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ORIGINAL ARTICLE

Pelvic thickness, sex, ethnicity, and age affect pelvic incidence in healthy volunteers of Multi-Ethnic Alignment Normative Study (MEANS) database

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Abstract

Background The purpose of this study was to investigate the affecting factors on pelvic incidence (PI) and to test the hypothesis that PI changes even after skeletal maturity probably due to hypermobility of the sacroiliac joint using a large international multi-center database.

Methods A prospective and cross-sectional healthy adult volunteers, ages 18–80 years, across 5 countries were used. Radiographic measurements included standard whole body alignment parameters. Bivariate regression analyses between PI versus demographics and spino-pelvic anatomical parameters were performed. An effect of sex on pelvic anatomical parameters was also investigated. Multivariate logistic regression with a forward stepwise procedure was performed to identify the contributing factors to PI, and an appropriate model was obtained.

Results PI showed a significant positive correlation with age in pooled data. Divided by sex, however, there was no correlation in men, but women showed a significant higher correlation coefficient. Pelvic thickness (PTh) had a significant negative correlation with age in pooled data. Divided by sex, no correlation was found in men, but there was a significant correlation in women with higher correlation coefficient. The stepwise multivariate analysis for the factors on PI identified four significant factors: age, sex, ethnicity, and PTh.

Conclusions PTh, sex, ethnicity, and age affected PI. There was a positive correlation between PI and age. The tendency was more significant in woman than in man. The results support the hypothesis that PI increases with aging, but the change seems to be small and needs to be verified in a longitudinal evaluation.

Keywords Age · Ethnicity · Pelvic incidence · Pelvic thickness · Sex

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Abbreviations

ASD	Adult spine deformity
ANOVA	Analysis of variance
BMI	Body mass index
CI	Confidence interval
EOS	Biplanar slot-scanning stereoradiography
HA	Hip axis
LL	Lumbar lordosis
PI	Pelvic incidence
PTh	Pelvic thickness
PT	Pelvic tilt
SIj	Sacroiliac joint
SS	Sacral slope
3D	Three-dimensional

Introduction

Half a century ago, Duval-Beaupère discovered a new pelvic parameter, which they originally called angle of sacral incidence, an anatomical variable that is specific to each individual [1]. The angle is defined by the lines from the midpoint between the two femoral heads (hip axis [HA]) to the center of the sacral endplate, and the perpendicular to the center, representing the sum of the positional parameters: sacral slope (SS) and pelvic tilt (PT). The term "angle of incidence" was chosen in analogy to geometric optics, where it describes the angle between a ray incident on a surface (e.g., mirror) and the line perpendicular to the surface at the point of incidence, in the X-ray film, the incident ray originates from HA, while the mirror surface is represented by the sacral endplate [2]. Sacral incidence was later published in English as the term pelvic incidence (PI) and is now commonly used instead of "angle of sacral incidence" [3] although it is less precise than the original term. PI illustrates that the sacral endplate is located more or less backwards and upwards in relation to the hip joints and determines the amount of L1-S1 lumbar lordosis (LL) that provides the most economical upright posture for each individual at a given PT in terms of muscle fatigue and vertebral strain [1, 2]. Therefore, PI is used as an important parameter for evaluation of spinal deformity and the surgical planning. In adult spine deformity surgery (ASD), pelvic parameters, especially PI, help dictate the optimal sagittal profile, i.e., the proportional LL in relation to the patient's PI, achieving a satisfactory postoperative result [4, 5]. The basic condition in evaluation and surgical planning is that PI is a fixed value that does not change in each individual.

A review article on sagittal pelvic alignment parameters, however, described that PI tends to increase with age in both normal and scoliotic subjects [6]. Legaye reported that the correlation between age and PI was observed significant only for the 60 years cases with low back pain, and the mean values of PI of these cases were greater than those of the groups 19–40 years cases or 40–60 years cases [7]. It is also reported that PI was positively correlated with age, even in healthy adult subjects, with around 10° higher in 70 years of age compared in 20 years [8]. Duval-Beaupère et al. investigated the variation of PI value in the same patient with several radiographs in supine, standing, or sitting position and found that the difference of PI values was 1° to 2° with a maximum of 6°, suggesting slight mobility of sacroiliac joint (SIj) due to positioning [1]. Wei et al. [9] showed PI changed $\geq$ 6.0° in 36.8% of patients who underwent correction surgery with S2 alar iliac screw fixation and sagittal cantilever correction immediately postoperatively, and the ASD patients with a high preoperative PI were more likely to have a significant PI change than those with a normal or low PI. Ohya et al. reported that intraoperative X-ray in the patients with prone position on the operating table before surgery under general anesthesia showed that 12.5% of the patients showed a decrease in PI > 10° while in the prone compared to preoperative PI value of standing X-ray film [10].

The clinical findings in the recent papers suggest that PI can change even after skeletal maturity and aging and/or SIj osteoarthrosis can induce SIj hypermobility bring about PI change. The evidence for the hypothesis is, however, insufficient. The purpose of this study was to investigate the affecting factors on PI and to test the hypothesis using a large international multi-center database.

Materials and methods

Study design

This is a large multi-ethnic, multi-center, cross-sectional radiographic study conducted across 5 countries (France, Japan, Singapore, Tunisia, and the United States), named the Multi-Ethnic Alignment Normative Study (MEANS). The study was approved by the Institutional ethics review boards of all centers.

Subjects

Healthy adult volunteers, aged 18–80-years-old, were prospectively enrolled at each center to study normative values of key standing sagittal whole body radiographic parameters and to understand the spinal and pelvic morphologies. Subjects underwent thorough clinical assessments to screen for exclusion criteria of:

(1) History of surgical or non-surgical treatment to the spine disease
(2) Inability to stand or non-ambulatory

(3) Suspected or known pregnancy
(4) Oswestry Disability Index > 20%
(5) Cobb angle in the coronal plane > 20°.
(6) Abnormal vertebral counts or transitional vertebrae

Demographics measurements

Basic demographic data collected include age, sex, and body mass index (BMI). Health related quality of life of the subjects were scored by the Oswestry Disability Index (ODI) [11]. ODI is the principal condition-specific outcome measures used in the management of low back disorders with normal values without symptoms as 0% and worst symptom as 100%.

Measurement of standing whole spine alignment with the EOS system

Radiographs with the EOS system [12] were routinely obtained, as follows: (1) EOS radiographs were made from the head, including the center of the auditory canal, to the feet. (2) Each patient was asked to stand comfortably with their hands on their cheeks or clavicles. (3) A mirror placed at eye level in the inner wall of the EOS cabin helped the patient maintain a horizontal gaze [8]. The default scan speed of the EOS system was 7.6 cm/s. Acquisition time was linked to scan height: Time of acquisition (s) = height of acquisition (cm)/7.6. Scan speed can be increased if the patient is restless and having difficulty keeping still during the acquisition. Nevertheless, subtle artifacts in the images can occur due to body sway during scanning, but these are minimized because of the rapid X-ray detection time (0.8333 ms) with no blurring of the images.

EOS imaging supported the multicentric collaborative group by providing the 3D parameters for the MEANS cohort and a web-based solution for image review. Comparison between 2D vs. 3D measurements in 60 asymptomatic subjects (ages 20–81 years) showed that (1) The intraclass correlation coefficient was very high for the 3D measures (> 0.9) and excellent for the 2D measures (> 0.75). (2) The overall mean absolute difference between repeated 3D measures was less than 2°, or 2 mm. (3) The inter- and intra-observer reproducibility in 3D measures were significantly superior to 2D measures for all parameters [13].

Radiographic measurements performed automatically and manually using a commercially available 2D/3D sterEOS® modelling software include (1) global alignment: Sagittal Vertical Axis, T1-Pelvis Angle, Global Sagittal Angle and T9 Tilt, (2) cervical alignment: Cervical Sagittal Vertical Axis, C2–C7 Cervical Lordosis and T1 Slope, (3) thoracic alignment: T1-T12 Thoracic Kyphosis, (4) lumbar alignment: LL, and (5) pelvic alignment: PI, PT SS, pelvic thickness (PTh) [1]. In addition the standard parameters, we measured spinal three-dimensional length (spinal 3D length) (mm) which is defined as 3D curvilinear length of the spine from the tip of odontoid process to the center of S1 passing through all the vertebrae centers (Fig. 1).

Statistical analysis

The distribution normality of each parameter was determined using the Shapiro-Wilks test. The values for each parameter are shown as mean ± 95% confidence interval (CI) with minimum and maximum. Age, BMI, and ODI are compared between men and women using the Mann–Whitney U test and also compared among three main ethnicities (Arabo-Bèrbère [$n = 80$], Asian [$n = 185$], Caucasian [$N = 175$]) using analysis of variance (ANOVA) followed by post-hoc analysis with Steel–Dwass analysis. Bivariate regression analysis between PI versus the parameters of demographics and spino-pelvic anatomical parameters, PTh, and spinal 3D length was performed using Pearson's correlation coefficient with a significance level of $p < 0.05$.

To investigate an effect of sex on pelvic anatomical parameters, the relationships between PI and age, PTh, and age were analyzed in the pooled data and in the subgroups by sex using bivariate linear regression analysis

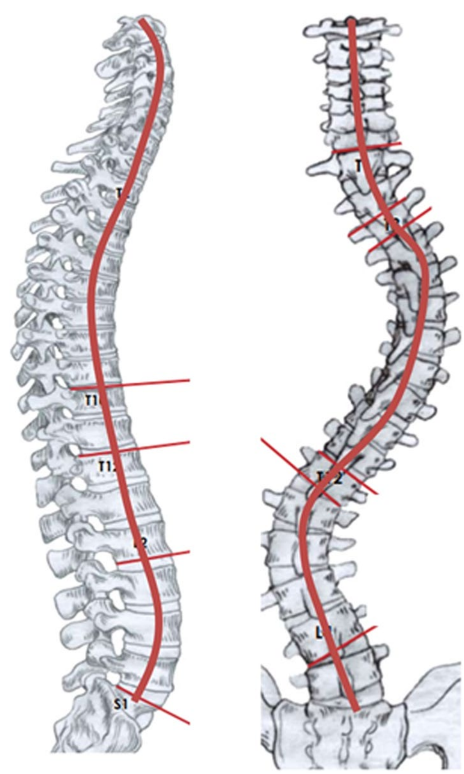

Fig. 1 Spinal three-dimensional length (spinal 3D length) (mm) which is 3D curvilinear length of the spine from the tip of odontoid process to the center of S1 passing through all the vertebrae centers

with Pearson's correlation coefficient (a significance level of $p < 0.05$). Bivariate analysis was also performed between PI and PTh in the same way, because previous articles reported an inverse relationship between PI and PT, but the gender difference is yet to be investigated [2, 8]. Multivariate logistic regression with a forward stepwise procedure ($p < 0.25$ for entry and $p < 0.10$ for exclusion) was performed for the factors in demographic and anatomical parameters (PI, PTh, spinal 3D length), while the other spino-pelvic alignment parameters were excluded because of the interdependency. Then, an appropriate model was obtained by nominal logistic regression. The JMP software package (ver.9.0.0, SAS Institute, Cary, NC) was used for all statistical analyses.

Results

Patient demographic data

Mean age and BMI were 40.4 years (18–80) and 24.5 kg/m^2 (14.5–44.7), respectively. The mean ODI score was 2.3% (0–20%). There was no significant difference in age and ODI between men and women. BMI of men was greater than that of women (Table 1).

Regarding the difference in demographic data among main ethnicities (Arabo-Bèrbère, Asian, Caucasian), Asian was younger than Arabo-Bèrbère and Caucasian. There was no difference in sex. Asian showed lower BMI than Arabo-Bèrbère and Caucasian. Caucasian had lower ODI score than Arabo-Bèrbère and Asian (Table 2, 3).

There was no significant difference in pelvic parameters except PTh among ethnicities. PTh of Arabo-Bèrbère was significantly small compared to that of Asian or Caucasian), while there was no difference between Asian and Caucasian (Table 2).

Bivariate regression analysis between PI versus demographics, ODI, and spinal 3D length in all participants and those divided by sex

PI showed a significant positive correlation with age in pooled data. Divided by sex, however, there was no correlation in men, while women had a significant correlation with higher correlation coefficient (Fig. 2). PI did not have a significant correlation with BMI ($R = 0.0361$, $p = 0.4965$), nor with ODI ($R = 0.0480$, $p = 0.3035$). There was a significant negative correlation between PI and Spinal 3D length ($R = 0.1409$, $p = 0.0023$).

Bivariate regression analysis between PTh versus demographics, ODI, and spinal 3D length in all participants and those divided by sex

PTh which represents pelvic size had a significant negative correlation with age in pooled data. Divided by sex, again no correlation was found in men, but there was a significant correlation in women with higher correlation coefficient (Fig. 3). PTh significantly correlated with BMI ($R = 0.2490$, $p < 0.0001$), but not with ODI ($R = 0.0342$, $p = 0.4601$). There was a significant positive correlation between PTh and Spinal 3D length ($R = 0.2245$, $p < 0.0001$).

Bivariate regression analysis between PI and pelvic thickness in all subjects and the subjects divided by sex

There was a significant negative correlation between PI and PTh in pooled data. Men had also a weak significant correlation, while women showed a higher negative correlation coefficient between PI and PTh (Fig. 4).

Table 1 Demographics and Oswestry Disability Index (ODI)

	mean ± SD (95% CI)				min max
	All, $n = 468$	Men, $n = 184$	Women, $n = 284$	p-value*	
Age (years)	40.4 ± 14.8 (39.1/40.4)	39.1 ± 14.7 (36.9/41.2)	41.3 ± 14.8 (39.5/43.0)	0.0774	18/79
BMI (Kg/m^2)	24.5 ± 5.3 (24.0/25.1)	24.9 ± 4.6 (24.1/25.7)	24.3 ± 5.7 (23.6/25.1)	0.0161	14.5/44.7
ODI	2.3 ± 4.1 (1.9/2.6)	2.1 ± 3.8 (1.5/2.6)	2.4 ± 4.3 (1.9/2.9)	0 .7181	0/20

mean ± SD: mean value ± standard deviation, 95% *CI*, confidence intervals (lower 95%/upper 95%), *min* minimum value, *max* maximum value, *BMI* body mass index was calculated as the weight in kilograms divided by the square of the height in meters (kg/m^2), *ODI* Oswestry disability index [11]

p-value*: Men vs Women by Mann–Whitney test

Table 2 Demographics and pelvic parameters divided by main ethnicities ($n = 441$)

	Arabo-Bèrbère ($n = 80$)		Asian ($n = 185$)		Caucasian ($n = 176$)	
Parameters	*mean* ± *SD* (95% CI)	*p*-value v s. Asian	*mean* ± *SD* (95% CI)	*p*-value v.s. Caucasian	*mean* ± *SD* (95% CI)	ANOVA *p*-value
Age	45.5 ± 1.6 (42.3/48.7)	< 0.0001	36.7 ± 1.1 (34.6/38.8)	0.1195	42.0 ± 1.1 (39.9/44.2)	< 0.0001
		0.1434				
Gender (men/women)[a1]	30/50	N.S	69/116	N.S	73/103	
		N.S				
BMI (Kg/cm^2)	27.1 ± 0.5 (26.1/28.2)	< 0.0001	22.1 ± 0.3 (21.4/22.7)	< 0.0001	27.3 ± 0.5 (26.2/28.3)	< 0.0001
		0.9386				
ODI	3.4 ± 0.4 (2.5/4.3)	N.S	3.3 ± 0.3 (2.7/3.9)	< 0.0001	0.9 ± 0.3 (0.3/1.5)	< 0.0001
		< 0.0001				
PI	52.0 ± 1.2 (49.6/54.3)	N.S	51.0 ± 0.8 (49.4/52.5)	N.S	52.5 ± 0.8 (51.0/54.1)	*N.S*
		N.S				
PT	12.3 ± 0.8 (10.7/13.9)	N.S	11.9 ± 0.5 (10.9/13.0)	N.S	12.9 ± 0.6 (11.8/14.0)	*N.S*
		N.S				
SS	39.7 ± 0.9 (37.8/41.5)	N.S	39.1 ± 0.6 (37.9/40.2)	N.S		
N.S	39.6 ± 0.6 (38.4/40.8)	N.*S*				
N.S						
		N.S				
PTh	102.1 ± 0.8 (100.5/13.9)	0.0020	107.3 ± 0.5 (106.3/108.4)	N.S	105.6 ± 0.6 (104.5/106.7)	< 0.0001
		< 0.0001				

mean ± SE: Mean value ± standard error, 95% CI: 95% confidence intervals (lower 95% / upper 95%), *BMI* Body mass index was calculated as the weight in kilograms divided by the square of the height in meters (kg/m^2), *ODI* Oswestry Disability Index [11], *PI* Pelvic incidence, *PT* Pelvic tilt, *SS* Sacral slope, *PTh* Pelvic thickness [1]

[a]1: Pearson's chi-square test was used for difference in gender. Regarding age, BMI, and ODI, post-hoc test using Steel–Dwass analysis following ANOVA was performed for comparison among ethnicities. N.S.: not significant

Table 3 Bivariate correlations among pelvic incidence (PI) and demographic / spinal morphological factors

Parameters	v.s. PI	
	Correlation coefficient	*p*-value
Age	0.1713	0.0002
BMI	0.0361	0.4965
Pelvic thickness	–0.3863	< 0.0001
Spinal 3D length	–0.1409	0.0023

Correlation coefficient: Pearson's correlation coefficient with *p*-value was calculated for each relationship

Multivariate factor analysis for pelvic incidence

Based on the bivariate analyses, we selected five variables, age, sex, ethnicity, PTh, and spinal 3D length, as independent factors for a forward stepwise multivariate logistic regression ($p < 0.25$ for entry, $p < 0.10$ for exclusion) regarding PI. Following the stepwise multivariate analysis, age (F ratio = 2.615, $p = 0.1066$), sex (F ratio = 5.048, $p = 0.0252$), ethnicity (F ratio = 2.1798, $p = 0.1143$), and PTh (F ratio = 74.3, $p < 0.0001$) were chosen.

Then, a nominal logistic regression modeling following stepwise regression analysis was performed, resulting in the predicted PI = 107.2–0.05*age ($p = 0.1066$) + 1.07*sex [man = 0, woman = 1] ($p = 0.0252$)–1.68*Ethnicity (Arabo-Bèrbère) ($p = 0.0423$) + 0.63*Ethnicity (Asian) ($p = 0.3471$) – 0.55*PTh ($p < 0.0001$), with adjusted $R^2 = 0.1652$. A prediction profiler of the logistic model with statistically significant four factors, age, sex, ethnicity, and pelvic thickness (PTh) is shown in Fig. 5. In case of 40.4-years-old women, Arabo-Bèrbère, and 105.7 mm in PTh, longitudinal dot lines in Fig. 5, the predicted PI = 50.6° (Fig. 5). Compared to PTh, the effects of age, sex, and ethnicity were inconsiderable. The difference of PI value between a 20-years-old woman (Arabo-Bèrbère, 105.7 mm in PTh) and a 80-years-old woman (Arabo-Bèrbère, 105.7 mm in PTh) was 3.2 ° (49.4° vs. 52.6°).

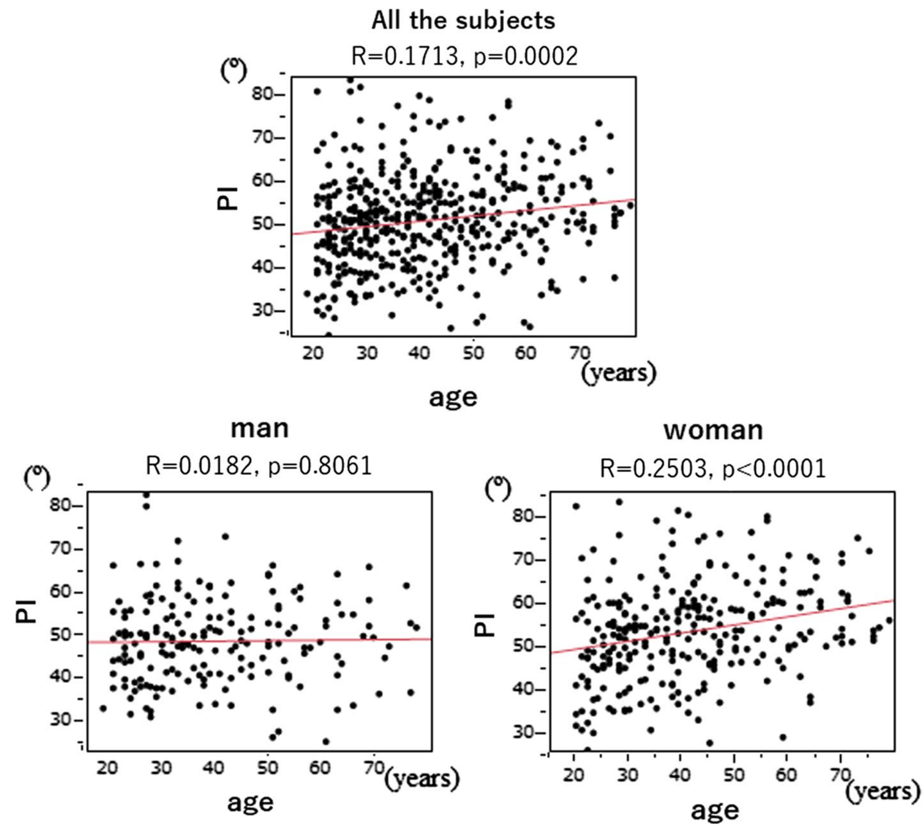

Fig. 2 Bivariable correlation: pelvic incidence (PI [°]) vs. age (years old) in all subjects and the subjects divided by sex

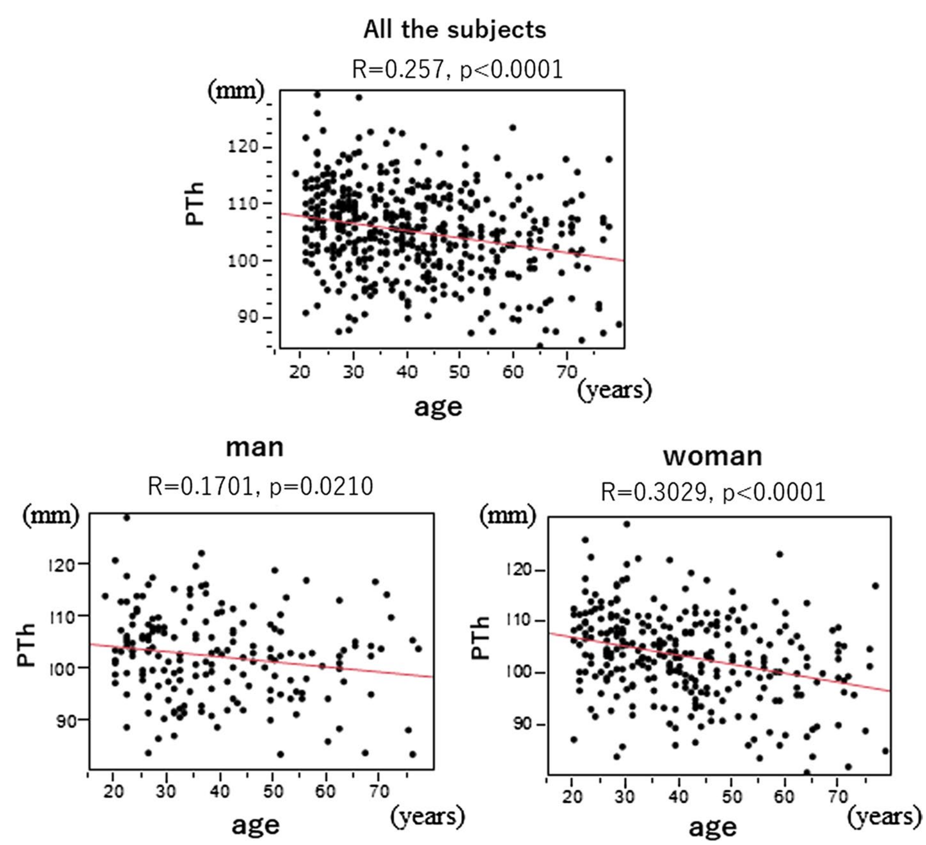

Fig. 3 Bivariable correlation: pelvic thickness (PTh [mm]) vs. age (years old) in all subjects and the subjects divided by sex

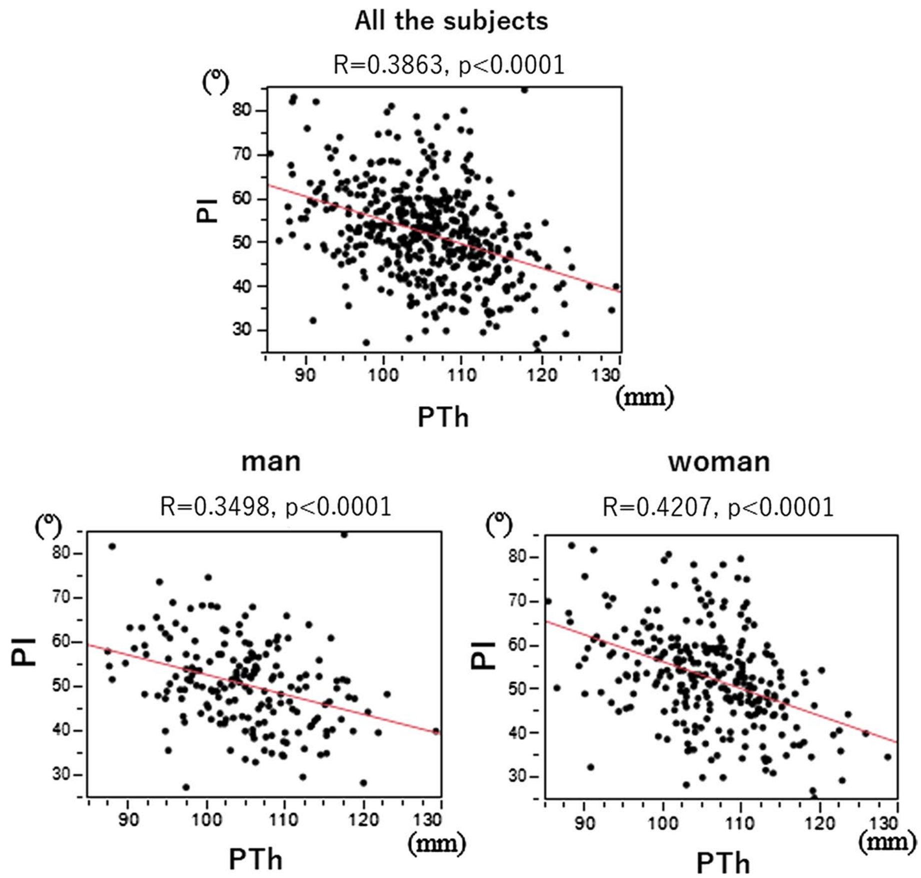

Fig. 4 Bivariable correlation: pelvic incidence (PI [°]) v.s. pelvic thickness (PTh [mm]) in all subjects and the subjects divided by sex

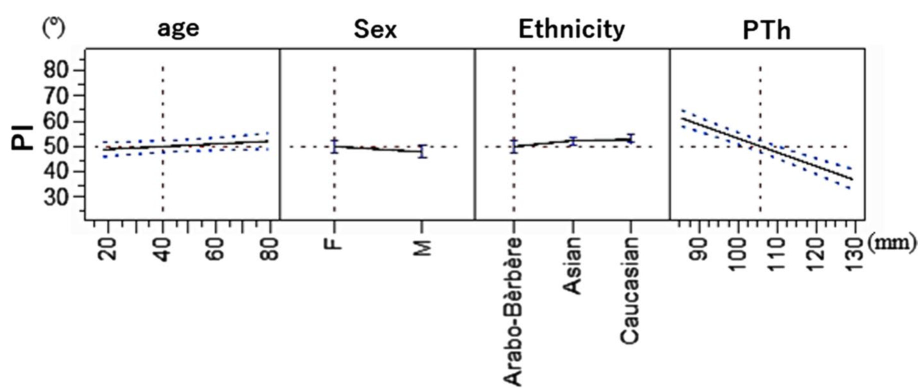

Fig. 5 Prediction profier of the logistic model with statistically significant four factors, age, sex, ethnicity, and pelvic thickness (PTh). In case of 40.4 in age, women, Arabo-Bèrbère, and 105.7 mm in PTh (longitudinal dot lines), the predicted PI = 50.6 °

Discussion

Mangion et al. measured PI on radiographs of 30 fetuses, 30 children, and 30 adults and found that PI considerably increases in the first few months of life, continues to increase during the early years, and stabilizes at around the age of 10 years [14]. The whole spine alignment is dependent to PI, and thus, PI is believed to be a constant and fundamental anatomical parameter for standing spinopelvic alignment in each adult individual [1]. There was, however, a significant correlation between PI and age in cross-sectional studies in the subjects with low back pain 60 years or over [7] or in healthy adult subjects in which PI increases around 10º on average from 20 to 70 years of age [8]. These findings are compatible with a review article on sagittal pelvic alignment parameters, which illustrated that PI tends to increase with age in both normal and scoliotic subjects [6].

In the present study, we found once again that there was a positive relationship PI and age in pooled data in a large multi-ethnic and multi-center database. On the other hand, there was no correlation in men, but women had a higher correlation coefficient than that in the pooled data (Fig. 2), suggesting that PI increases with aging during adult hood with significant gender difference, i.e., the PI increase is more remarkable in woman than in man. Duval-Beaupère described a possibility that a subtle motion in sacroiliac joints which induces PI variation in serial X-ray measurement in the same subject [1]. Because SIj is the only joint between sacral endplate and acetabulum, an increase of the value of PI was attributable to a twisting mobilization within the SIj, resulting in a forward projection of the gravity due to a sagittal disturbance and a compensatory pelvic backward rotation [7]. In a previous study, the authors (K.H., S.H.) compared original EOS images (standing position) and CT-generated EOS images (supine position) in the same patients using digital reconstructed radiography technique in 24 ASD patients (mean age 60.1 years, range 20–80 years, all women). With regard to pelvic alignment, PI was significantly greater in the standing position (mean 57.7°) than in the supine position (mean 53.4°) ($p=0.0013$, paired *t*-test), and PT was also significantly greater in the standing position (mean 30.7°) than in the supine position (mean 19.2°) ($p<0.0001$, paired *t*-test) [15]. We also found a significant positional difference in PTh, mean 103.2 mm in standing vs. mean 104.5 mm in supine ($p=0.0159$, paired *t*-test) in the same case series of ASD. PTh is a distance between HA and the center of sacral endplate, thus SIj intervenes the measurement, and the change of SIj could also affect PTh likewise as PI.

The classical studies on the anatomy and function of SIj could provide several suggestions to the results of the present study. In vivo SIj movements investigated using the 3-D roentgenographic method revealed that the position of the axes lie consistently in front of and below the joints with variation with the axes intersecting the median sagittal plane near the pubic symphysis, with the displacement of the iliac bones in rotation and forward translation on these axes, with the amplitude of rotation of 10 º to 12 º and translation of 6 mm on average in young adults [16]. Sturesson et al. also examined in vivo SIj movement using the same method in physiologic as well as in the extreme of physiologic positions in 25 patients (21 women, 4 men) and found that the rotation was mean 2.5 º (0.8 º~ 3.9 º), and the translation was mean 0.7 mm (0.1–1.6 mm) [17]. Observation on sectioned and opened preparations of human SIj show the presence of cartilage-covered ridges and depressions which have higher friction coefficients than that of coarse texture and are more pronounced in men than in women [18, 19]. Another photogrammetric and histologic study in seven pelvic specimens revealed that there were sex-specific differences; all joint surfaces from the pelvises in women showed circular contours, the centers of which coincided with the iliac tuberosities which were not discernible in the joint surfaces of men; this configuration involved distinct differences in mobility; rotation of the sacroiliac joints was markedly less in man than in women [20].

These previous reports give causative backgrounds to the gender difference in the relationships between PI and age, PTh and age, or PI and PTh (Figs. 2, 3, 4). We assumed that PI and PTh alteration mechanism in the standing posture as follows. In Fig. 6, PI-1 assumes an original PI in case without SIj osteoarthrosis nor mal-alignment. Aging or progression of deformity induces SIj osteoarthrosis with concomitant hypermobility, leading to loss of lumbar

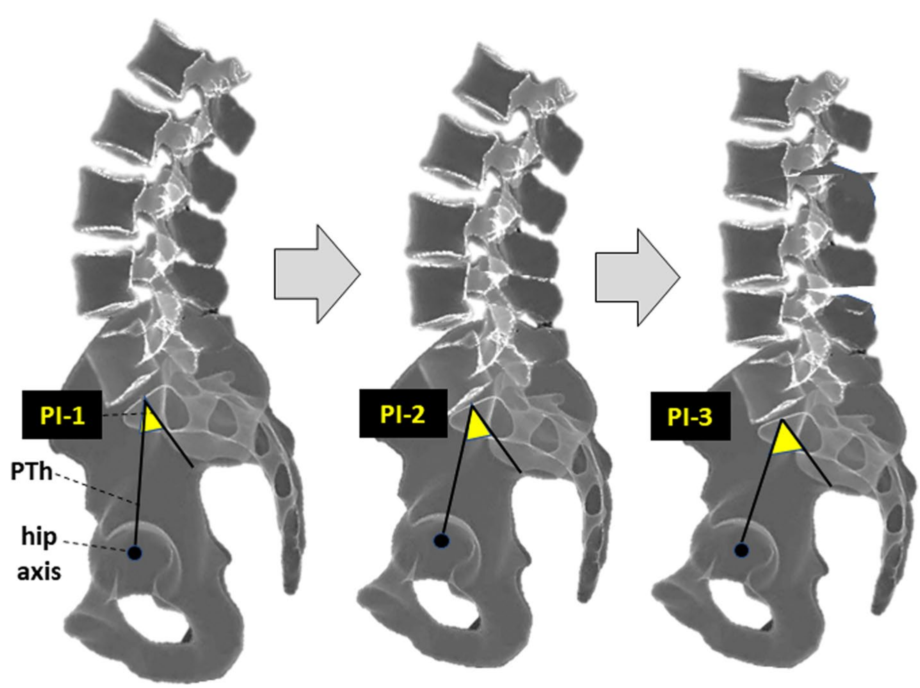

Fig. 6 Hypothetical alteration of PI and PTh values in the standing posture. PI-1 indicates an original PI in case of no sacroiliac joint (SIj) osteoarthrosis. Aging or progression of deformity induces SIj osteoarthrosis with hypermobility of SIj, leading to postero-inferior shift of the sacral endplate, that is, PI-2 then PI-3, due to the vertical loading in standing position and simultaneous increase of PT as compensation phenomenon. Contrary to PI, PTh decreases due to sinkage of the sacrum relative to ilium.

lordosis and postero-inferior shift of the sacral endplate, i.e., PI-2 then PI-3, due to the vertical loading in standing position and simultaneous increase of pelvic retroversion as compensation phenomenon. Contrary to PI, PTh decreases due to sinkage of the sacrum relative to ilium (Fig. 6). The PI alteration is predominant in woman than in man due to the anatomical difference of the SIj. The anatomical close relationship between PI and PTh (Fig. 4) could explain that the contribution of PTh to PI value was the highest among the affecting factors in multivariate regression analysis (Fig. 5). Compared to PTh, the effect of age was inconsiderable. Aging effect in the range of 20–80 years is expected less than 5 ° from the result of the prediction profier on PI (Fig. 5), thus the authors consider that PI increases with age, but the impact is small. On the other hand, PI change is considered more significant in the patients with spinal diseases, especially with adult spinal deformity, therefore we spine surgeons should keep the fact in mind. In case of long spinal fusion in an elderly female, it might be reliable to include the sacroiliac joints which have uncertain mobility and could affect the surgical result if not fused.

There are several limitations in this study. First, this is a cross-sectional study, thus definitive change of pelvic parameters with aging is yet to be verified. Secondly, this study statistically verified that age, sex, ethnicity, and PTh contribute PI value, but the adjusted decision coefficient of the nominal logistic regression model was 0.1652. This suggests that many other factors are involved in PI value. Therefore, the future study should be a prospective longitudinal approach with more demographic parameters, e.g., body weight, body length, maternity history, occupation, and sport activity. Nonetheless, this prospective research using MEANS database was performed with strict exclusion criteria, especially anomalous vertebral count or transitional vertebrae, with using EOS system for standing *whole body* sagittal alignment measurement. This is unprecedented, and consequently, we believe that the results of the present analyses could complement a ray of light to the understanding of PI.

Conclusion

Using a large multi-ethnic and multi-center database of healthy adult volunteers, the MEANS, we found that PTh, sex, ethnicity, and age affected PI. There was a positive correlation between PI and age, on the other hand, a negative correlation between PTh and age. The tendency was more significant in woman than in man. The results support the hypothesis that PI, a fundamental anatomical parameter, increases with aging, but the change seems to be small and needs to be verified in a longitudinal evaluation of volunteers and/or patients over time.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethical approval and consent to participate The study was approved by the Institutional ethics review boards of all centers. The ethics committee of Niigata Spine Surgery Center approved with the committee's reference number: IRB Approval #6 (R3)-2021.

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