

Characteristics of sagittal spinopelvic alignment in asymptomatic Han Chinese adults

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Abstract. The aim of the present study was to investigate patterns of spine sagittal alignment in asymptomatic patients using radiological analysis. A number of studies focused on investigating normal patterns of spinal and pelvic alignment in Chinese populations, while few have evaluated Caucasian and other Asian populations. A total of 10 relevant pelvic and spinal parameters, including pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), cervical lordosis (CL), thoracic kyphosis (TK), sagittal vertical axis (SVA), lumbopelvic lordosis angle (PR-T12), spino-sacral angle (SSA) and sacral pelvic angle (SPA), were evaluated in asymptomatic Chinese adults from Beijing, aged 21-65 years. Correlations among these parameters, as well as between these parameters and age, and associations with gender and body mass index (BMI) were assessed using Pearson's correlation analysis. A total of 39 males and 46 females, aged 50.9±13.2 and 41.8±13.6 years, respectively, were enrolled in the present study. The results of PI, PT, SS, LL, TK, CL, SVA, PR-T12, SSA and SPA values suggested that age was positively correlated with TK, CL and SVA, while it was negatively correlated with LL, PR-T12 and SSA. SSA and SVA were revealed to differ significantly between sexes. It was also demonstrated that LL and TK may be associated with BMI. In conclusion, the results of the present study indicate that spinopelvic parameters in the asymptomatic Chinese Han population (in Beijing) are correlated with age and may be associated with individuals' ethnicity, sex and BMI. The results of the current study may provide a basis for the restoration of LL or similar diseases.

Introduction

The primary goal of treating adult spinal diseases is to reconstruct the overall balance of the spine, relieve pain symptoms and improve patients' quality of life. The effects of spinopelvic sagittal balance on the prognosis and treatment of adult spinal diseases have been investigated in previous reports (1-3). In the adult body, spinal sagittal balance is not determined solely by spinal sagittal shape; the pelvis is also able to adjust the overall body balance and serves a key role in spinal sagittal balance (1). Clinical studies have demonstrated that there are different characteristic changes to spinopelvic sagittal balance parameters in patients with spine-associated degenerative diseases (1-3). However, little is known about spine-pelvic sagittal balance in asymptomatic adults.

Sagittal plane contour serves a vital role in maintaining a balanced posture with minimum energy expenditure and pain (1-5). A number of important spinopelvic parameters, including pelvic incidence (PI), sacral slope (SS), lumbar lordosis (LL), thoracic kyphosis (TK) and cervical lordosis (CL) are used to evaluate spine and pelvis function (6). A database containing these parameters may be used to estimate the diseased spine and pelvis and may serve as reference for patients with similar spinal diseases (5). However, bias of these parameters for asymptomatic patients exist, therefore, further study with a large sample size is required. Furthermore, studies are often limited by small sample sizes.

A number of studies have been performed assessing the morphology and orientation of the spine and pelvis in asymptomatic adults. These studies covered a wide range of populations, including European Caucasian (7), Japanese (8), Korean (9) and Chinese (10). Together, the results of these studies have suggested that these parameters (PI, SS, LL, TK and CL) are correlated with age, sex and ethnicity, even though normal values fluctuated.

The aim of the present study was to evaluate spinopelvic morphology in asymptomatic Chinese Han patients and to identify correlations between these parameters (PI, SS, LL, TK and CL) and their association with patient characteristics.

Materials and methods

Subjects. A total of 85 asymptomatic Chinese Han volunteers (39 males, 46 females) were enrolled in the present study

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Table I. Measurement methods for spinopelvic parameters.

Spinopelvic parameter	Measurement method
Pelvic incidence	Angle between the line perpendicular to the sacral plate at its midpoint and the line connecting the point to the middle axis of the femoral heads.
Pelvic tilt	Angle between the line connecting the midpoint of the sacral plate to the axis of the femoral heads and the vertical axis.
Sacral slope	Angle between the superior endplate of S1 and a horizontal axis.
Lumbar lordosis	Angle from the upper endplate of L1 to the upper end plate of S1.
Thoracic kyphosis	Angle between the cranial endplate of T4 and the caudal endplate of T12.
Cervical lordosis	Angle between the horizontal plane and the line joining the centre of C7 and the centre of the sacral endplate.
Sagittal vertical axis	Horizontal distance between the C7 plumb line and the posterior superior corner of the superior margin of S1.
Lumbopelvic lordosis angle	Angle between the PR line and a tangent line along the inferior endplate of T12 vertebral body.
Spino-sacral angle	Angle subtended by the upper sacral endplate and the line from the centre of C7 vertebral body to the centre of the upper sacral endplate.
Sacral pelvic angle	Angle between PR line and the line perpendicular to the sacral endplate.

Table II. Basic participant characteristics and measured spinopelvic parameters.

Parameters	Mean	Range	Standard deviation	Standard error	95% Confidence interval
Age (years)	46.0	21-65	14.1	1.53	43.0-49.0
Body mass index (kg/m ²)	21.7	17.3-24.5	1.7	0.19	21.3-22.1
Pelvic incidence (°)	51.1	35-70	8.2	0.89	49.4-52.9
Pelvic tilt (°)	18.5	3-50	8.0	0.86	16.7-20.2
Sacral slope (°)	32.8	20-53	6.3	0.69	31.4-34.2
Lumbar lordosis (°)	36.7	10-58	11.8	1.28	34.1-39.2
Thoracic kyphosis (°)	20.8	1-57	11.3	1.23	18.3-23.2
Cervical lordosis (°)	11.2	0-50	9.7	1.06	9.1-13.3
Sagittal vertical axis (mm)	14.9	-87.0-116.1	39.6	4.35	4.9-22.2
Lumbopelvic lordosis angle (°)	75.6	50-90	9.8	1.07	73.5-77.7
Spino-sacral angle (°)	122.9	105-143	7.8	0.84	121.2-124.6
Sacral pelvic angle (°)	54.3	40-74	7.1	0.77	52.8-55.8

between August 2015 and August 2017 from the Beijing Tiantan Hospital (Beijing, China). The present study was approved by the Ethical Research Committee of Beijing Tiantan Hospital (Beijing, China). All participants provided informed consent. Inclusion criteria were as follows: 21-65 years of age, no prior spinal surgery, no history of lower back pain (except for occasional episodes) for ≥ 6 months prior to participation and no history of hip, pelvic or lower limb disorders. The mean age, weight and height of participants were 46.0 ± 14.1 years, 61.2 ± 8.3 kg, 167.7 ± 8.3 cm, respectively. The body mass index (BMI) of each participant was also calculated and recorded.

Radiography. Whole-body radiographs prior to surgery were taken of each participant, including frontal and left lateral images to cover the full spine and the hip joints (11). Hips and knees were fully extended in both

frontal and left lateral direction (12). As described previously (8-10,13), 10 representative radiographic parameters were assessed: PI, pelvic tilt (PT), SS, LL, TK, CL, sagittal vertical axis (SVA), lumbopelvic lordosis angle (PR-T12), spino-sacral angle (SSA) and sacral pelvic angle (SPA; Fig. 1; Table I). Radiography was performed using the pelvic radius measurement technique (14). Radiographs were stored in a picture archiving communications system (PACS; Concord Technology (Tianjian) Co., Ltd. (Tianjin, China) in Digital Imaging and Communications in Medicine (DICOM) format. Parameters associated with sagittal alignment were measured using the ruler and protractor function in Neusoft PACS (Concord Technology (Tianjian) Co., Ltd.). Radiographs were analyzed by two orthopedic doctors. Using PACS software (Version 6.0; Concord Technology (Tianjian) Co., Ltd.), the inter- and intraobserver reliability were evaluated using inter- and



Figure 1. Measurement methods for spinopelvic parameters. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; CL, cervical lordosis; TK, thoracic kyphosis; SVA, sagittal vertical axis; PR-T12, lumbopelvic lordosis angle; SSA, spino-sacral angle; SPA, sacral pelvic angle.

intraclass correlation coefficients and radiological parameter reliabilities were >0.900 .

Statistical analysis. Data were analyzed using SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). All quantitative data were expressed as the mean \pm standard deviation. An unpaired Student's t-test was performed to compare male and female results. Correlations were evaluated using Pearson's correlation coefficient. The inter- and intraobserver/class correlation coefficients were assessed for angles, levels and distances of parameters. $P<0.05$ was considered to indicate a statistically significant difference.

Results

Clinical data. A total of 39 males and 46 females were enrolled in the present study, with mean ages of 50.9 ± 13.2 and 41.8 ± 13.6 years, respectively. Mean values and 95% confidence intervals of PI, PT, SS, LL, TK, CL, SVA, PR-T12, SSA and SPA, as well as patient characteristics, are presented in Table II.

Ethnic variation between spinopelvic characteristics. The spinopelvic characteristics of patients enrolled in the present study are presented in Table III along with those of other reported populations, including Korean, Japanese, Caucasian and another Chinese Han population (7-10).

Sex differences in spinopelvic parameters. Sex differences in spinopelvic parameters are presented in Table IV. Female participants were observed to have decreased PT, TK and CL values compared with males. In addition, females demonstrated higher values of PI, SS, LL, PR-T12 and SPA, but these differences were not statistically significant. However, SVA and SSA in females were significantly higher than those in males ($P<0.05$).

BMI affects specific spinopelvic parameters. Based on previous studies, a BMI of 22.0 was chosen as a boundary (9,10). A comparison between patients with BMI >22.0 and those with <22.0 is presented in Table V. The results revealed that LL and TK markedly differed between groups. The LL value of patients with a BMI of >22.0 were

Table III. Comparison of Spinopelvic Parameters between Chinese Populations and Caucasian populations.

Author, year	Ethnicity	n	Age (years)	Weight (kg)	BMI (kg/m ²)	PI (°)	PT (°)	SS (°)	LL (°)	TK (°)	(Refs.)
Mac-Thiong <i>et al</i> , 2011	Caucasian	737	36.8 ± 14.3	ND	ND	52.6 ± 10.4	13.0 ± 6.8	39.6 ± 7.9	ND	ND	(7)
Endo <i>et al</i> , 2014	Japanese	86	35.9 ± 11.1	ND	21.4 ± 2.8	46.7 ± 8.9	13.2 ± 8.2	34.6 ± 7.8	43.4 ± 14.6	27.5 ± 9.6	(8)
Lee <i>et al</i> , 2011	Korean	86	28.19	64.05	ND	47.8 ± 9.3	11.5 ± 5.3	36.3 ± 7.8	49.6 ± 9.6	32.0 ± 9.2	(9)
Zhu <i>et al</i> , 2014	Chinese	260	34.3 ± 12.6	59.6 ± 13.2	ND	44.6 ± 11.2	11.2 ± 5.8	32.5 ± 6.5	48.2 ± 9.6	27.8 ± 11.4	(10)
Present study	Chinese	85	46.0 ± 14.1	61.2 ± 8.3	21.7 ± 1.7	51.1 ± 8.2	18.5 ± 8.0	32.8 ± 6.3	36.7 ± 11.8	20.8 ± 11.3	

BMI, body mass index; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; TK, thoracic kyphosis; ND, no data.

Table IV. Sex distribution of spinopelvic parameters.

Parameters	Male (n=39)	Female (n=46)	P-value
Age (years)	50.9±13.2	41.8±13.6	0.0026
Height (cm)	174±4	162±4	0.0000
Weight (kg)	68.7±4.1	54.9±5.0	0.0000
Body mass index (kg/m ²)	22.6±1.1	20.9±1.8	0.0000
Pelvic incidence (°)	50.7±8.9	51.5±7.7	0.6531
Pelvic tilt (°)	19.2±9.0	17.8±7	0.4216
Sacral slope (°)	31.5±5.8	33.9±6.7	0.0822
Lumbar lordosis (°)	35.1±11.8	38.0±11.8	0.2507
Thoracic kyphosis (°)	22.9±13.4	19±8.9	0.1158
Cervical lordosis (°)	12.1±10.2	10.5±9.4	0.4539
Sagittal vertical axis (mm)	25.6±42.5	35.2±3.4	0.0099
Lumbopelvic lordosis angle (°)	73.9±11.4	77.1±8.2	0.1429
Spino-sacral angle (°)	120.8±7.0	124.7±8.0	0.0218
Sacral-pelvic angle (°)	54.4±7	54.3±7.2	0.9364

Table V. Comparison of spinopelvic parameters by BMI.

Parameters	BMI (≤22.0)	BMI (>22.0)
BMI (kg/m ²)	20.1±1.2	23.0±0.7
Pelvic incidence (°)	52.0±7.8	50.4±8.5
Pelvic tilt (°)	18.5±7.1	18.4±8.7
Sacral slope (°)	33.4±6.9	32.3±5.8
Lumbar lordosis (°)	38.8±11.3	34.9±12.1 ^a
Thoracic kyphosis (°)	19.4±11.0	22.0±11.5 ^a
Cervical lordosis (°)	10.9±10.5	11.5±9.1

BMI, body mass index; ^aP<0.05 vs. BMI (≤22.0).

significantly lower than those with a score of <22.0 (P<0.05). Furthermore, patients with a BMI of >22.0 exhibited a significantly higher TK value (P<0.05) compared with those with a BMI of <22.0. However, there no significant differences were identified regarding PI, PT, SS or CL between the two groups.

Correlation between spinopelvic parameters. The correlation matrix for spinopelvic parameters is presented in Table VI. PI was correlated with PT, SS, PR-T12 and SPA. PT was correlated with PI, SS, LL, PR-T12, SSA and SPA. SS was correlated with PI, PT, LL, PR-T12 and SSA. LL was correlated with PT, SS, PR-T12 and SSA. TK and CL were correlated with each other. SVA was correlated with PR-T12. PR-T12 was correlated with PI, PT, SS, LL, SVA, SSA and SPA. SSA was correlated with PT, SS, LL and PR-T12. SPA was correlated with PI, PT and PR-T12.

Age differences in spinopelvic parameters. Correlations between age and spinopelvic parameters are presented in Table VII. Age was positively correlated with TK, CL and SVA, while it was negatively correlated with LL, PR-T12 and

SSA. No significant correlation was observed for age with PI, PT, SS or SPA.

Discussion

A number of studies have reported that PI is an important parameter for determining the shape of sagittal curvature (6,15-17). Studying the corresponding spinopelvic parameters in asymptomatic adults may allow for the development of suitable spinal surgical protocols. These parameters (PI, SS, LL, TK and CL) may aid the understanding of degenerative spine disorders and scoliosis (1-3). LL can be predicted based on preoperative PI and TK (18). Unsuccessful TK restoration may be associated with large preoperative PI and PT (19). A number of studies have focused on normal spinal alignment and evaluated the correlation between spinopelvic parameters (7-10,20). However, a small sample size has often led to the bias of these parameters. Consequently, more data are required to improve prognostic tools.

A total of 85 asymptomatic Chinese Han adults were enrolled in the present study. A series of spinopelvic parameters were measured and it was revealed that the mean value of PI, one of the important parameters that is not affected by gesture or spinal pathology (6), was increased compared with previous reports on Chinese, Korean and Japanese populations (8-10). The PI recorded in the present study was similar to that reported in a paper involving Caucasian participants (7). The mean value for PT was much higher compared with the results of a Caucasian population study and three other Asian population studies (7-10). LL and TK exhibited the opposite tendency; these spinopelvic parameters were decreased in the current study compared with a Caucasian and three Asian populations. SS was comparable with the previous results of these studies (7-10).

One of the major contributing factors affecting the parameters was participant age. Compared with the mean age of 34.3±12.6 years described by Zhu *et al* (10), 35.9±11.1 years

Table VI. Correlation matrix for the spinopelvic parameters.

Parameters	PI	PT	SS	LL	TK	CL	SVA	PR-T12	SSA	SPA
PI	1									
PT	0.690 ^b	1								
SS	0.426 ^b	-0.349 ^b	1							
LL	0.178	-0.244 ^a	0.534 ^b	1						
TK	-0.019	-0.009	0	0.078	1					
CL	-0.002	0.042	-0.039	-0.025	0.272 ^a	1				
SVA	0.094	0.014	0.112	-0.161	0.211	0.023	1			
PR-T12	-0.322 ^b	-0.641 ^b	0.394 ^b	0.510 ^b	0.047	-0.007	-0.273 ^a	1		
SSA	0.053	-0.277 ^a	0.406 ^b	0.486 ^b	-0.053	-0.157	-0.209	0.311 ^b	1	
SPA	0.675 ^b	0.544 ^b	0.199	0.203	0.064	-0.004	0.089	-0.278 ^a	0.016	1

^aP<0.05 and ^bP<0.01. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; CL, cervical lordosis; TK, thoracic kyphosis; SVA, sagittal vertical axis; PR-T12, lumbopelvic lordosis angle; SSA, spino-sacral angle; SPA, sacral pelvic angle.

Table VII. Pearson correlation between spinopelvic parameters and age.

Parameters	Coefficient	P-value
Pelvic incidence (°)	0.105	0.337
Pelvic tilt (°)	0.116	0.290
Sacral slope (°)	0.018	0.868
Lumbar lordosis (°)	-0.251	0.020
Thoracic kyphosis (°)	0.225	0.039
Cervical lordosis (°)	0.180	0.098
Sagittal vertical axis (mm)	0.459	0.000
Lumbopelvic lordosis angle (°)	-0.296	0.006
Spino-sacral angle (°)	-0.222	0.041
Sacral pelvic angle (°)	-0.016	0.888

reported by Endo *et al* (8) and 28.2 reported by Lee *et al* (9), participants in the current study had a mean age of 46.0±14.1 years. Several recent studies have demonstrated that sagittal spinopelvic alignment varies with age and that these parameters (PI, SS, LL, TK and CL) gradually deteriorate with age (21-23). A weak correlation was observed between age and spinopelvic parameters by Mac-Thiong *et al* (7), while Zhu *et al* (10) reported that PT significantly increased with age. Hamerberg and Wood (24) demonstrated that there was no association between age and spinopelvic parameters. The current study suggested that age was positively correlated with TK, CL and SVA, while negatively correlated with LL, PR-T12 and SSA. SS was suggested to be independent of age. These results suggest that age should be taken into consideration prior to establishing a surgical plan for patients with spinal deformities.

Ethnicity was reported to be associated with sagittal parameters of the spine in several studies (9,10,25-27). When comparing the results of the current study with previous reports of Asian and Caucasian populations, SS was found to have an association with ethnicity. The mean value of SS

in the current study was 32.8±6.3°, which is similar to that reported for a Japanese (34.6±7.8°) (8), Korean (36.3±7.8°) (9) and other Chinese (32.5±6.5°) (10) populations, but decreased compared with the SS reported for a Caucasian population (39.6±7.9°) (7). These findings were consistent with the data reported by Zhu's *et al* (10). For patients with spinal deformities, ethnicity may be considered an important factor for the selection of the appropriate treatment strategy.

The sex distribution of spinopelvic parameters was evaluated. SS and PI were significantly influenced by sex as suggested by Vialle *et al* (12) and Vira *et al* (28), who reported that men exhibit increased knee flexion and women exhibit increased pelvic tilt and hip extension. Janssen *et al* (29) and Zhu *et al* (10) reported no significant differences in SS, PT and PI between males and females. In the present study, it was determined that SSA and SVA were significantly different in males compared with females.

The effect of BMI on spinopelvic parameters was further evaluated. It was suggested that LL and TK may be associated with BMI, while other parameters exhibited no association. Individual physiological characters, including sex and BMI, may be considered as effectors of spinopelvic parameters.

Associations between spinopelvic parameters were evaluated. PI was considered to be the most important factor among all parameters. It was concluded that PI was associated with SSA, PR-T12, PT and SPA. This suggests that PI measurement may be substituted with SSA, PR-T12 or SPA measurements, as these parameters are more convenient to measure and may make the evaluation more objective.

To the best of the authors' knowledge, there have been several studies on the sagittal alignment of the spine and pelvis in asymptomatic adults, conducted in various countries and suggesting various correlations between parameters (7-10,20). In the present study, it was suggested that age was positively correlated with TK, CL and SVA, while it was negatively correlated with LL, PR-T12 and SSA. SSA and SVA were significantly different in males compared with females, while other spinopelvic parameters exhibited no significant differences. LL and TK were suggested to potentially be associated with BMI, while other parameters did not appear

to be correlated with BMI. The results of the present study are comparable with those of previous studies and different in others. However, the results may offer significant qualitative and quantitative references for treating patients with spinal degenerative diseases.

The present study was not without limitations. For instance, the study size was too small and so was not representative of the general population. Furthermore, although participants were screened in compliance with the outlined rules, data obtained from certain individuals did not fall within the expected ranges. Future studies should recruit a wider range of participants to improve the results.

In summary, the present study suggests that certain spino-pelvic parameters are correlated with age, while others may be associated with ethnicity, sex and BMI. These results may provide a surgical reference for restoring LL or similar diseases.

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Availability of data and materials

All data generated or analyzed during the present study are included in this published article.

Authors' contributions

ZZ and YH designed and planned the study. YB collected the data. BW analyzed the data and performed statistical analyses. ML and YL helped with data interpretation. ZZ prepared the manuscript and YL performed a literature analysis. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The present study was approved by the Ethics Committee of Beijing Chaoyang Hospital (Beijing, China). Written informed consent was obtained from the participants.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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