)	83.1 (±53.6)	0.027*
	P-value	0.872	0.020*	---	0.433	<0.001 ***	---	0.182	<0.001 ***	---
EQ-5D	2014	0.896 (±0.134)	0.914 (±0.122)	0.663	0.842 (±0.150)	0.797 (±0.150)	0.124	0.758 (±0.122)	0.719 (±0.100)	0.463
	2018	0.921 (±0.129)	0.863 (±0.145)	0.203	0.862 (±0.169)	0.818 (±0.165)	0.174	0.727 (±0.115)	0.727 (±0.160)	0.976

	P-value	0.227	0.006**	---	0.547	0.174	---	0.313	0.808	---
ODI	2014	7.3 (±9.2)	7.4 (±8.4)	0.479	10.9 (±10.6)	13.6 (±12.1)	0.198	13.0 (±12.9)	18.9 (±12.9)	0.175
	2018	6.2 (±7.8)	8.6 (±10.7)	0.285	10.9 (±11.3)	15.7 (±13.5)	0.068	20.5 (±12.1)	20.7 (±13.3)	0.963
	P-value	0.385	0.248	---	>0.99	0.103	---	0.005**	0.459	---

TK: thoracic kyphosis, TS; T1 slope, CL; cervical lordosis, SVA; sagittal vertical axis.

*; P<0.05, **; P<0.01, ***; P<0.001

TABLE 4. The evaluation of risk factor of increased PT in females from 2014 to 2018			
N=138 females	ΔPT ≥5° (N=32)	ΔPT <5°(N=106)	P-value
ΔPT (degrees)	8.1±2.8	0.5±3.1	<0.001*
Age (years)	72.3±5.1	73.0±6.3	0.592
Body mass index (kg/m^2)	21.9±2.9	22.2±3.3	0.603
Grip strength (kg)	21.8±4.1	21.1±4.1	0.402
Body fat percentage (%)	26.0±9.0	27.9±7.8	0.249
Muscle volume (kg)	32.8±3.4	32.1±3.4	0.285
Base metabolism (kcal/day)	979.8±106.3	963.4±113.1	0.474
Bone mineral density (%YAM)	69.3±15.3	71.6±13.9	0.424
Number of childbirths	2.5±1.0	2.4±0.9	0.574
Drinking (+, -)	(7, 25)	(25, 81)	0.821

Tobacco (+, -)	(0, 32)	(3, 103)	0.447
Occupation (light-manual work, indoor work)	(11, 21)	(49, 57)	0.197
Sporting activity (+, -)	(14, 18)	(41, 64)	0.635
Hip osteoarthritis in 2014 (+, -)	(1, 31)	(14, 92)	0.108
Knee osteoarthritis in 2014 (+, -)	(17, 15)	(58, 48)	0.874
Hip or knee osteoarthritis in 2014 (+, -)	(18, 14)	(63, 43)	0.749

ΔPT: change in pelvic tilt

*; $P<0.001$

Figure Legends

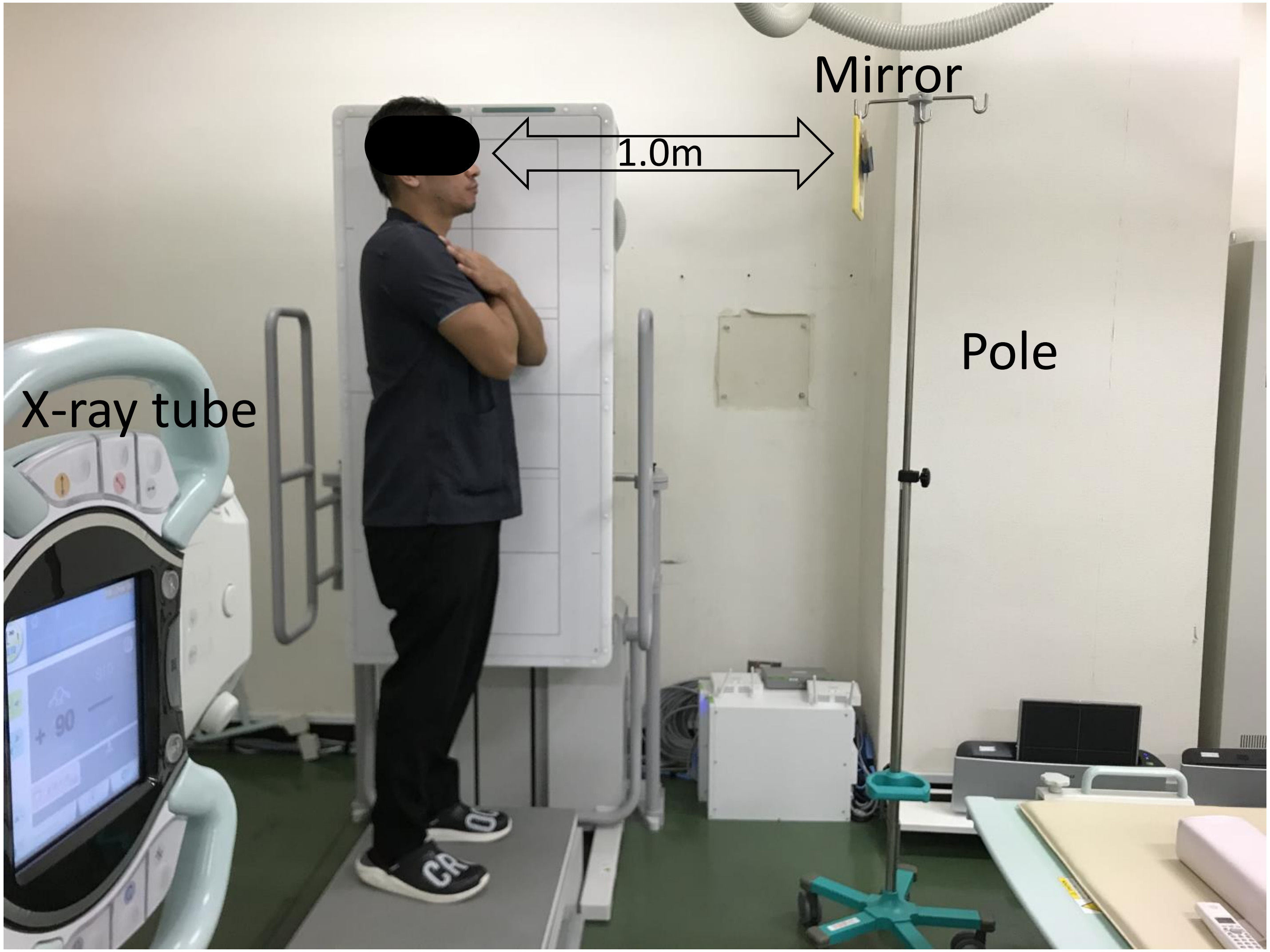
Figure 1. Standardization of spinal radiographs. Participants stood with hands on clavicles, at a 1.5 m distance from the X-ray tube. A 15×20 cm mirror was placed at eye-level for each participant, at a distance of 1.0 m in front of participants.

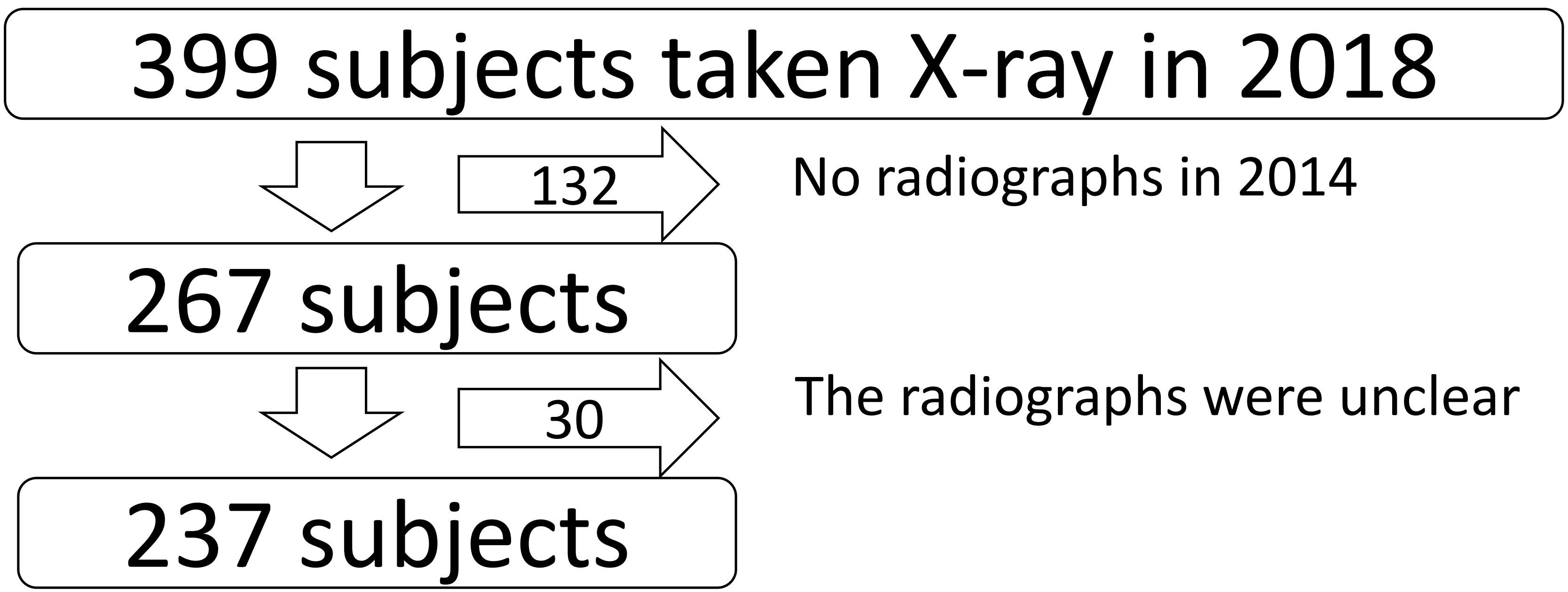
Figure 2. The flow chart of participant recruitment.

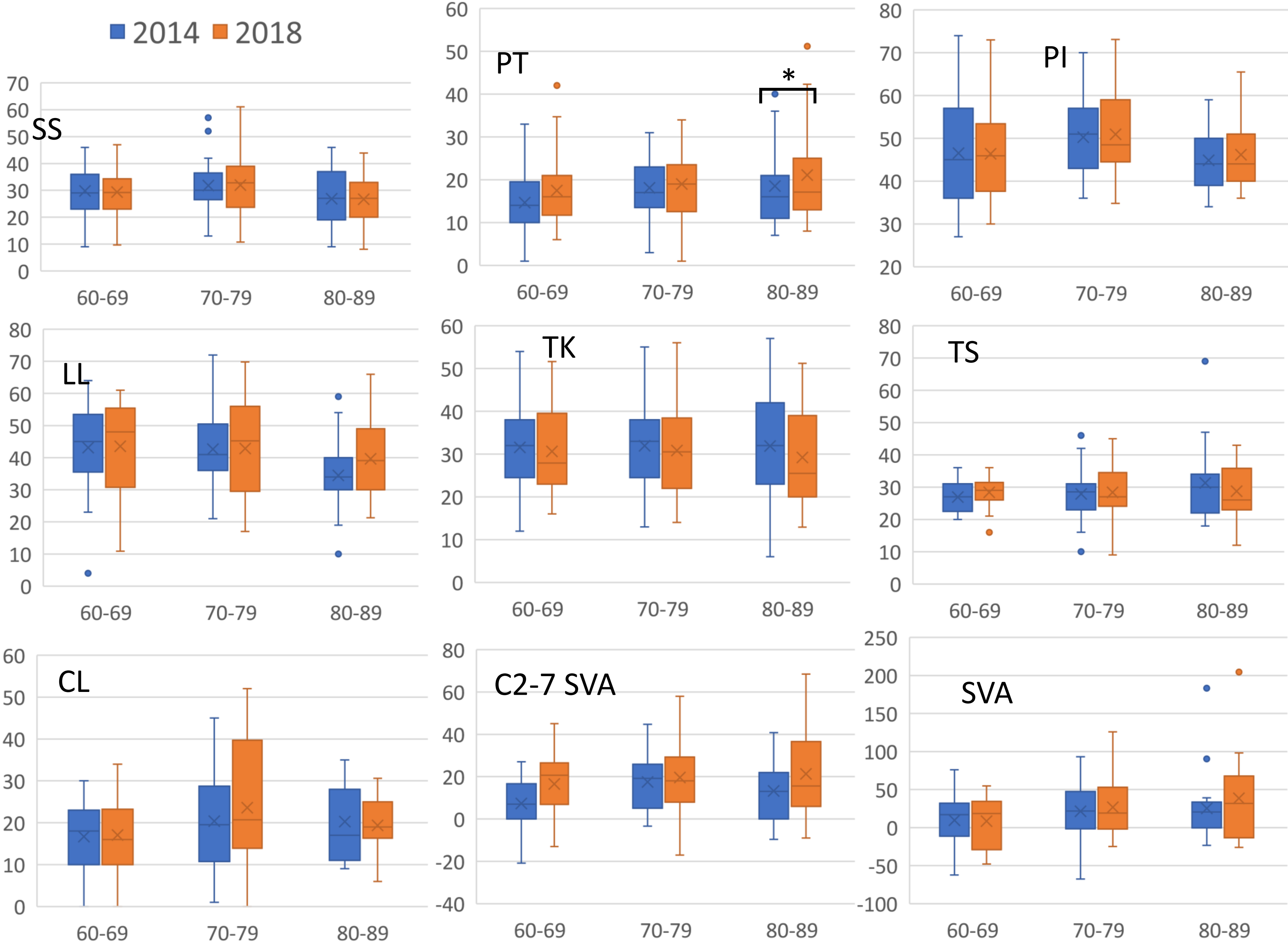
Figure 3. The change in spinal alignment from 2014 to 2018 in males. The PT increased significantly in the eighth decade, with no other significant change in alignment parameters noted over the 4-year period of observation.

Figure 4. The change in spinal alignment from 2014 to 2018, in females. A significant increase in the posterior tilt of the pelvis occurred by the sixth decade, with a further increase in TS and CL in the seventh decade.

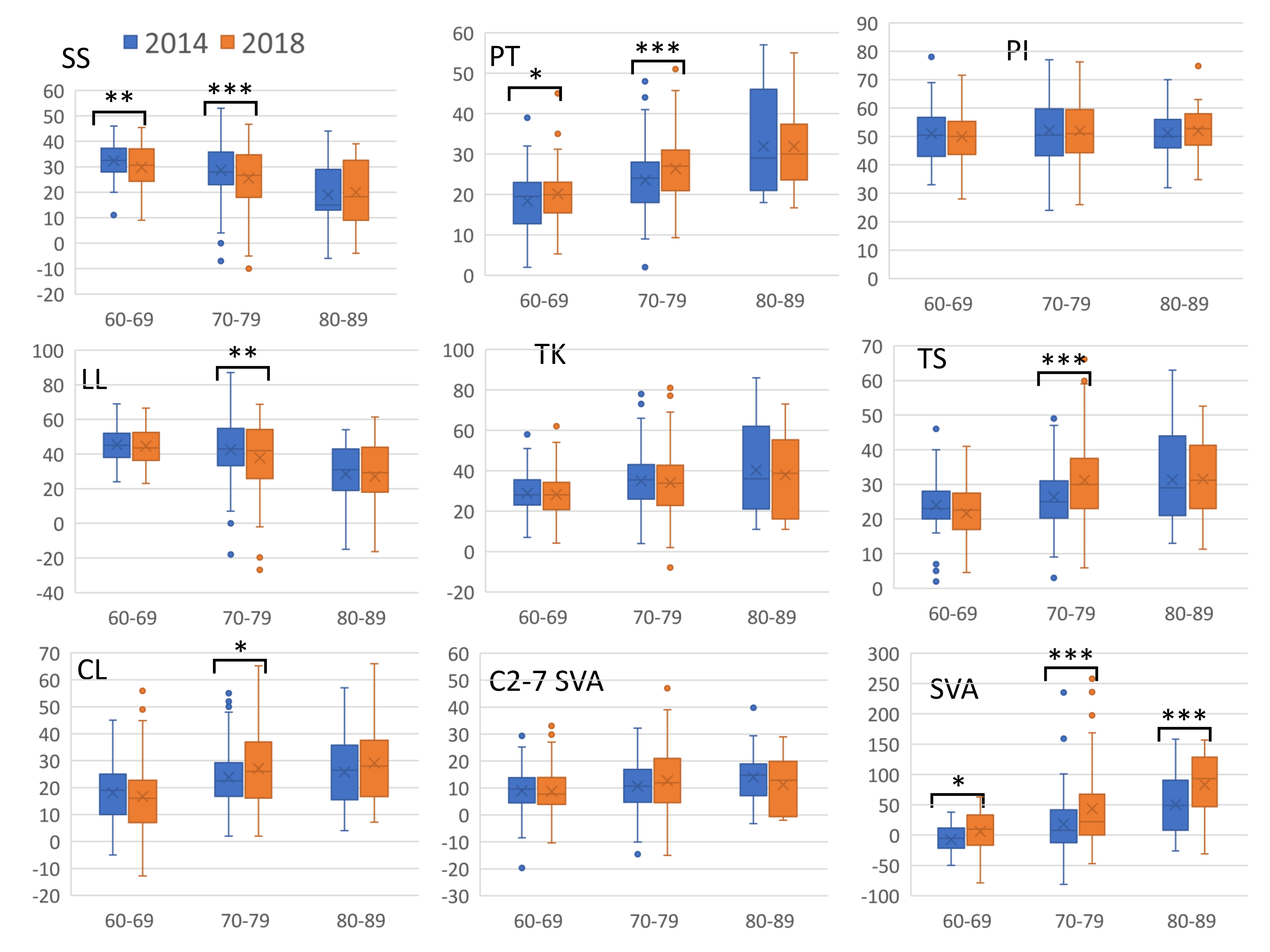
Figure 5. The change of average height and weight in 18-year-old males and females obtained from the Statistics Bureau, Ministry of Internal Affairs and Communications in Japan. The average height and weight of both males and females have gradually increased over the past 100 years.


Mirror
1.0m
Pole
X-ray tube


399 subjects taken X-ray in 2018
132
No radiographs in 2014
267 subjects
30
The radiographs were unclear
237 subjects



2014
2018
SS
PT
PI
LL
TK
TS
CL
C2-7 SVA
SVA
60-69
70-79
80-89
*


2014
2018
SS
PT
PI
LL
TK
TS
CL
C2-7 SVA
SVA
60-69
70-79
80-89
*
**
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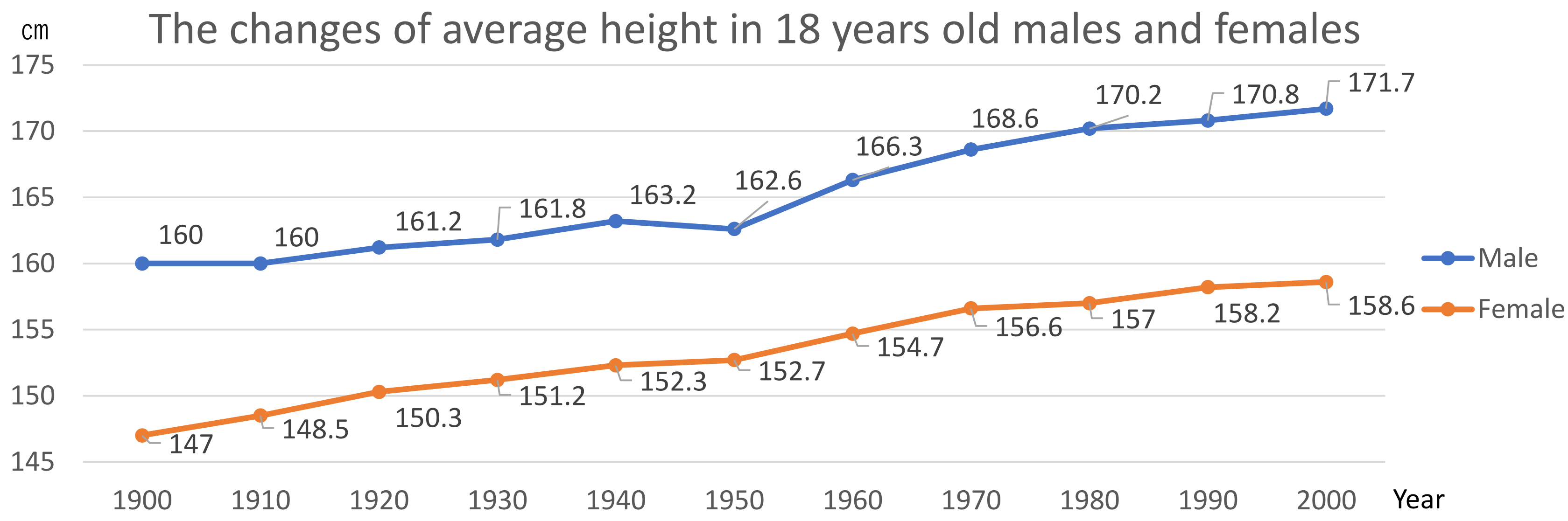
cm
The changes of average height in 18 years old males and females
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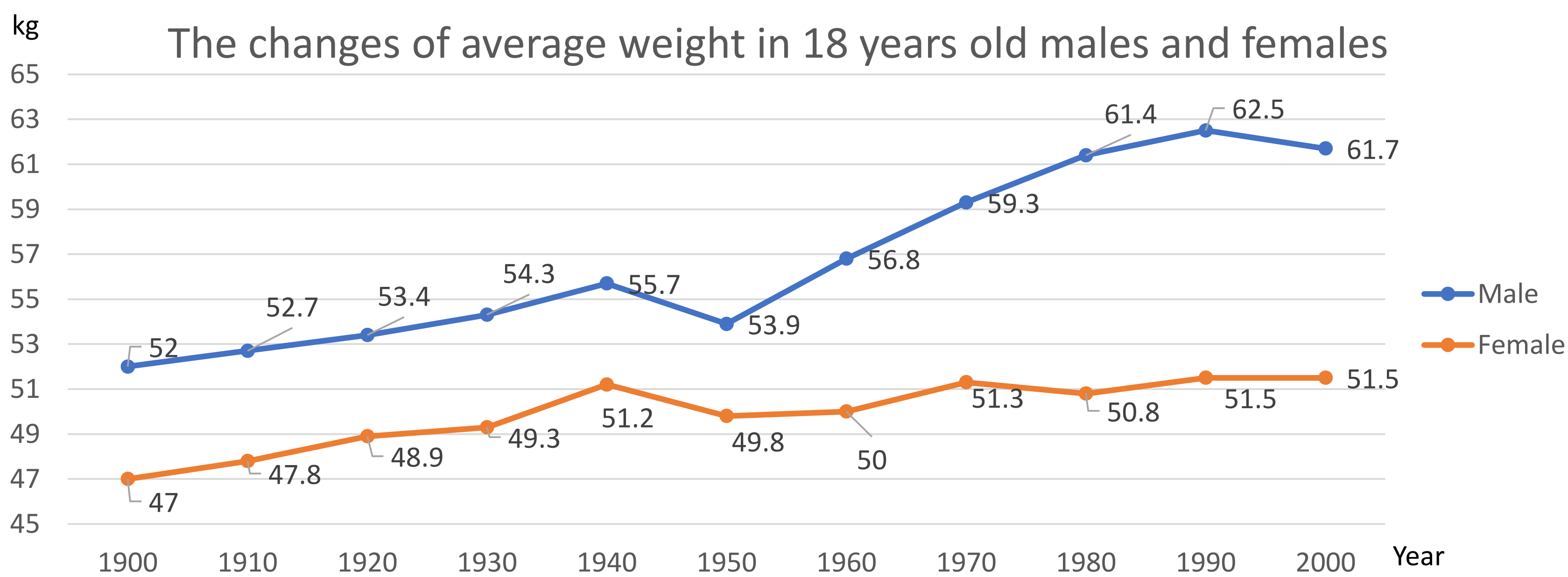
170
165
160
155
150
145
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
Male
Female
160
160
161.2
161.8
163.2
162.6
166.3
168.6
170.2
170.8
171.7
147
148.5
150.3
151.2
152.3
152.7
154.7
156.6
157
158.2
158.6


kg
The changes of average weight in 18 years old males and females
65
63
61
59
57
55
53
51
49
47
45
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
Male
Female
52
52.7
53.4
54.3
55.7
53.9
56.8
59.3
61.4
62.5
61.7
47
47.8
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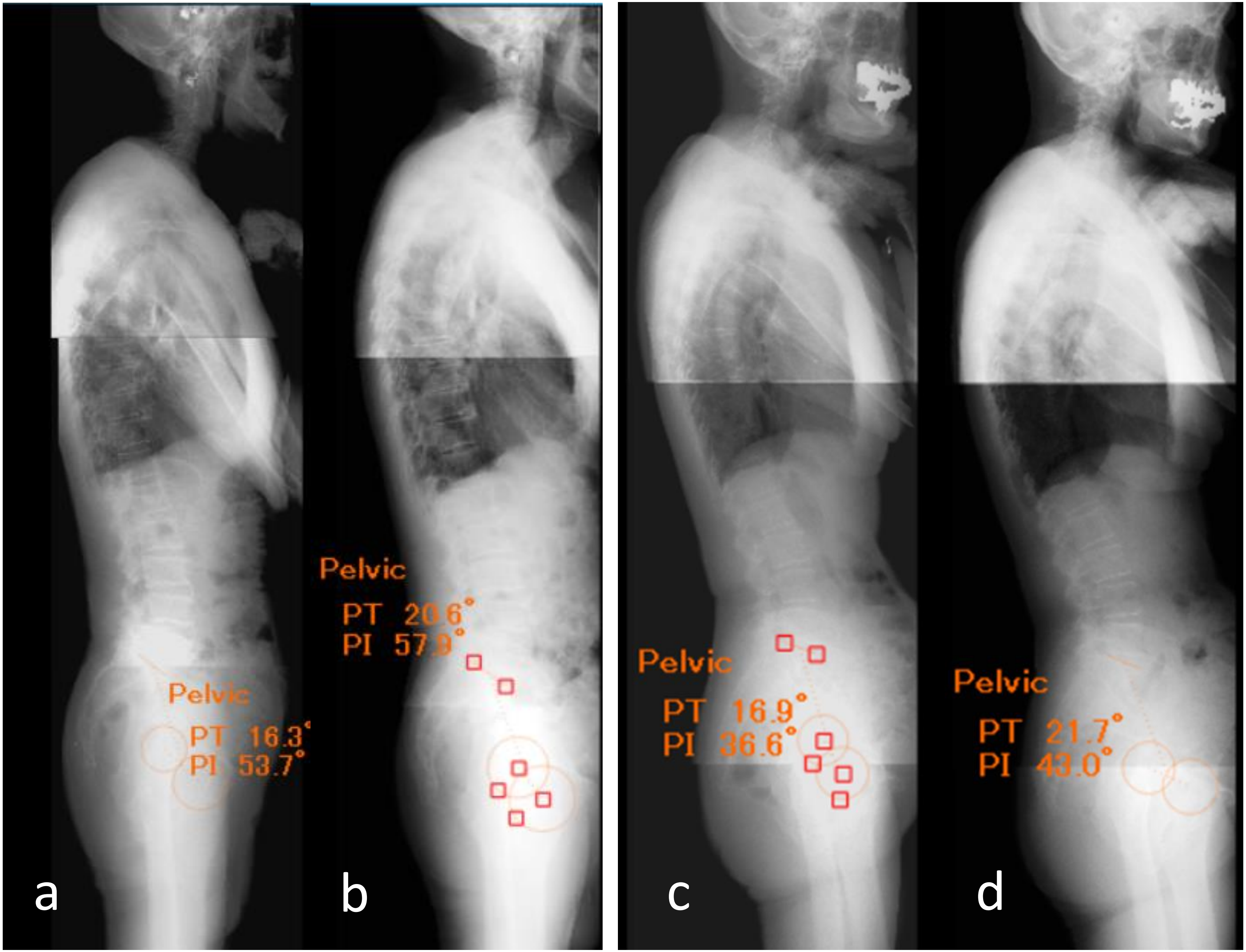
50.8
51.5
51.5


Pelvic
PT 16.3°
PI 53.7°
Pelvic
PT 20.6°
PI 57.9°
Pelvic
PT 16.9°
PI 36.6°
Pelvic
PT 21.7°
PI 43.0°
a
b
c
d