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ORIGINAL ARTICLE

Age-based normal sagittal alignment in Chinese asymptomatic adults: establishment of the relationships between pelvic incidence and other parameters

Siyu Zhou[1,2] · Fei Xu[1,2] · Wei Wang[1,2] · Da Zou[1,2] · Zhuoran Sun[1] · Weishi Li[1]

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Abstract

Purpose To investigate the age-based normal values of sagittal parameters and establish the relationships between them in Chinese population.

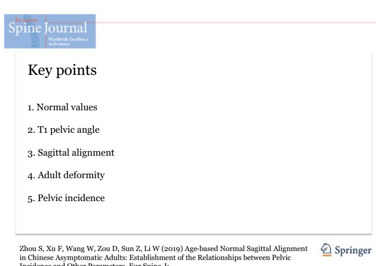
Method Two hundred eighteen asymptomatic adult volunteers were included in this cross-sectional study. The whole spine standing radiograph was taken from them, and the parameters including sagittal vertical axis (SVA), T1 pelvic angle (TPA), global tilt (GT), spino-sacral angle, lumbar lordosis (LL), thoracic kyphosis (TK), T1 slope (T1S), cervical lordosis (CL), C2–C7SVA, pelvic tilt (PT), sacral slop (SS) and pelvic incidence (PI) were measured. The gender differences in sagittal alignment were compared. Pearson correlation was calculated, and a linear regression analysis was used to establish the relation between PI and other parameters.

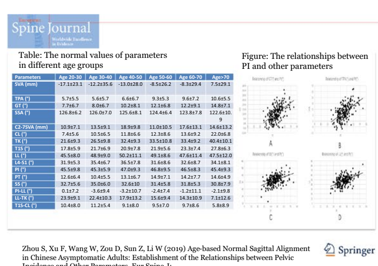
Results The average values of PI, LL, TPA and GT were 46.2°, 48.2°, 7.8° and 10.6°, respectively, in this cohort. SVA, GT, TPA, TK, T1S, CL and PT significantly increased with age ($p < 0.05$). The females presented smaller T1S, C2–C7SVA and larger PI, PT than the males. The relationships between PI and TPA, GT, SS, LL could be presented as $\text{TPA} = 0.411 * \text{PI} - 11.2$ ($R^2 = 0.328$, $p < 0.001$), $\text{GT} = 0.483 * \text{PI} - 11.7$ ($R^2 = 0.297$, $p < 0.001$), $\text{SS} = 0.354 * \text{PI} + 16.1$ ($R^2 = 0.203$, $p < 0.001$), $\text{LL} = 0.588 * \text{PI} + 21.0$ ($R^2 = 0.267$, $p < 0.001$), respectively.

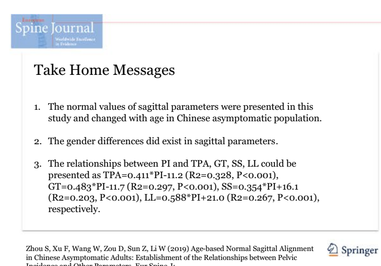
Conclusion The normal values of sagittal parameters were presented and changed with age in Chinese asymptomatic population. The gender differences existed in sagittal parameters. The relationships between PI and other parameters were established which could be used for further research.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Normal values · T1 pelvic angle · Sagittal alignment · Adult deformity · Pelvic incidence

Siyu Zhou and Fei Xu contributed equally to this work.

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Extended author information available on the last page of the article

Introduction

Since the conception "cone of economy" was proposed by Dubousset [1], the importance of spinopelvic sagittal alignment in the management of spinal disorders has been noticed by more and more spine surgeons. Previous studies reported that restoring the suitable sagittal alignment could predict a better surgical outcome [2, 3] and less mechanical complications [4, 5] for patients with adult spinal deformity (ASD). Schwab et al. proposed three key sagittal modifiers including sagittal vertical axis (SVA), pelvic tilt (PT) and pelvic incidence minus lumbar lordosis (PI–LL) which were most highly related with health-related quality of life (HRQOL) of patients [6, 7], and keeping SVA less than 40 mm, PT less than 20° as well as PI–LL within 10° should be the corrective goal. Apart from these classical parameters, some new sagittal parameters such as T1 pelvic tilt (TPA) have also been introduced to evaluate the sagittal balance. Accounting for both truncal inclination and pelvic tilt, TPA was highly correlated with HRQOL and less influenced by posture [8], which could predict the surgical outcome more effectively than SVA [9]. Global tilt (GT) is a similar parameter developed recently which reflects the global sagittal balance as TPA [10].

A lot of work has been done to define the optimum values of these sagittal parameters as references for correction surgery [11–14]. Mac-Thiong et al. [15] described age-based normative sagittal parameters in the spine of Caucasian adults. Lee et al. [13] and Endo et al. [14] reported the characteristics of young population in Korea and Japan, respectively. Zhu et al. [16] investigated the norms of Chinese adults and found that the Chinese population showed a different sagittal alignment including smaller pelvic incidence and sacral slope from the age-matched Caucasian population. However, the sagittal parameters discussed in their study were not comprehensive since the useful novel parameters such as TPA and cervical parameters were not included, and also the age-based variation in sagittal parameters had not been demonstrated yet.

Meanwhile, describing the normal variation of sagittal parameters was not enough. Since PI was the constant parameter in adults, which could provide the primary information of the degenerative spine, it was important to establish the relation between PI and other sagittal parameters. Compared with using a finite value of sagittal parameter such as PT = 20° to judge balance, which could be mistaken for patients with high or low PI, evaluating other parameters in relation to pelvic incidence was more suitable and accurate, especially for patients with extreme PI [4]. But these relations between PI and other parameters have not been well demonstrated yet in Chinese population.

Thus, the present study aimed to demonstrate the age-stratified standard values of classical and novel sagittal parameters in Chinese asymptomatic population and establish the relationships between PI and other parameters.

Method

Study design

This was a cross-sectional study which got approved by the relevant institutional Ethics Committee and was conducted in the light of the Declaration of Helsinki. All volunteers were fully informed about the methods, purposes, and risks involved in the study protocol and signed the informed consent.

Patients

All volunteers had undergone a detailed history taking and physical examination before participating in this study. In the end, 218 asymptomatic Chinese volunteers were included in this study based on following inclusion criteria.

1. Age > 18 years.
2. No neck and back pain in previous 6 months.
3. No history of radicular symptoms.
4. No history of chronic neck or back pain.
5. No history of spinal diseases and surgery.
6. No coronal deformity or lumbar spondylolisthesis.
7. No history of hip or knee arthroplasty or other realignment surgery of the lower.

Extremities

8. No history of neuromuscular disorders.
9. Non-pregnant.
10. With normal sagittal balance (SVA < 5 cm).

Radiographic evaluation

The anteroposterior and lateral standing radiograph including the whole spine and pelvis was obtained from all volunteers. The volunteers were instructed to stand straightly, with eyes looking straight ahead and fingers touching on the collar bones. Two orthopedic specialists who were not otherwise involved in this study performed all the radiographic measurements, and the average of their results was recorded. By using the PACS system (Picture Archiving and Communication System, GE healthcare, Mount prospect, IL, USA), the following parameters were measured. (1) Global parameters: sagittal vertical axis (SVA) T1 pelvic angle (TPA), global tilt (GT), spinal-sacral angle (SSA). (2) Local curvature: lumbar lordosis (LL), lordosis of L4–S1 (L4–S1), thoracic kyphosis (TK), T1 slope (T1S), C2–7SVA and cervical lordosis (CL). (3) Pelvic parameters: pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS). The measurements of sagittal parameters are shown in Table 1 and Fig. 1.

Statistical analysis

All the analyses were performed using SPSS version 19.0 (SPSS Inc, Chicago, IL, USA). Independent t test was used to compare the differences of parameters between males and females. The relations between PI and other parameters were evaluated by using Pearson's correlation coefficient. The linear regression analysis was used to establish the predictive formulas of other parameters based on PI. Statistical significance was set at a level of $p < 0.05$.

Results

Demographics

Of 218 healthy volunteers recruited in the present study, there were 114 males and 104 females, with an average age of 48.4 ± 16.9 years (range 21–79 years). The average height, weight and BMI of the volunteers were 166.8 ± 8.7 cm (range 150–187 cm), 65.9 ± 10.9 kg (range 42–125 kg) and 23.6 ± 3.2 kg/m^2 (range 17.5–43.3 kg/m^2), respectively. The volunteers were divided into six groups including age 20–30 group (N = 41), age 30–40 group (N = 33), age 40–50 group (N = 39), age 50–60 group (N = 43), age 60–70 group (N = 41) and age > 70 group (N = 21).

The normative values of sagittal parameters in different age groups

The inter-observer reliability of the measurements for all parameters is shown in Table 2, and the measurements were reliable.

The normal values of spinopelvic parameters are listed in Table 3. Compared with present study which focused on the Chinese population [16], the values of LL, SS, PT and PI in our study were generally consistent with theirs, but TK was relatively higher in our volunteers group (30.6° vs 27.8°). The average value of TPA, GT and SSA was 7.8°, 10.6° and 125°, respectively.

With respect to the changes of parameters with age (Table 6), we found that the parameters reflecting the global balance increased with age including SVA (r = 0.189), TPA (r = 0.291) and GT (r = 0.291), followed by an increase in PT (r = 0.163) to compensate. In addition, TK (r = 0.475) and T1S (r = 0.329) increased with age, followed by an increase in CL (0.398) to maintain the horizontal eyesight, and SSA (r = − 0.189) also decreased indicating increased whole spinal kyphosis. These changes with age could be seen from Fig. 2. As shown in Table 4, we found that TPA, GT, CL, TK, T1S and L4–S1 were significantly different among different age groups, but LL and SSA were not significantly different among different age groups by performing one-way ANOVA. The differences in SVA (p = 0.05) and PT (p = 0.058) approached the borderline significance.

When examining the differences between males and females, the females presented larger PI and PT than the males did, while the males showed larger T1S and C2–7SVA than the females as listed in Table 5. We also performed multiple regression analysis to explore the relationship

Table 1 The measurements of sagittal parameters

Parameters	Measurements
SVA	The offset between the center of C7 and the plumb line drawn from posterosuperior corner of S1
TPA	The angle between the line from the femoral head axis to the centroid of T1 and the line from the femoral head axis to the middle of the S1 endplate [8]
GT	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 [17]
SSA	The angle between a line from the center of C7 to the center of the sacral endplate and the sacral endplate itself [18]
C2–7SVA	The offset between the center of C2 and the plumb line drawn from posterosuperior corner of C7
CL	The angle between the lower endplate of C2 and C7
TK	The angle between the upper endplate of T4 and lower endplate of T12
T1slope	The angle between the upper endplate of T1 and the horizontal line
LL	The angle between the superior endplate of S1 and L1
L4–S1	The angle between the superior endplate of S1 and L4
PI	The angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral head axis
PT	The angle between the vertical line and the line joining the middle of the sacral plate and the hip axis
SS	The angle between the sacral endplate and the horizontal line

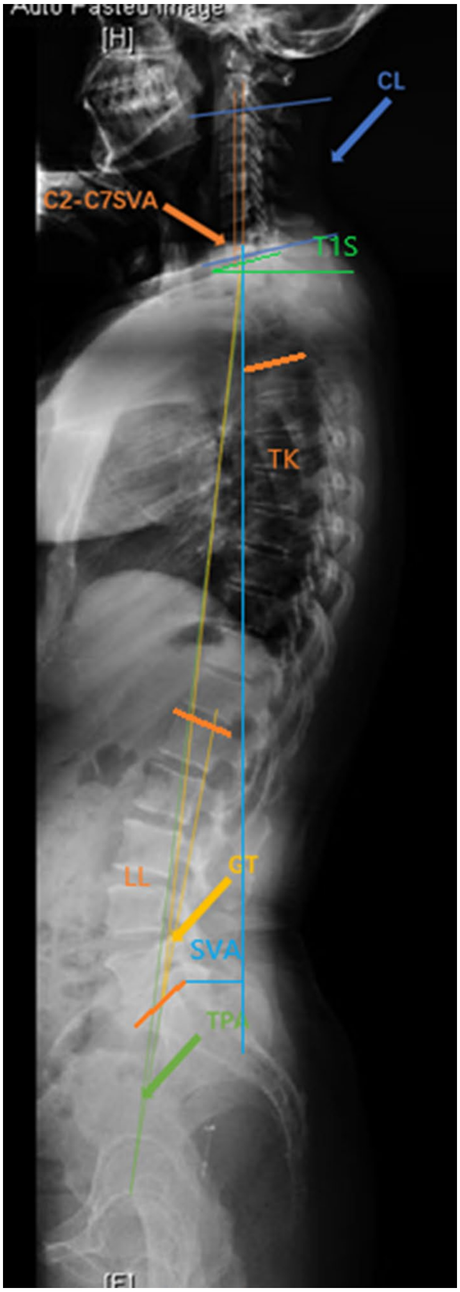

Fig. 1 The measurements of some sagittal parameters

Table 2 The inter-observer reliability for measured parameters

Parameters	Inter-rater ICC	Intra-rater ICC
SVA	0.98	0.98
TPA	0.90	0.95
GT	0.93	0.98
SSA	0.85	0.91
C2–7SVA	0.99	0.98
CL	0.96	0.86
TK	0.95	0.94
T1slope	0.93	0.82
LL	0.95	0.94
L4–S1	0.97	0.85
PI	0.97	0.91
PT	0.99	0.84
SS	0.98	0.85

Table 3 The average values of all measured parameters

Parameters	Mean	SD	Min	Max	95% CI of mean
SVA (mm)	−9.9	28.9	−91.6	63.4	−13.8 to −6.0
TPA (°)	7.8	6.3	−7.4	27.2	6.9–8.6
GT (°)	10.6	7.8	−6.2	35.5	9.6–11.6
SSA (°)	125.0	7.6	102.5	152.9	124.0–126.1
C2–7SVA (mm)	14.4	10.9	−14.0	52.6	12.9–15.8
CL (°)	12.2	8.3	−16.2	38.1	11.1–13.3
TK (°)	30.6	11.1	3.2	62.1	29.1–32.1
T1S (°)	21.7	7.1	−0.9	41.3	20.8–22.7
LL (°)	48.2	10.0	20.9	82.9	46.8–49.5
L4–S1 (°)	33.5	7.7	13.6	53.5	32.5–34.6
PI (°)	46.2	8.8	25.5	74.7	45.0–47.4
PT (°)	13.3	6.7	0.2	34.2	12.4–14.2
SS (°)	32.4	6.9	2.4	53.7	31.5–33.4
PI–LL (°)	−2.0	9.3	−29.0	27.4	−3.2 to −0.7
LL–TK (°)	17.5	11.8	−14.0	49.1	15.9–19.1
T1S–CL (°)	9.5	7.7	−15.2	30.6	8.5–10.6

between PI and other parameters including age, sex, BMI, weight and height. Then we found that only sex significantly correlated with PI ($p=0.003$).

The correlation between each parameter and the other is listed in Table 6. T1S was significantly associated with SVA ($r=0.318$), and the cervical alignment was significantly influenced by T1S since T1 was the foundation of cervical spine. On the other hand, T1S was influenced by TK ($r=0.399$), and TK was conducted by lumbar spine and pelvis, so the whole spine and pelvis formed a chain of correlation.

Meanwhile, by using the linear regression analysis, we established the following relationships between PI and the other parameters which were widely used in the correction surgery (Fig. 3).

$$\mathrm{TPA} = 0.411 * \mathrm{PI} - 11.2 \left(R^2 = 0.328,\ P < 0.001\right)$$

$$\mathrm{GT} = 0.483 * \mathrm{PI} - 11.7 \left(R^2 = 0.297,\ P < 0.001\right)$$

$$\mathrm{SS} = 0.354 * \mathrm{PI} + 16.1 \left(R^2 = 0.203,\ P < 0.001\right)$$

$$\mathrm{LL} = 0.588 * \mathrm{PI} + 21.0 \left(R^2 = 0.267,\ P < 0.001\right)$$

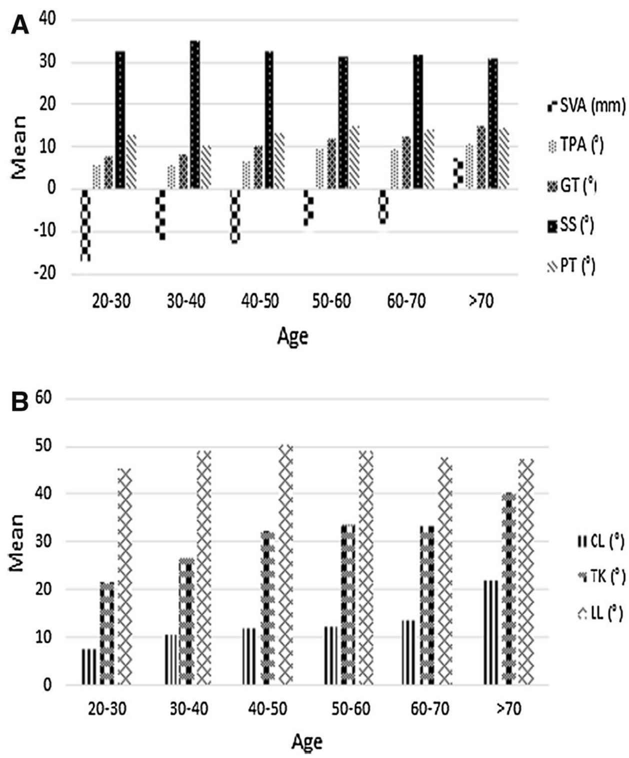

Fig. 2 Changes in sagittal parameters with age

With respect to the high correlation between TPA, GT and age, we used the multifactor regression analysis to establish the following equations as:

$$TPA = 0.407 * PI + 0.104 * age - 16.1 \left(R^2 = 0.406,\ P < 0.001\right);$$
$$GT = 0.479 * PI + 0.129 * age - 17.8 \left(R^2 = 0.375,\ P < 0.001\right).$$

Discussion

With increasing attention to spinopelvic sagittal alignment, some novel parameters have been introduced to better evaluate the sagittal balance, which overcame the deficiencies of classical parameters. With respect to global balance parameters, the normal values of TPA, GT and SSA have not been well demonstrated in Chinese population yet. TPA, a new parameter combining truncal inclination and pelvic tilt, could successfully assess the surgical outcome of ASD patients and was less influenced by posture [8, 19]. Besides, the change in TPA correlated to the osteotomy degrees of pedicle subtraction osteotomy (PSO) [20]. GT, which was similar to TPA and represented the whole spinal sagittal balance, has been reported to effectively predict mechanical complication after corrective surgery [4]. SSA was reported to be a good indicator of the whole kyphosis in patients with severe kyphosis. With respect to the cervical parameters, C2–C7SVA, similar to SVA, was a useful parameter to cervical sagittal balance and associated with surgery outcome [21]. T1S, which reflected the overall sagittal alignment and influenced the cervical parameters, combined with CL was reported to correlate significantly with neck disability index (NDI) of patients [22]. As these parameters were so important during the management of spinal disorders, we need to know the normal variations of them in the asymptomatic population, to better understand the clinical characteristics of sagittal alignment in patients and design the most suitable goal.

This study provided the normative values of sagittal parameters in Chinese asymptomatic population with age ranging from 21 to 79 years. Previous studies also reported

Table 4 The average values of all parameters in different age groups

Parameters	Age 20–30	Age 30–40	Age 40–50	Age 50–60	Age 60–70	Age > 70
SVA (mm)	− 17.1 ± 23.1	− 12.2 ± 35.6	− 13.0 ± 28.0	− 8.5 ± 26.2	− 8.3 ± 29.4	7.5 ± 29.1
TPA (°)	5.7 ± 5.5	5.6 ± 5.7	6.6 ± 6.7	9.3 ± 5.3	9.6 ± 7.2	10.6 ± 5.5
GT (°)	7.7 ± 6.7	8.0 ± 6.7	10.2 ± 8.1	12.1 ± 6.8	12.2 ± 9.1	14.8 ± 7.1
SSA (°)	126.8 ± 6.2	126.0 ± 7.0	125.6 ± 8.1	124.4 ± 6.4	123.8 ± 7.8	122.6 ± 10.9
C2–7SVA (mm)	10.9 ± 7.1	13.5 ± 9.1	18.9 ± 9.8	11.0 ± 10.5	17.6 ± 13.1	14.6 ± 13.2
CL (°)	7.4 ± 5.6	10.5 ± 6.5	11.8 ± 6.6	12.3 ± 8.6	13.6 ± 9.2	22.0 ± 6.8
TK (°)	21.6 ± 9.3	26.5 ± 9.8	32.4 ± 9.3	33.5 ± 10.8	33.4 ± 9.2	40.4 ± 10.1
T1S (°)	17.8 ± 5.9	21.7 ± 6.9	20.9 ± 7.8	21.9 ± 5.6	23.3 ± 7.4	27.8 ± 6.3
LL (°)	45.5 ± 8.0	48.9 ± 9.0	50.2 ± 11.1	49.1 ± 8.6	47.6 ± 11.4	47.5 ± 12.0
L4–S1 (°)	31.9 ± 5.3	35.4 ± 6.7	36.5 ± 7.8	31.6 ± 8.6	32.6 ± 8.7	34.1 ± 8.1
PI (°)	45.5 ± 9.8	45.3 ± 5.9	47.0 ± 9.3	46.8 ± 9.5	46.5 ± 8.3	45.4 ± 9.3
PT (°)	12.6 ± 6.4	10.4 ± 5.5	13.1 ± 6.7	14.9 ± 7.1	14.2 ± 7.7	14.6 ± 4.9
SS (°)	32.7 ± 5.6	35.0 ± 6.0	32.6 ± 10	31.4 ± 5.8	31.8 ± 5.3	30.8 ± 7.9
PI–LL (°)	0.1 ± 7.2	− 3.6 ± 9.4	− 3.2 ± 10.7	− 2.4 ± 7.4	− 1.2 ± 11.1	− 2.1 ± 9.8
LL–TK (°)	23.9 ± 9.1	22.4 ± 10.3	17.9 ± 13.2	15.6 ± 9.4	14.3 ± 10.9	7.1 ± 12.6
T1S–CL (°)	10.4 ± 8.0	11.2 ± 5.4	9.1 ± 8.0	9.5 ± 7.0	9.7 ± 8.6	5.8 ± 8.9

Table 5 The comparison between males and females in sagittal parameters

	Male $N=114$	Female $N=104$	*p* value
Age (year)	46.5 ± 17.6	50.6 ± 16.0	0.072
BMI (kg/m^2)	23.8 ± 3.4	23.5 ± 3.1	0.442
SVA (mm)	− 7.6 ± 29.7	− 12.4 ± 28.0	0.223
TPA (°)	7.0 ± 6.2	8.5 ± 6.3	0.081
GT (°)	9.5 ± 7.6	11.8 ± 7.9	0.035*
SSA (°)	124.4 ± 7.8	125.8 ± 7.4	0.176
C2–7SVA (mm)	16.7 ± 11.4	11.8 ± 9.6	0.001*
CL (°)	12.4 ± 8.1	12.0 ± 8.5	0.765
TK (°)	32.0 ± 11.1	29.1 ± 11.1	0.054
T1S (°)	23.1 ± 6.9	20.3 ± 7.2	0.004*
LL (°)	47.7 ± 10.1	48.7 ± 9.8	0.428
L4–S1 (°)	33.3 ± 7.3	33.7 ± 8.3	0.700
PI (°)	44.5 ± 8.7	48.0 ± 8.5	0.003*
PT (°)	11.9 ± 6.3	14.8 ± 6.8	0.001*
SS (°)	32.3 ± 7.0	32.6 ± 6.8	0.738
PI–LL (°)	− 3.2 ± 8.8	− 0.7 ± 9.7	0.050
LL–TK (°)	15.6 ± 12.1	19.6 ± 11.2	0.013*
T1S–CL (°)	10.7 ± 7.5	8.3 ± 7.8	0.020*

"*" means that $p < 0.05$

the normal sagittal alignment of different races. Endo et al. [14] reported the average values of PI, PT, SS, LL and TK were 46.7°, 13.2°, 34.6°, 43.4° and 27.5°, respectively, in Japanese young adults. Another study showed that the normal values were 47.8° for PI, 11.5° for PT, 36.3° for SS, 49.6° for LL and 32° for TK [13] in Korean population. For Caucasian, Vialle et al. [23] reported PI at 54.7° ± 10.6°, PT at 13.2° ± 6.1°, SS at 41.2° ± 8.4°, LL at 60.2° ± 10.3° and TK at 40.6° ± 10° in asymptomatic adults. Our study measuring PI at 46.2°, PT at 13.3°, SS at 32.4° and LL at 48.2° were in keeping with the results drawn from Asian population, and our values of PI and LL were smaller than those of Caucasian. Han et al. [24] reported that higher PI might be related with the pathogenesis of degenerative lumbar scoliosis, so the higher PI in Caucasian might explain more incidence of sagittal correction surgery. Apart from the classical parameters, the normal values of TPA, GT and SSA were presented at 7.8°, 10.6° and 125.0° in this study, respectively. Another study [25] reported the values to be 8.6° for TPA, which was consistent with our study. Roussouly et al. measured SSA at 134.7° [18], which was larger than our result, and this disagreement might be resulted from the larger PI and correspondingly larger SS of their patients group. With respect to the cervical parameters, we found the normal values to be 12.4° for CL, 16.7 mm for C2–C7SVA and 23.1° for T1S, and these results were keeping in good agreement with previous study [26, 27].

This study also demonstrated the gender differences in sagittal alignment. As shown in Table 5, the females presented a larger PI and PT than the males, while the males presented larger T1S and C2–C7SVA than the females. These findings fitted with previous literatures [11, 14, 26] and should be noticed in coming studies.

In addition, by correlating sagittal parameters to age, we found the age-related changes in sagittal alignment existing in the normal population. As shown in Tables 4 and 6, TPA and GT significantly increased with age, and these relations were even higher than the relations between PT, SVA and age, since TPA and GT incorporated truncal inclination and pelvic retroversion. Meanwhile, increasing age was also accompanied by increasing TK, T1S and CL, which was in common with Iyer's study [11]. Since age-related degeneration also involved in the muscular system [28], the weakness of lumbodorsal muscle might attribute to the increase in TK.

Table 6 The relation of the parameters and age

	SVA	TPA	GT	SSA	C2–7SVA	CL	TK	T1S	LL	PI	PT	SS
TPA	0.485**											
GT	0.487**	0.929**										
SSA	− 0.326**	− 0.196**	− 0.259**									
C2–7SVA	0.130	0.023	0.060	− 0.179**								
CL	0.184**	0.032	0.057	− 0.086	− 0.010							
TK	0.071	0.039	0.062	0.006	0.225**	0.400**						
T1S	0.318**	0.077	0.118	− 0.204**	0.274**	0.509**	0.399**					
LL	− 0.294**	− 0.192**	− 0.217**	0.725**	− 0.021	0.120	0.376**	− 0.013				
PI	0.052	0.573**	0.545**	0.472**	− 0.043	− 0.063	− 0.025	− 0.140*	0.517**			
PT	0.113	0.749**	0.758**	− 0.121	0.000	− 0.023	− 0.070	− 0.051	− 0.149*	0.559**		
SS	− 0.061	− 0.140*	− 0.176**	0.596**	− 0.164*	0.040	− 0.007	− 0.118	0.607**	0.450**	− 0.232**	
Age	0.189**	0.291**	0.291**	− 0.189**	0.111	0.398**	0.475**	0.329**	0.040	0.019	0.163*	− 0.134*

"*" means that $p < 0.05$ and "**" means that $p < 0.01$

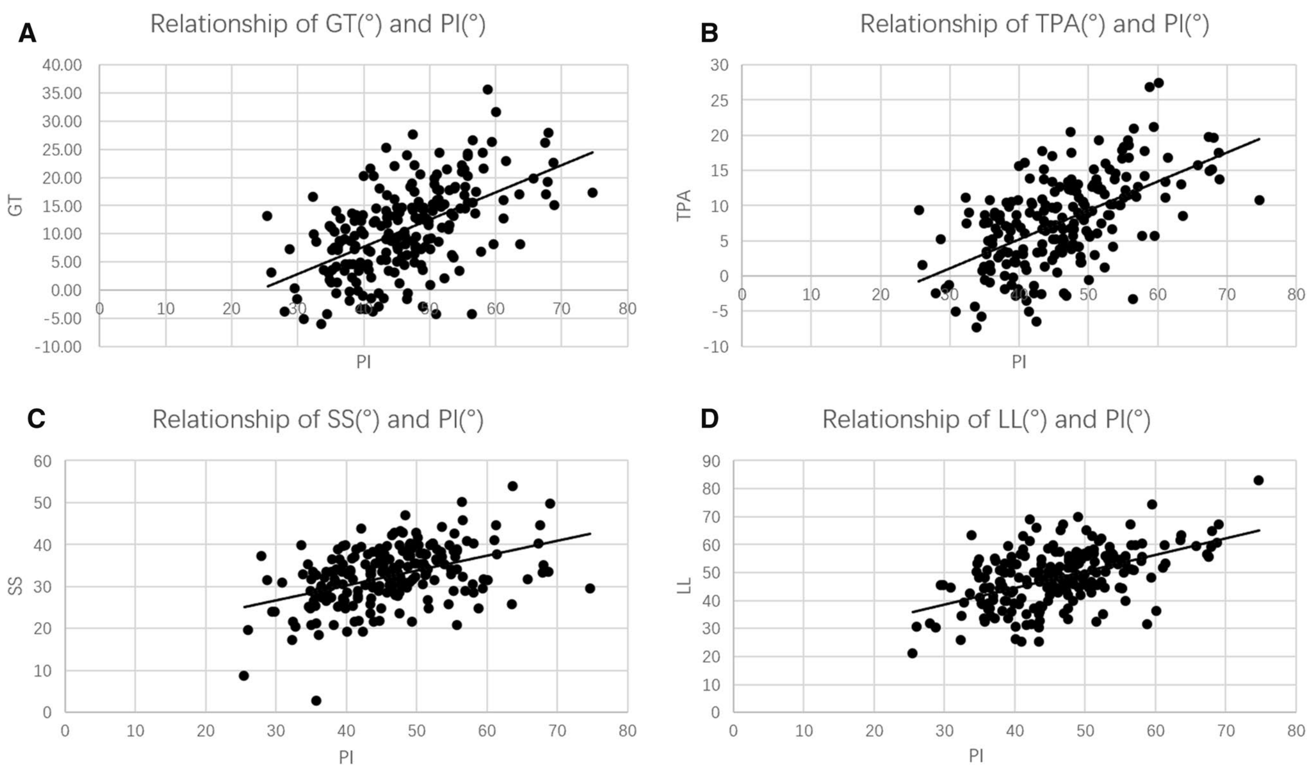

Fig. 3 The relationships between PI and other parameters

Usually, LL decreased with age due to age-related degeneration in lumbar spine. However, in our volunteers group, LL did not significantly decrease with age, and this might be due to the increase in TK compensating for the loss of LL. This finding was consistent with Korovessis [29], who reported that TK increased with age and LL was not age-related. On the other hand, we also found that SVA increased with age due to increased TK and then PT increased to compensate for the increased SVA and rebalance the spine against the aging process, though the differences in SVA and PT among different age groups just approached the borderline of significance.

As proposed by recent research, defining the suitable sagittal alignment for patients should account for age [30]. Since the age-related change in sagittal alignment could be the adaptation to the degeneration of musculoskeletal system in the elderly, the correction goal was not to make the spine as new, but to rebuild it in harmony with the patient's status. Thus, the age-stratified normal values of parameters presented by this study could be the references for planning correction.

In the end, we established the relationships between PI and other parameters. Recently, spine surgeons realized that, for patients with PI near the higher-normal or lower-normal limits, the corrective goals which set the definite values such as PT < 20° [6], TPA < 20° [9] might be mistaken. As presented by Yilgor et al. [4], these parameters should be evaluated in relation to PI, and they proposed that the "relative SS," which is equal to actual SS minus ideal SS (ideal $SS = 0.59 \times PI + 9$, and this equation was drawn by using simple linear regression from the data of asymptomatic population), from − 7° to 5° was aligned. It is the same for relative GT to be aligned from − 7° to 10°. However, the formulas based on other population were not suitable for Chinese population [31], so the relationships presented in this study were important when evaluating the sagittal balance in Chinese population. For example, a patient with PI at 67.4°, PT at 27.3°, SS at 40.1° and GT at 26° could be judged as sagittal imbalance based on previous criteria, but regarding the relationships presented in our study ($GT = 0.483 * PI - 11.7$, $SS = 0.354 * PI + 16.1$), his relative SS and GT was 0.1° and 5.1°, respectively, which should be aligned.

Some limitations still existed in the present study. First, the number of volunteers with age > 70 years was relatively small since many elderly volunteers did not pass our strict inclusion criteria. Second, the radiograph did not include the lower extremities of the subjects. But despite these weakness, our study provided the age- stratified normal values of widely used sagittal parameters for surgeons, which filled the vacancy in data of Chinese population. In addition, the correlations between PI and other parameters established by the present study were useful to better understand the correction strategy.

Conclusion

This study presented the age-stratified normal variations of sagittal parameters in Chinese adult population, comprising new global parameters and cervical parameters. We also investigated the gender differences in sagittal alignment and established the relationships between PI and other parameters. The information provided in the present study could serve as important references for surgeons making corrective plan.

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Compliance with ethical standards

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Affiliations

Siyu Zhou[1,2] · Fei Xu[1,2] · Wei Wang[1,2] · Da Zou[1,2] · Zhuoran Sun[1] · Weishi Li[1]

✉ Weishi Li
puh3liweishi@163.com

1 Orthopaedic Department, Peking University Third Hospital, No. 49 North Garden Road, Haidian District, Beijing 100191, China

2 Peking University Health Science Center, No. 38 Xueyuan Road, Haidian District, Beijing 100191, China