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Investigation of spinopelvic sagittal alignment and its correlations in asymptomatic pediatric populations

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The sagittal alignment of the cervical spine and its relationship with spinopelvic parameters plays a crucial role in maintaining overall postural balance. This study aims to provide normative values for these parameters in asymptomatic pediatric subjects, aiding in the enhancement of treatment and evaluation strategies for spinal deformities and disorders. Conducted at the Third Hospital of Hebei Medical University, this retrospective study included 307 asymptomatic pediatric volunteers aged 4–18 years, screened for scoliosis from January 2021 to July 2023. Participants underwent whole-length EOS examinations following a standard protocol. Radiographic measurements of cervical and spinopelvic parameters were taken, and statistical analyses were performed using SPSS software to assess variations by age and gender. Normative values for cervical sagittal and spinopelvic parameters were established, demonstrating significant differences based on age and sex. Key findings include a strong correlation between the C2-7 Cobb angle and T1 and C7 slopes, with an observed increase in cSVA particularly pronounced in boys. Age and gender significantly influenced the normative values of these parameters, suggesting the importance of considering these factors in pediatric spinal assessments. This study establishes crucial normative values for cervical and spinopelvic parameters in a large pediatric cohort, highlighting the influence of age and sex on spinal sagittal alignment. The findings underscore the necessity of tailoring spinal assessment approaches in pediatric populations to improve the clinical evaluation and management of spinal health, providing a foundational benchmark for future research in pediatric spinal deformities and disorders.

Keywords Cervical spine alignment, Pediatric spinal health, Spinopelvic parameters, Sagittal balance, Scoliosis screening

The cervical spine, a crucial segment known for its high mobility, plays a vital role in maintaining horizontal gaze and whole-body balance[1,2]. It is recognized that the sagittal alignment of the cervical spine is essential in linking the cervical vertebrae, both at local and regional levels, to ensure an economical equilibrium, with the T1 slope (T1S) being a fundamental determinant of this balance[3–6]. As a morphological parameter, T1S not only delineates the position of the thorax but also serves as a critical junctional parameter that bridges the cervical and thoracic spine[7,8]. Perturbations in cervical balance have notable implications, adversely impacting clinical outcomes in patients with conditions like cervical compressive myelopathy and spinal deformities[9–11]. Consequently, restoring and maintaining optimal cervical spine alignment is a primary goal in both surgical and conservative management approaches, including physical therapy, chiropractic care, and other therapeutic interventions[12–18].

In cases of adolescent idiopathic scoliosis, deformities in the coronal plane are known to influence the sagittal alignment of the cervical spine[19]. Surgical interventions aimed at correcting scoliosis have a significant impact on cervical spine balance in the sagittal plane, with some studies reporting complications arising from cervical imbalance post-operation[20–22].

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Pelvic parameters also change with growth[23]. Abnormal pelvic incidence may result in a sagittal imbalance of the spine, potentially giving rise to spinal pathologies[24,25]. Given these complexities, understanding the typical sagittal sequence of the sagittal spine in pediatric populations becomes imperative for improving both treatment and evaluation strategies. However, there's a noticeable scarcity of research providing normative values for spinopelvic sagittal balance parameters, particularly for the cervical spine and pelvic region, in large pediatric cohorts.

Therefore, this observational study aims to investigate the normal distribution of spinopelvic sagittal alignment and explore its relationship with global spinal balance in asymptomatic pediatric subjects.

Materials and methods
Study population
This retrospective study encompasses asymptomatic pediatric participants who underwent medical evaluation for scoliosis screening at the Outpatient Spinal Surgery Department of the Third Hospital of Hebei Medical University from January 2021 to July 2023. The term 'asymptomatic' was used specifically to indicate the absence of clinical symptoms or complaints, which describes our study population following our comprehensive screening. This is different from 'healthy', which could suggest a broader, more generalized state. Ethical approval and consent to participate in this study was approved by the ethics committee of the Third Hospital of Hebei Medical University (K2022-067-1).

Inclusion criteria
All participants and their legal guardians received comprehensive information about the clinical trial protocol. Written informed consent was obtained from legal guardians prior to enrollment. Study participants met the following criteria: (1) age below 18 years; (2) ability to independently maintain standing position for radiographic examination; (3) no radiological evidence of scoliosis (Cobb angle < 10°) on whole-length EOS imaging; and (4) normal findings on detailed physical examination with no evidence of spinal deformity.

Exclusion criteria
Participants were excluded if they met any of the following criteria: (1) history of spinal surgery, trauma, or infection; (2) presence of congenital spinal abnormalities or transitional vertebral malformations; (3) current or chronic headaches requiring medical intervention; (4) current or chronic neck or back pain requiring medical intervention; (5) history of neurological disorders affecting posture; (6) history of musculoskeletal disorders; (7) systemic diseases affecting bone or muscle development; (8) participation in contact sports or high-impact athletic activities; (9) reported excessive use of electronic devices (> 4 h daily); or (10) any other condition that could affect normal spinal alignment or posture.

All procedures performed in this study adhered to the Declaration of Helsinki, and all methods were performed following institutional and national regulations. Height, weight and other personal information were not included in the current analysis. Only age and gender were documented.

Radiographic measurements and data collection
In our hospital, full-length X-rays of the entire body were captured with patients standing in a natural, upright position, their hands on clavicle, and eyes looking straight ahead to minimize errors caused by head movement. The imaging covered from the base of the skull to the soles of the feet[26–29]. EOS imaging examination is guided by senior radiologic technician Zuzhuo Zhang. All data were saved, extracted, and measured through the Surgimap software (Nemaris, Inc., New York, NY, USA).

Radiographic parameters included (The detailed measurement method is shown in Fig. 1):

Overall parameters
C7-S1 Sagittal Vertical Axis (C7-S1 SVA), the horizontal shift from a plumb line drawn from C7 center to S1 posterosuperior corner[30,31]. If the center of mass of C7 is in front of the posterior upper corner of the S1 vertebral body, SVA is a positive value, otherwise it is recorded as a negative value.

T1 Pelvic Angle (T1PA): the angle formed by a line extending from the femoral heads to the center of the T1 vertebral body and the vertical line[32,33].

T1 Spinopelvic inclination (T1SPI): the angle formed by a line extending from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral endplate[34,35].

Local parameters:

C2–7 Sagittal Vertical Axis (cSVA): distance from a plum line through the C2 center to the poster upper endplate of C7 C2 center is indicated as a positive value before the poster upper endplate of C7[36,37].

The C2-7 Cobb: calculated from perpendicular lines drawn from the inferior endplates of C2 and C7[38].

C0-2 Cobb (O-C2): Cobb angle between McGregor's line (line between the hard palate and the opisthion) and C2 inferior end plate[39,40].

Chin Brow Vertical Angle (CBVA): an angle corresponding to the line connecting the eyebrow arch to the mandible and the vertical line passing through the eyebrow arch[41,42]. If the center of the eyebrow is in front of the mandible, it is recorded as a positive value, otherwise it is recorded as a negative value.

T1 Slope (T1S) and C7 Slope (C7S): measure the inclination of the upper thoracic spine and C7 vertebra, respectively[43–45].

lumbar lordosis (LL) and Thoracic Kyphosis (TK): are measured from the superior endplates of L1 to S1 for LL, and T5 to T12 for TK, using the Cobb method[46–49].

Spinopelvic parameters:

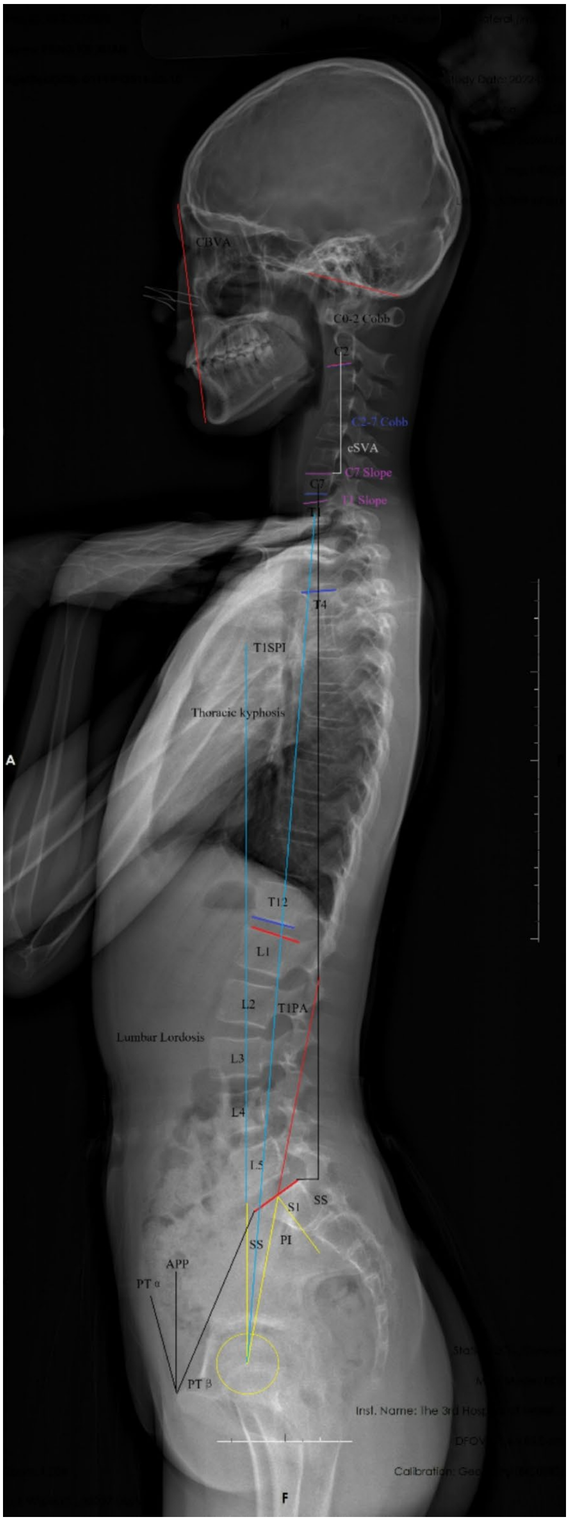

Fig. 1. Detailed measurements of spinopelvic parameters.

Pelvic Tilt (PT): the angle between the vertical line originating at the center of the femur heads and the line drawn between the same point and the middle of the superior endplate of S1. If the midpoint of the upper endplate of S1 is behind the center of the femoral head, it is recorded as a positive value; otherwise, it is recorded as a negative value. Sacral Slope (SS): angle between the superior endplate of S1 and the horizontal line. indicating sacral endplate inclination. Pelvic Incidence (PI): the angle formed by the line at a right angle to the superior endplate of S1 at its middle point and the line connecting this point to the axis linking the bilateral femoral heads[50–52].

Pelvic Tilt α (APPA): angle between the vertical line and the sagittal projection of the anterior pelvic plane, defined as the line connecting the pubic tubercles to the anterior superior iliac spine[53]. If the anterior superior iliac spine is in front of the pubic symphysis, it will be recorded as a negative value, and if it is in front of the pubic symphysis, it will be recorded as a positive value.

Pelvic Tiltβ (PSA): angle between the horizontal line and the line connecting the pubic tubercles to the sacral promontory[54].

The age groupings were based on prior studies such as Gutman et al. (2016)[55], and Zhou et al. (2020)[56], who divided pediatric populations into stages corresponding to key growth milestones. These groupings capture distinct periods of spinal development, facilitating the analysis of changes in spinopelvic parameters. In this study, 9 participants were between 4 and 6 years, 50 participants between 7 and 9 years, 84 participants were between 10 and 12 years, 104 participants were between 13 and 15 years, 60 participants between 16 and 18 years. And another group was divided based on PT values.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA) and Microsoft Excel (Microsoft Corp., Redmond, WA, USA). Continuous variables are presented as mean ± standard deviation (SD). The normality of data distribution was assessed using the Kolmogorov-Smirnov test. Between-group comparisons were conducted using independent Student's t-tests for two-group comparisons and one-way analysis of variance (ANOVA) for multiple group comparisons. When ANOVA showed significant differences, post-hoc analyses were performed using Bonferroni correction for multiple comparisons. Relationships between spinopelvic parameters were evaluated using Pearson's correlation coefficient (r). Statistical significance was set at $p < 0.05$, and all tests were two-tailed.

A post-hoc power analysis was conducted using G*Power 3.1 software to determine the statistical power of our study with 307 participants. Based on an alpha level of 0.05, a medium effect size (d = 0.5), and our sample size of 307 participants, the calculated power was 0.99 for detecting differences between age groups and gender comparisons. This indicates that our study had sufficient statistical power to detect meaningful differences in spinopelvic parameters.

Results

In this study, we enrolled 307 asymptomatic pediatric volunteers, consisting of 167 males (54.4%) and 140 females (45.6%), aged between 4 and 18 years, with an average age of 12.49 years. Post-hoc power analysis revealed that with our sample size of 307 participants (167 males, 140 females), the study achieved 99% power to detect significant gender differences and 95% power to detect age-related variations in spinopelvic parameters at an alpha level of 0.05. For correlation analyses between cervical and global spine parameters, the study achieved 98% power to detect moderate correlations ($r \geq 0.3$).

The distribution of radiographic parameters is detailed in Table 1. The average cervical sagittal parameters were as follows: -24.95 ± 7.80° for C0-2 Cobb, -10.31 ± 9.56° for C2–7 Cobb, 6.17 ± 6.42° for CBVA, 17.66 ± 8.39° for C7S, 20.62 ± 8.49° for T1S, and 18.13 ± 11.69 mm for C2–7 SVA. The average values for thoracic kyphosis (TK) and lumbar lordosis (LL) were 30.28 ± 10.25° and − 45.23 ± 11.23°, respectively. Spinopelvic parameters averaged as follows: 38.54 ± 9.91° for PI, 7.35 ± 8.81° for PT, 31.25 ± 8.24° for SS, -2.55 ± 9.18° for APPA, 67.91 ± 9.34° for PSA, -2.90 ± 3.75° for T1SPI, 4.20 ± 7.10° for T1PA, and 2.89 ± 24.64 mm for C7-S1 SVA. Figure 2 illustrates age-related variations across multiple correlated parameters.

Cervical parameters

C0-2 Cobb angle

A significant variance across age groups was observed (-23.4 ± 7.4°, -24.3 ± 8.5°, -26.7 ± 5.7°, -24.1 ± 6.8°, and − 28.1 ± 6.6°; $p = 0.012$), particularly in males ($p = 0.015$). Differences between boys and girls were not significant in any age group.

C2-7 Cobb Angle:

A significant variance across age groups was noted (-11.4 ± 7.3°, -13.7 ± 11.2°, -16.0 ± 8.0°, -8.4 ± 8.8°, and − 9.3 ± 6.2°; $p = 0.024$). Gender differences were significant across the entire dataset ($p = 0.005$).

CBVA

Significant variance was observed across age groups (10.1 ± 7.8°, 7.8 ± 7.5°, 10.9 ± 3.6°, 5.6 ± 6.4°, and 3.8 ± 4.0°; $p = 0.0012$), especially in males ($p = 0.024$). Gender differences were significant overall ($p < 0.001$).

cSVA

Significant age group variance was found (17.5 ± 6.5°, 13.5 ± 7.1°, 13.5 ± 5.3°, 19.3 ± 8.2°, and 21.9 ± 20.0°; $p = 0.0023$), particularly in males ($p = 0.001$). Differences between boys and girls were not significant within any age group.

C7S

Age group variance was significant (18.9 ± 7.5°, 19.8 ± 9.3°, 23.6 ± 7.6°, 15.9 ± 8.0°, and 19.6 ± 6.1°; $p = 0.015$), especially in females ($p = 0.036$). Gender differences were significant overall ($p = 0.014$).

T1S

Significant variance across age groups was found (17.1 ± 5.5°, 21.4 ± 9.8°, 24.5 ± 6.8°, 19.4 ± 8.1°, and 23.6 ± 7.0°; $p = 0.02$), particularly in females ($p = 0.028$). Notable gender differences in Group A (aged 4–6 years) were

Parameter	Sex	4–6 years old A (N=9)	7–9 years old B (N=51)	10–12 years old C (N=84)	13–15 years old D (N=104)	16–18 years old E (N=60)	All	ANOVA
APPA	Male	− 16.0 ± 5.1	− 1.1 ± 10.5	0.3 ± 11.2	− 1.1 ± 9.1	− 3.1 ± 8.9	− 2.64 ± 9.43	0.151
	Female	− 2.8 ± 13.7	− 2.7 ± 11.3	2.1 ± 9.8	− 2.1 ± 8.1	− 4.8 ± 4.4	− 2.46 ± 8.92	0.674
	P	0.015*	0.747	0.707	0.798	0.597	0.240	
	All	− 5.7 ± 13.4	− 1.8 ± 10.8	1.2 ± 10.5	− 1.6 ± 8.6	− 3.8 ± 7.4	− 2.55 ± 9.18	0.460
PSA	Male	77.1 ± 2.3	69.3 ± 8.7	72.5 ± 6.1	67.9 ± 7.0	65.6 ± 8.5	68.73 ± 8.48	0.028*
	Female	74.5 ± 8.1	64.2 ± 21.6	70.4 ± 7.5	66.3 ± 6.0	64.6 ± 3.8	66.90 ± 10.23	0.076
	P	0.351	0.502	0.501	0.590	0.740	0.071	
	All	75.1 ± 7.2	67.0 ± 15.8	71.4 ± 6.8	67.1 ± 6.6	65.2 ± 7.0	67.91 ± 9.34	0.0034*
SS	Male	36.8 ± 2.8	27.0 ± 7.5	32.4 ± 8.2	33.1 ± 8.7	29.9 ± 5.3	31.99 ± 7.87	0.001*
	Female	34.4 ± 9.8	29.3 ± 9.6	34.1 ± 6.8	29.1 ± 7.7	26.5 ± 4.6	30.41 ± 8.64	0.003*
	P	0.473	0.558	0.620	0.291	0.143	0.089	
	All	34.9 ± 8.6	28.0 ± 8.5	33.2 ± 7.5	31.2 ± 8.4	28.5 ± 5.3	31.25 ± 8.24	0.00011*
PT	Male	3.4 ± 1.5	6.5 ± 7.6	12.8 ± 5.4	7.3 ± 7.7	7.2 ± 9.1	6.10 ± 8.00	0.226
	Female	3.8 ± 8.0	6.8 ± 10.8	11.9 ± 4.6	11.0 ± 11.7	11.6 ± 3.9	8.87 ± 9.51	0.044*
	P	0.880	0.944	0.693	0.416	0.185	0.009*	
	All	3.7 ± 6.9	6.6 ± 9.0	12.3 ± 5.0	9.0 ± 9.9	8.9 ± 7.7	7.35 ± 8.81	0.010*
PI	Male	40.1 ± 4.2	33.6 ± 7.8	45.2 ± 6.3	40.2 ± 10.6	37.0 ± 10.3	38.12 ± 9.93	0.088
	Female	38.8 ± 10.9	35.6 ± 9.2	46.1 ± 5.7	39.7 ± 11.6	38.1 ± 2.4	39.13 ± 9.87	0.384
	P	0.731	0.607	0.742	0.921	0.749	0.231	
	All	39.1 ± 9.6	34.5 ± 8.4	45.6 ± 6.0	39.9 ± 11.0	37.5 ± 8.1	38.54 ± 9.91	0.050*
LL	Male	− 59.1 ± 4.8	− 41.4 ± 11.0	− 47.9 ± 10.4	− 48.4 ± 9.9	− 39.9 ± 7.9	− 46.24 ± 10.02	< 0.001*
	Female	− 50.3 ± 13.9	− 43.1 ± 15.1	− 49.2 ± 8.3	− 43.1 ± 13.2	− 39.0 ± 6.0	− 44.05 ± 12.48	0.054
	P	0.085	0.777	0.761	0.324	0.778	0.052	
	All	− 52.2 ± 12.8	− 42.2 ± 12.8	− 48.5 ± 9.3	− 46.0 ± 11.8	− 39.5 ± 7.1	− 45.23 ± 11.23	< 0.001*
TK	Male	31.8 ± 8.2	30.3 ± 9.1	25.6 ± 7.3	32.3 ± 10.1	32.5 ± 9.8	31.81 ± 10.05	0.922
	Female	28.4 ± 9.2	28.9 ± 10.7	27.4 ± 6.1	29.0 ± 9.4	28.0 ± 5.7	28.44 ± 10.26	0.987
	P	0.395	0.756	0.557	0.459	0.229	0.029*	
	All	29.2 ± 8.6	29.7 ± 9.8	26.5 ± 6.7	30.7 ± 9.9	30.7 ± 8.6	30.28 ± 10.25	0.945
T1S	Male	12.2 ± 7.8	22.2 ± 7.5	25.4 ± 6.2	20.5 ± 8.2	22.8 ± 6.9	21.34 ± 8.18	0.348
	Female	18.5 ± 4.4	20.5 ± 12.2	23.6 ± 7.4	18.1 ± 7.9	24.8 ± 7.0	19.74 ± 8.81	0.028*
	P	0.043*	0.713	0.563	0.514	0.528	0.040*	
	All	17.1 ± 5.5	21.4 ± 9.8	24.5 ± 6.8	19.4 ± 8.1	23.6 ± 7.0	20.62 ± 8.49	0.020*
C7S	Male	13.1 ± 11.7	21.2 ± 7.7	24.3 ± 8.4	16.7 ± 7.7	18.6 ± 5.7	18.19 ± 8.10	0.185
	Female	20.5 ± 6.2	18.1 ± 11.0	22.9 ± 6.9	14.9 ± 8.2	21.1 ± 6.5	16.98 ± 8.73	0.036*
	P	0.099	0.476	0.689	0.619	0.373	0.014*	
	All	18.9 ± 7.5	19.8 ± 9.3	23.6 ± 7.6	15.9 ± 8.0	19.6 ± 6.1	17.66 ± 8.39	0.015*
cSVA	Male	12.9 ± 8.3	11.6 ± 7.3	14.2 ± 5.9	19.8 ± 9.6	25.6 ± 24.2	18.31 ± 14.29	0.001*
	Female	18.8 ± 6.0	15.8 ± 6.2	12.8 ± 4.7	18.7 ± 6.3	16.2 ± 8.9	17.91 ± 7.63	0.425
	P	0.087	0.183	0.565	0.766	0.273	0.983	
	All	17.5 ± 6.5	13.5 ± 7.1	13.5 ± 5.3	19.3 ± 8.2	21.9 ± 20.0	18.13 ± 11.69	0.0023*
C2-7 Cobb	Male	− 9.1 ± 5.9	− 14.6 ± 12.6	− 15.8 ± 7.6	− 9.6 ± 7.8	− 10.7 ± 7.1	− 11.43 ± 9.96	0.186
	Female	− 12.1 ± 8.0	− 12.7 ± 9.4	− 16.2 ± 8.3	− 6.9 ± 9.7	− 7.4 ± 3.9	− 8.94 ± 8.94	0.088
	P	0.354	0.707	0.912	0.502	0.219	0.005*	
	All	− 11.4 ± 7.3	− 13.7 ± 11.2	− 16.0 ± 8.0	− 8.4 ± 8.8	− 9.3 ± 6.2	− 10.31 ± 9.56	0.024*
C0-2 Cobb	Male	− 19.6 ± 7.5	− 24.0 ± 8.2	− 26.3 ± 5.4	− 23.7 ± 6.9	− 28.4 ± 6.9	− 24.74 ± 7.58	0.015*
	Female	− 24.5 ± 7.5	− 24.6 ± 9.1	− 27.1 ± 6.0	− 24.6 ± 6.8	− 27.8 ± 6.2	− 25.23 ± 8.09	0.576
	P	0.161	0.879	0.758	0.772	0.840	0.833	
	All	− 23.4 ± 7.4	− 24.3 ± 8.5	− 26.7 ± 5.7	− 24.1 ± 6.8	− 28.1 ± 6.6	− 24.95 ± 7.80	0.012*
CBVA	Male	12.9 ± 2.2	7.0 ± 8.7	10.7 ± 3.9	3.8 ± 6.1	2.9 ± 3.3	4.75 ± 6.36	0.024*
	Female	9.3 ± 8.8	8.9 ± 5.8	11.2 ± 3.4	7.5 ± 6.3	5.2 ± 4.6	7.82 ± 6.12	0.146
	P	0.238	0.574	0.763	0.199	0.217	< 0.001*	
	All	10.1 ± 7.8	7.8 ± 7.5	10.9 ± 3.6	5.6 ± 6.4	3.8 ± 4.0	6.17 ± 6.42	0.0012*
Continued								

Parameter	Sex	4–6 years old	7–9 years old	10–12 years old	13–15 years old	16–18 years old	All	ANOVA
		A (*N* = 9)	B (*N* = 51)	C (*N* = 84)	D (*N* = 104)	E (*N* = 60)		
SVA	Male	− 19.0 ± 20.1	− 0.2 ± 17.8	2.1 ± 19.2	5.1 ± 31.4	24.0 ± 15.8	5.40 ± 26.37	< 0.001*
	Female	5.3 ± 10.6	− 3.8 ± 18.0	3.5 ± 17.3	− 3.4 ± 25.0	3.2 ± 16.3	− 0.09 ± 22.23	0.522
	P	0.005*	0.658	0.866	0.512	0.010*	0.099	
	All	− 0.1 ± 15.8	− 1.8 ± 17.8	2.8 ± 18.2	1.1 ± 28.8	15.7 ± 18.9	2.89 ± 24.64	0.00029*
T1SPI	Male	− 5.5 ± 3.9	− 3.6 ± 2.7	− 1.8 ± 4.2	− 2.5 ± 4.4	− 0.3 ± 3.0	− 2.51 ± 3.67	< 0.001*
	Female	− 2.2 ± 2.5	− 4.0 ± 3.1	− 2.1 ± 3.8	− 3.8 ± 3.8	− 4.3 ± 1.5	− 3.36 ± 3.83	0.117
	P	0.039*	0.762	0.869	0.489	0.002*	0.008*	
	All	− 2.9 ± 2.9	− 3.8 ± 2.8	− 1.9 ± 4.0	− 3.1 ± 4.2	− 1.9 ± 3.2	− 2.90 ± 3.75	0.137*
T1PA	Male	− 2.8 ± 5.8	4.0 ± 6.4	6.7 ± 6.3	4.1 ± 8.1	5.4 ± 6.1	3.65 ± 7.43	0.150
	Female	2.1 ± 7.0	1.7 ± 8.0	5.9 ± 5.1	5.5 ± 6.1	6.8 ± 4.2	4.88 ± 6.66	0.086
	P	0.106	0.487	0.759	0.668	0.558	< 0.001*	
	All	1.0 ± 6.7	3.0 ± 7.2	6.3 ± 5.7	4.8 ± 7.2	6.0 ± 5.4	4.20 ± 7.10	0.063

Table 1. Shows the distribution of radiographic parameters within the five groups in terms of age. Difference between sex within the five groups also exhibited. *$p < 0.05$ indicates that the difference is statistically significant. Negative values for LL, C2-7 Cobb and C0-2 Cobb indicate lordosis, positive values indicate kyphosis.

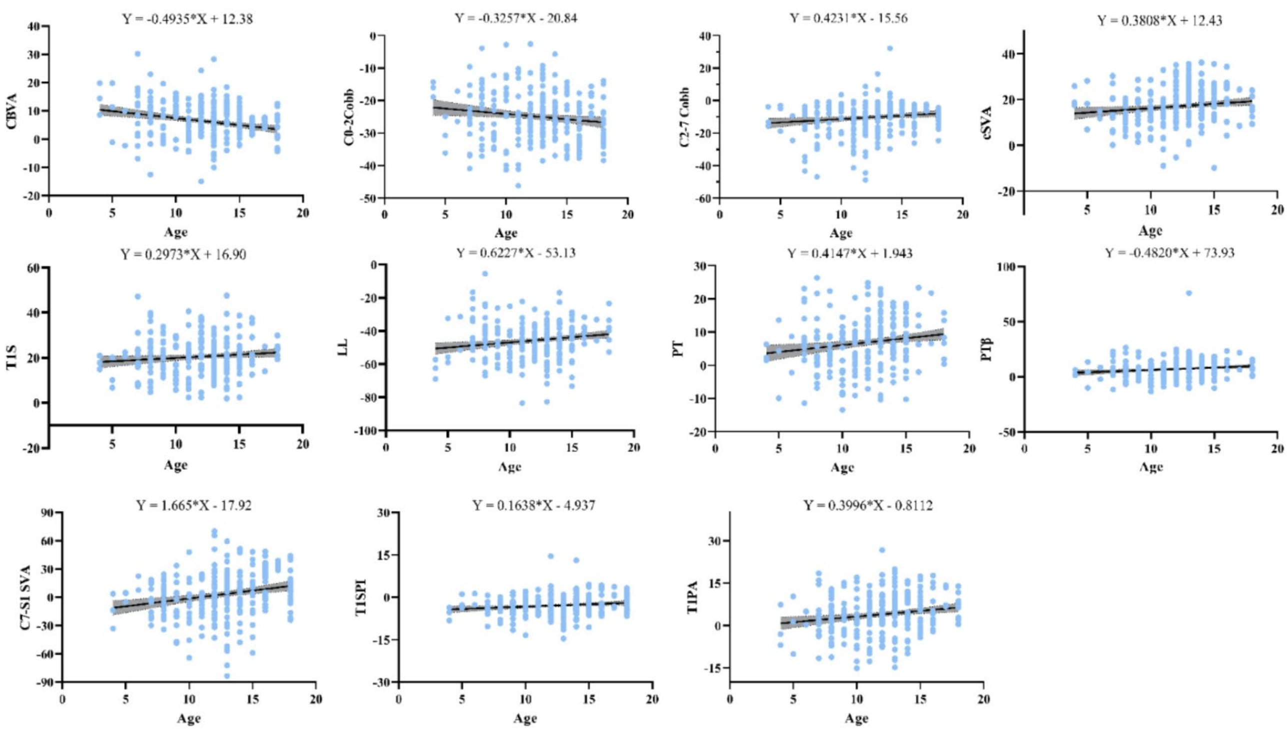

Fig. 2. Variations in multiple parameters correlated with age.

observed, with males exhibiting higher T1S (12.2 ± 7.8° for males vs. 18.5 ± 4.4° for females; $p = 0.043$). Overall, gender differences were significant ($p = 0.04$).

Thoracic and lumbar parameters

Thoracic kyphosis (TK)
No significant variance across age groups was observed (29.2 ± 8.6°, 29.7 ± 9.8°, 26.5 ± 6.7°, 30.7 ± 9.9°, and 30.7 ± 8.6°; $p = 0.945$). However, gender differences were significant overall ($p = 0.029$).

Lumbar lordosis (LL)
Significant variance was observed across age groups (-52.2 ± 12.8°, -42.2 ± 12.8°, -48.5 ± 9.3°, -46.0 ± 11.8°, and − 39.5 ± 7.1°; $p < 0.001$), especially in males ($p < 0.001$). Differences between boys and girls were not significant in any age group.

Spinopelvic parameters

Sacral slope (SS)

Significant variance across age groups was observed (34.9 ± 8.6°, 28.0 ± 8.5°, 33.2 ± 7.5°, 31.2 ± 8.4°, and 28.5 ± 5.3°; $p = 0.00011$), significant in both males ($p = 0.001$) and females ($p = 0.003$). Differences between boys and girls were not significant in any age group.

Pelvic Tilt (PT)

Significant variance across age groups was found (3.7 ± 6.9°, 6.6 ± 9.0°, 12.3 ± 5.0°, 9.0 ± 9.9°, and 8.9 ± 7.7°; $p = 0.01$), particularly in females ($p = 0.044$). Overall gender differences were significant ($p = 0.009$).

Pelvic incidence (PI)

Age group variance was significant (39.1 ± 9.6°, 34.5 ± 8.4°, 45.6 ± 6.0°, 39.9 ± 11.0°, and 37.5 ± 8.1°; $p = 0.05$). Differences between boys and girls were not significant in any age group.

APPA

No significant variance across age groups was observed (-5.7 ± 13.4°, -1.8 ± 10.8°, 1.2 ± 10.5°, -1.6 ± 8.6°, and − 3.8 ± 7.4°; $p = 0.46$). Differences between boys and girls were not significant in any age group.

PSA

Significant variance across age groups was found (75.1 ± 7.2°, 67.0 ± 15.8°, 71.4 ± 6.8°, 67.1 ± 6.6°, and 65.2 ± 7.0°; $p = 0.0034$), especially in males ($p = 0.028$). Differences between boys and girls were not significant in any age group.

T1SPI

Age group variance was significant (-2.9 ± 2.9°, -3.8 ± 2.8°, -1.9 ± 4.0°, -3.1 ± 4.2°, and − 1.9 ± 3.2°; $p = 0.137$), particularly in males ($p < 0.001$). Gender differences were observed in Group A (aged 4–6 years) and Group E (aged 16–18 years), with males exhibiting higher T1SPI levels.

T1PA

No significant variance across age groups was observed (1.0 ± 6.7°, 3.0 ± 7.2°, 6.3 ± 5.7°, 4.8 ± 7.2°, and 6.0 ± 5.4°; $p = 0.063$). Differences between boys and girls were not significant in any age group.

Table 2 presents the distribution of spinopelvic parameters across various groups categorized by Pelvic Tilt (PT). There were no remarkable differences in cSVA, C0-2 Cobb, CBVA, and C7-S1 SVA between the two PT-based groups. When considering the whole spinal sagittal alignment, significant differences were observed in subjects with negative PT. Specifically, in the negative PT group, it was noted that participants were younger, with smaller values for APPA, PI, and T1PA, while PSA, SS, LL, TK, T1S, C7S, C2-7 Cobb, and T1SPI were larger.

Roussouly meticulously categorized six distinct pelvic balance types using the center of the sacral 1 superior endplate, the hip axis, and the C7 plumb line as reference points, emphasizing the interaction between the pelvis and spine. For our study, this classification has been streamlined into two principal categories for ease of analysis. Pelvic tilt (PT) anterior to the femoral head, showing a negative value, is classified as Group N (Negative Group). Conversely, Group P (Positive Group) includes all other cases. Group P consists of 252 individuals, accounting for 82.08% of the study population. In Group P, males and females constitute 127 (50.4%) and 125 (49.6%),

Parameter	PT positive($n = 252$)	PT negative($n = 55$)	*P* value
Age	12.7 ± 3.3	11.8 ± 2.8	0.042*
APPA	− 1.5 ± 8.7	− 7.3 ± 10.0	< 0.001*
PSA	65.7 ± 8.6	78.3 ± 4.5	< 0.001*
SS	30.4 ± 8.2	35.2 ± 7.0	< 0.001*
PI	40.1 ± 9.8	31.2 ± 6.6	< 0.001*
LL	− 44.2 ± 11.4	− 50.1 ± 9.0	< 0.001*
TK	29.6 ± 10.4	33.4 ± 9.1	0.0085*
T1S	20.1 ± 8.3	22.9 ± 8.9	0.037*
C7S	17.2 ± 8.5	19.8 ± 7.8	0.032*
cSVA	17.5 ± 8.3	20.9 ± 21.1	0.245
C2-7 Cobb	− 9.7 ± 9.9	− 13.2 ± 7.5	0.0048*
C0-2Cobb	− 25.1 ± 7.7	− 24.0 ± 8.5	0.381
CBVA	6.3 ± 6.5	5.4 ± 6.1	0.332
SVA (C7-S1)	3.4 ± 24.2	0.6 ± 26.7	0.477
T1SPI	− 3.3 ± 3.7	− 0.9 ± 3.2	< 0.001*
T1PA	5.5 ± 6.3	− 1.7 ± 7.5	< 0.001*

Table 2. Differences between each parameter distinguished by positive and negative PT values. *$p < 0.05$ indicates that the difference is statistically significant. Negative values for LL, C2-7 Cobb and C0-2 Cobb indicate lordosis, positive values indicate kyphosis.

respectively. Group N, with a PT value below zero, includes 55 participants, or 17.91% of the total sample. In Group N, males (38, 69.09%) are the majority, followed by females (17, 30.91%).

Correlation between cervical sagittal alignment and global spine sagittal alignment

Table 3; Fig. 3 illustrate the correlation between cervical sagittal alignment and global spine sagittal alignment. Significant correlations were found between age and the following parameters: PSA (r=-0.17, p = 0.00), PT (r = 0.17, p = 0.00), LL (r=-0.19, p = 0.00), T1S (r = 0.11, p = 0.00), cSVA (r = 0.19, p = 0.00), C2-7 Cobb (r=-0.14, p = 0.01), C0-2 Cobb (r = 0.13, p = 0.02), CBVA (r=-0.25, p = 0.00), C7-S1 SVA (r = 0.22, p = 0.00), T1SPI (r = 0.14, p = 0.01), and T1PA (r = 0.18, p = 0.00).

Significant correlations were also observed between APPA and the following parameters: PSA (r=-0.48, p = 0.00), SS (r=-0.23, p = 0.00), PT (r = 0.43, p = 0.00), PI (r = 0.17, p = 0.00), LL (r=-0.16, p = 0.01), C2-7 Cobb (r=-0.15, p = 0.01), C7-S1 SVA (r = 0.21, p = 0.00), and T1PA (r = 0.4, p = 0.00). Figure 4 presents the analysis of parameters strongly associated with PT.

For PSA, significant correlations were found with SS (r = 0.22, p = 0.00), PT (r=-0.73, p = 0.00), PI (r=-0.4, p = 0.00), LL (r = 0.19, p = 0.00), C2-7 Cobb (r = 0.12, p = 0.03), C7-S1 SVA (r=-0.22, p = 0.00), T1SPI (r = 0.14, p = 0.01), and T1PA (r=-0.48, p = 0.00).

Significant correlations were noted between SS and PT (r=-0.3, p = 0.00), PI (r = 0.6, p = 0.00), LL (r = 0.78, p = 0.00), T1SPI (r = 0.16, p = 0.01), and T1PA (r=-0.22, p = 0.00).

PT showed significant correlations with PI (r = 0.56, p = 0.00), LL (r=-0.27, p = 0.00), TK (r=-0.13, p = 0.03), C7-S1 SVA (r = 0.17, p = 0.00), T1SPI (r=-0.29, p = 0.00), and T1PA (r = 0.66, p = 0.00).

PI was significantly correlated with LL (r = 0.45, p = 0.00), C2-7 Cobb (r=-0.12, p = 0.04), C7-S1 SVA (r = 0.13, p = 0.02), and T1PA (r = 0.35, p = 0.00).

LL had significant correlations with TK (r = 0.38, p = 0.00), C7-S1 SVA (r=-0.25, p = 0.00), and T1PA (r=-0.34, p = 0.00).

TK was significantly correlated with T1S (r = 0.59, p = 0.00), C7S (r = 0.59, p = 0.00), cSVA (r = 0.3, p = 0.00), C2-7 Cobb (r = 0.25, p = 0.00), and T1PA (r=-0.18, p = 0.00).

T1S showed significant correlations with C7S (r = 0.87, p = 0.00), cSVA (r = 0.32, p = 0.00), C2-7 Cobb (r = 0.42, p = 0.00), CBVA (r=-0.25, p = 0.00), C7-S1 SVA (r = 0.39, p = 0.00), and T1SPI (r = 0.27, p = 0.00).

C7S was significantly correlated with cSVA (r = 0.32, p = 0.00), C2-7 Cobb (r = 0.45, p = 0.00), C0-2 Cobb (r = 0.12, p = 0.04), CBVA (r=-0.24, p = 0.00), C7-S1 SVA (r = 0.35, p = 0.00), and T1SPI (r = 0.25, p = 0.00).

Significant correlations were observed between cSVA and C0-2 Cobb (r = 0.21, p = 0.00), C7-S1 SVA (r = 0.23, p = 0.00), and T1SPI (r = 0.16, p = 0.00).

C2-7 Cobb had significant correlations with CBVA (r=-0.32, p = 0.00), C7-S1 SVA (r = 0.13, p = 0.02), and T1SPI (r = 0.12, p = 0.03).

Significant correlations were noted between C0-2 Cobb and CBVA (r=-0.28, p = 0.00).

CBVA showed significant correlations with C7-S1 SVA (r=-0.14, p = 0.01).

Lastly, significant correlations were found between C7-S1 SVA and T1SPI (r = 0.75, p = 0.00) and T1PA (r = 0.39, p = 0.00).

Discussion

This investigation represents the first large-scale analysis of comprehensive spinopelvic parameters in an asymptomatic Chinese pediatric population, our study of 307 asymptomatic pediatric subjects (167 males, 140 females) aged 4–18 years established normative values for cervical and spinopelvic parameters, demonstrating significant age and sex-related variations. Key findings include: mean values of -24.95° ± 7.80° for C0-2 Cobb, -10.31° ± 9.56° for C2-7 Cobb, and 18.13 ± 11.69 mm for cSVA; a strong correlation between C2-7 Cobb angle and both T1 and C7 slopes; and an age-related increase in cSVA particularly pronounced in boys. We observed that 17% of participants exhibited negative PT values, indicating anterior pelvic rotation, with these subjects showing greater lumbar lordosis and thoracic kyphosis. Our findings highlight that age and gender significantly influence the normative values of cervical and spinopelvic parameters, which could have important implications for clinical evaluation and treatment planning in pediatric populations.

The role of cervical sagittal balance in maintaining proper head posture and a horizontal gaze is well documented[57,58], this underscores the importance of understanding cervical sagittal alignment norms in asymptomatic youth throughout their development. Abelin et al.[39,59] examined 150 asymptomatic children, reporting mean values of -18.3 ± 7.9° for the C2-7 Cobb and − 0.7 ± 13.8° for the C0-2 Cobb. Our research uniquely demonstrates previously uncharacterized correlations between cervical parameters and global spinal alignment in the pediatric population, providing new insights into the interconnected nature of spinal segments during development. Contrarily, our study presents normative values for the C2-7 Cobb at 10.31 ± 9.56° and for the C0-2 Cobb at 24.95 ± 7.80°, indicating a significant discrepancy with their findings. We observed a strong correlation between the C2-7 Cobb with T1 and C7 slopes. Additionally, we observed a trend of decreasing C2-7 Cobb with age. Ames et al.[40,60] highlighted in their review that a substantial portion of cervical lordosis is localized in the upper cervical spine (OC2), with minimal lordosis in the lower segments, a pattern that is consistent with our observations in the pediatric cohort. In our study, the C0-2 Cobb angle increases with age in boys, with no significant gender differences or changes across age groups noted, highlighting variability in cervical profile.

Previous research[61] establishes the reference cSVA in asymptomatic minors at 16.03 ± 10.33 mm, spanning − 3.91 to 65.31 mm. Our study, with a mean cSVA of 18.13 ± 11.69 mm, supports these findings but reveals a broader range, from − 9.8 to 36.2 mm. This suggests that negative cSVA values, indicative of cervical lordosis, are not necessarily associated with spinal disorders in children. Additionally, our data shows an age-related increase in cSVA, particularly pronounced in boys, highlighting the need to consider age and gender in assessments

	Age	PTα	PTβ	SS	PT	PI	LL	TK	T1S	C7S	cSVA	C2-7 Cobb	C0-2Cobb	CBVA	SVA	T1SPI	T1PA
Age	1.00																
PTα	− 0.01	1.00															
PTβ	− 0.17*	− 0.48 *	1.00														
SS	− 0.11 *	− 0.23*	0.22 *	1.00													
PT	0.17 *	0.43 *	− 0.73*	− 0.30*	1.00												
PI	0.04	0.16 *	− 0.40*	0.60 *	0.56*	1.00											
LL	− 0.18 *	− 0.16*	0.19 *	0.78 *	− 0.26*	0.46 *	1.00										
TK	0.03	− 0.06*	0.04	0.03	− 0.13 *	− 0.09 *	0.38*	1.00									
T1S	0.11 *	0.04	− 0.02	− 0.09 *	− 0.02	− 0.10*	− 0.01	0.59*	1.00								
C7S	− 0.02	0.04	0.01	− 0.01	− 0.05*	− 0.07 *	0.07 *	0.59*	0.87 *	1.00							
cSVA	0.19 *	0.04	− 0.05 *	0.05*	− 0.02	0.03	0.09 *	0.30*	0.32*	0.32 *	1.00						
C2− 7 Cobb	− 0.14*	− 0.15 *	0.12 *	− 0.06*	− 0.07 *	− 0.12 *	− 0.07 *	0.25 *	0.42 *	0.45 *	0.00	1.00					
C0− 2Cobb	0.14*	0.01	− 0.08*	− 0.04	0.02	− 0.02	− 0.03	0.05 *	0.08*	0.11 *	0.21 *	0.01	1.00				
CBVA	− 0.25*	0.09 *	− 0.02	0.05	0.01	0.06 *	0.07 *	− 0.11 *	− 0.25*	− 0.24 *	0.03	− 0.31 *	− 0.28 *	1.00			
SVA	0.22*	0.21 *	− 0.22*	0.00	0.17*	0.13 *	− 0.25 *	0.01	0.39*	0.34 *	0.23 *	0.13 *	0.04	− 0.14 *	1.00		
T1SPI	0.14*	− 0.05*	0.14*	0.16 *	− 0.29*	− 0.10 *	− 0.11 *	0.00	0.27	0.25*	0.16 *	0.12 *	− 0.07 *	− 0.08 *	0.75 *	1.00	
T1PA	0.18*	0.39 *	− 0.48 *	− 0.22 *	0.66 *	0.35 *	− 0.34 *	− 0.18 *	0.10 *	0.07	0.02	0.05	0.02	− 0.04	0.39 *	0.06 *	1.00

Table 3. Pearson correlation matrix between different parameters. *$p < 0.05$ indicates that the correlation is significant.

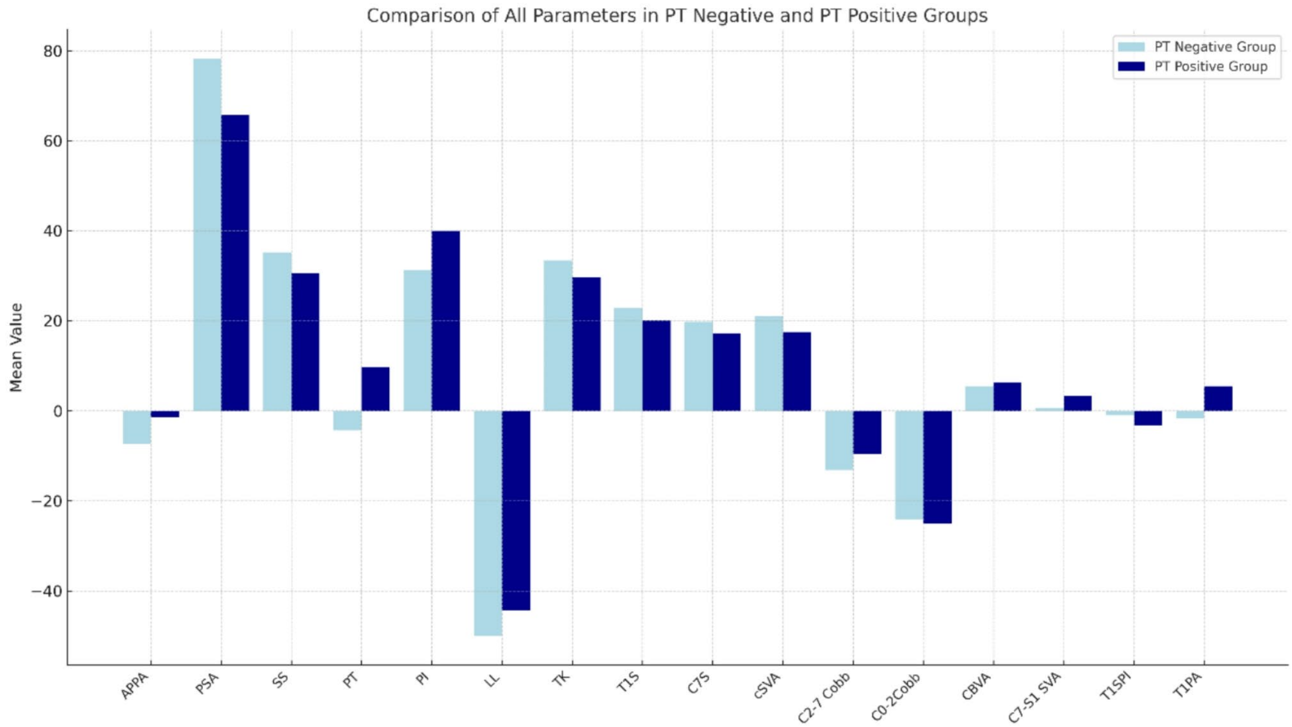

Fig. 3. Differences between parameters is in PT negative group and PT positive group.

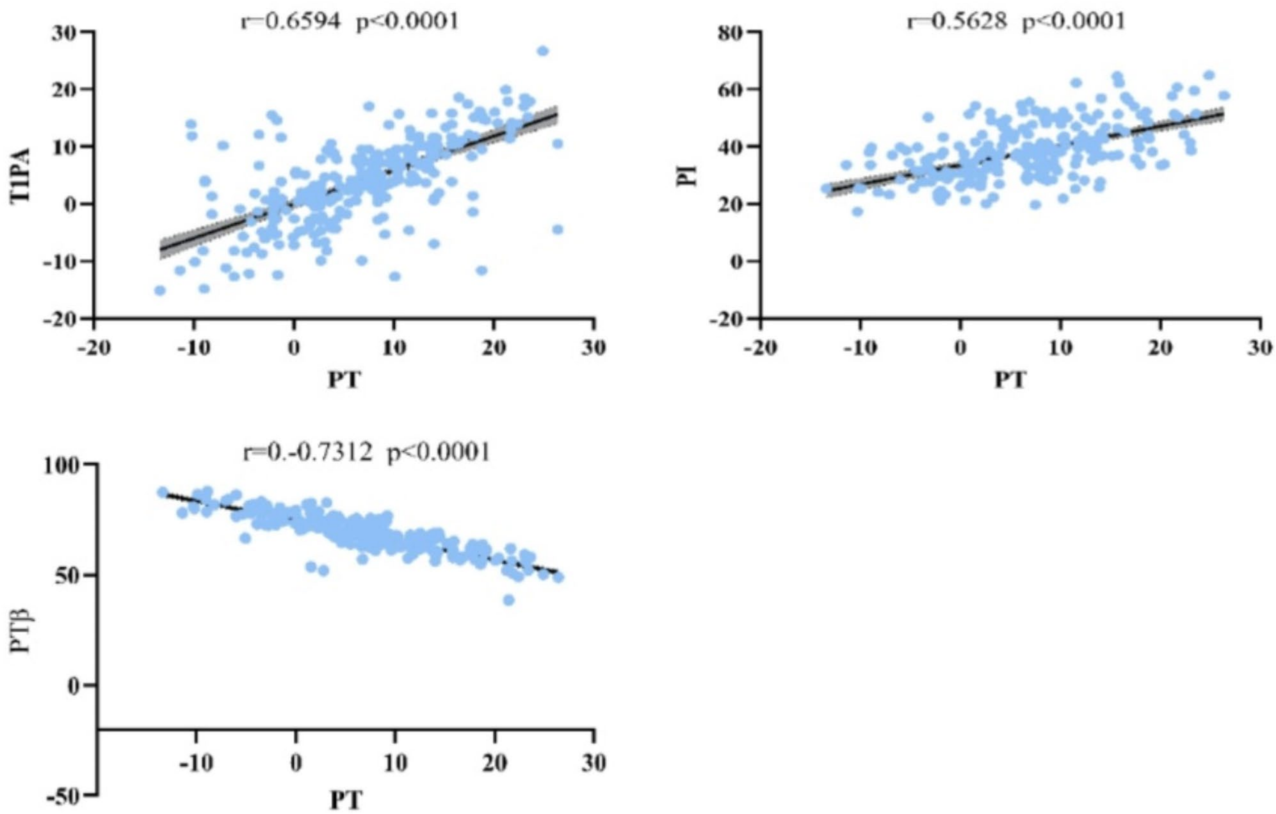

Fig. 4. Analysis of parameters strongly related to PT.

of cervical spine alignment. It is essential to acknowledge the potential methodological differences when comparing our EOS-derived measurements with those obtained through conventional radiography[61]. The EOS imaging system could effectively eliminate projection magnification differences in the vertical dimension and uses proprietary algorithms to reduce horizontal plane distortion inherent to the fan beam imaging process. Recent research by Birkenmaier et al.[62]. (2024) has demonstrated quantifiable measurement variations between EOS and conventional imaging modalities, particularly for linear measurements like femoral head diameter. Similarly, cSVA may exhibit similar technological artifacts when comparing across diverse imaging platforms. These technological distinctions warrant careful consideration when interpreting comparative analyses. Future studies directly comparing spinopelvic sagittal alignment parameters between EOS and conventional imaging would significantly contribute to establishing adjustment protocols for enhanced cross-study comparison reliability.

The T1 and C7 slopes are pivotal for maintaining overall sagittal spine alignment[61,63], linking the occipitocervical and thoracolumbar spine. These parameters may predict the future sagittal alignment of the spine following fusion surgeries, a relationship substantiated by multiple studies. The literature presents average values of 17.4 ± 8 for C7S and 27.42 ± 8.81 for T1S. Our results agree, showing normative values of 17.66 ± 8.39 for C7S and 20.62 ± 8.49 for T1S. Contrary to prior findings, our study indicates that C7S decreases with age, while T1S increases, yet they remain positively correlated. This observation prompts further investigation. Additionally, our research corroborates the phenomenon that an increased T1 slope enhances the C2-C7 Cobb angle, potentially maintaining a reduced cSVA through a continuous and compensatory mechanism. Moreover, the established association between the C2-7 Cobb and thoracic kyphosis, C7 slope, and T1 slope is confirmed[59,63], alongside a newfound negative correlation with pelvic tilt, indicating a connection between cervical and pelvic alignment. These age-specific variations we identified establish crucial reference values that would significantly enhance the precision of clinical assessments and facilitate early detection of spinal disorders in pediatric populations.

To evaluate horizontal gaze, CBVA was used. Despite varying head positions, individuals can maintain a horizontal gaze within a specific range[64]. Previous study[65] showed a CBVA range of -1.5° to 5.8°, while our results indicate a CBVA of 6.17 ± 6.42. Our study also confirms a significant correlation between CBVA and cervical spine parameters, but not with thoracic or lumbar spine parameters, nor overall spinal balance. Importantly, we found that CBVA decreases with age, a trend especially pronounced in males.

Understanding the morphology of the thoracic and lumbar spine is critical due to its significant association and alignment with sacropelvic alignment in the evaluation and management of spinal disorders. TK and LL[66,67]are commonly employed metrics for describing sagittal spinal alignment. Detailed results of our study are presented in Table 1. Ghandhari[68] evaluated sagittal spinal alignment in 98 healthy individuals, finding average TK and LL values of 37.1 ± 9.9° and 39.6 ± 12.4°, respectively. Our measurements found TK, from the T5 upper endplate to the T12 lower endplate, to be 30.28 ± 10.25°, and LL, from the L1 upper endplate to the S1 upper endplate, to be 45.23 ± 11.23°. We observed a decreasing trend in LL, while TK remained relatively stable. Contrary to Cil et al.'s[69] findings of TK and LL increasing with age, our study noted the opposite trend, indicating a discrepancy. Previous research showed no significant gender differences in TK and LL. However, our study identifies significant gender differences in TK, with males showing higher values, while no gender differences were observed in LL. The gender-specific patterns in spinal development identified in our analysis expand current knowledge and provide empirical support for the importance of considering sex as a factor in spinal evaluation and treatment planning.

In the evaluation of 341 healthy children and adolescents, Mac-Thiong et al.[70] reported mean values of PI at 49° ± 11°, PT at 8° ± 8°, and SS at 41° ± 8°. Conversely, our investigation of 307 asymptomatic children revealed mean PI values of 38.54° ± 9.91°, PT values of 7.35° ± 8.81°, and SS values of 31.25° ± 8.24°, respectively.

PT, which indicates the pelvis's rotation around the femoral heads, averaged 13 ± 6° in previous studies[71], with values below 5° typically signaling excessive anterior pelvic rotation. An increase in PT suggests posterior rotation, whereas a decrease implies anterior rotation. To enhance the assessment and definition of pelvic sagittal rotation, we evaluated two novel angles.

By introducing APPA and PSA as innovative analytical approaches for evaluating pelvic sagittal rotation, our study provides a more comprehensive assessment framework that extends beyond traditional PT, SS, and PI parameters, enriching the methodological approaches to pelvic posture evaluation. Nathan J et al.[72] used APPA and PSA to describe pelvic orientation, highlighting aspects often overlooked in sagittal balance evaluations. Normative CT values for APPA and PSA from 200 asymptomatic subjects were 23.02 ± 6.56°and 56.52 ± 9.00°, respectively, while our standing X-ray results showed −2.55 ± 9.18° and 67.91 ± 9.34°. In our view, a decrease in APPA and an increase in PSA both indicate anterior pelvic rotation, assisting in the evaluation of pelvic sagittal assessment. A decreasing trend in PSA suggests a gradual posterior rotation of the pelvis, a physiological process we believe reflects the pelvis returning to a standard position from a previously anteriorly tilted state during development. This physiological change is normal in children and should be recognized as an age-related transition. The gradual decrease in SS and increase in PT are consistent with this description of pelvic parameters and are considered reasonable[73,74]. Significant correlations were found between PI and both PT and SS, as well as between PI and the angles APPA and PSA. However, studies on these angles for assessing pelvic sagittal balance are limited, and their clinical relevance in healthy children remains to be fully explored.

Mac-Thiong et al.[23,75] noted a progressive increase in PI up to adulthood, a trend consistent with our findings (see Table 1). Contrarily, Zhou[76] reported a correlation between PI and age, which our results do not support, highlighting a need for further research to elucidate this discrepancy.

The Sacral Slope (SS) is a parameter that varies with changes in sagittal spinal balance and age[76,77], directly influencing the orientation and shape of the lumbar spine and the entire spine. Zhou and colleagues measured normal SS values in children as 31.53 ± 7.09° for males and 32.75 ± 6.15° for females. Our observations yielded

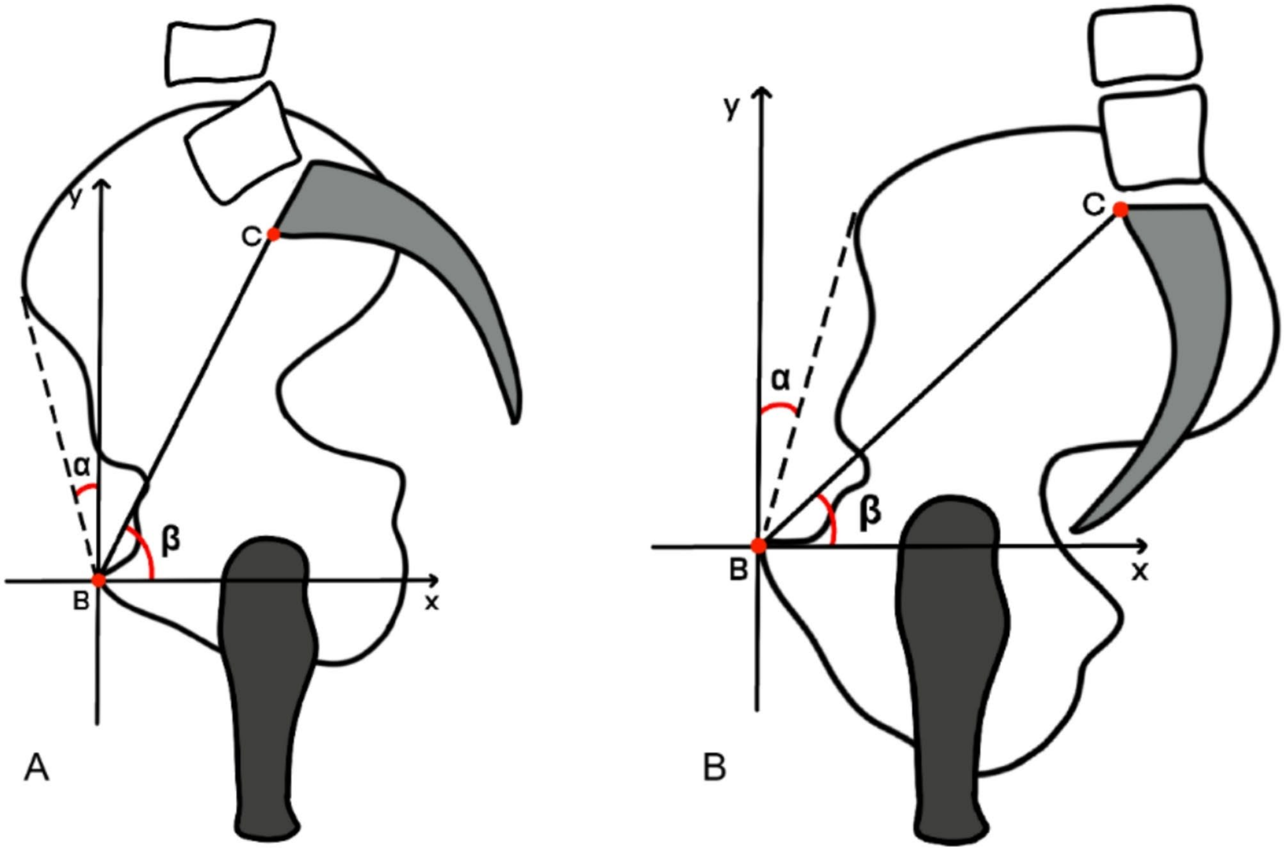

Fig. 5. Schematic diagram of PT negative group and PT positive group. Figure A depicts the anterior pelvic tilt, symbolizing the PT negative group in a schematic format, while figure B illustrates the posterior pelvic tilt, corresponding to the PT positive group.

SS values of 31.99 ± 7.87° for males and 30.41 ± 8.64° for females, showing no significant gender difference. We noted a gradual decrease in SS among children with age. Mac-Thiong et al. also demonstrated that the increase in PI with age is modest, and this pattern remains consistent before and after the age of 10 in the pediatric population following the onset of bipedalism.

Theoretically, the presence of negative PT values suggests an extreme anterior pelvic rotation, which may increase muscular energy expenditure. In our study, negative PT values were observed in 55 individuals, constituting 17% of the pediatric individuals. We propose that pelvic rotation plays a pivotal role in maturation, facilitating balance adjustment between the spine and lower limbs. A classification system[55,78,79] delineating sagittal global balance, we have streamlined this system into two categories based on the midpoint of the S1 upper endplate and the center of the femoral heads, making it more clinically practical. The group with negative PT values exhibited larger lumbar lordosis and thoracic kyphosis, though the causality remains uncertain.

In the negative PT value group (schematic representation of the two pelvic types is shown in Fig. 5), individuals were younger on average. They had smaller APPA values, consistent with reduced PT, indicating more pronounced anterior pelvic tilt. PSA values were higher in this group, which also showed greater SS, TK, LL, C7S, and T1S, along with increased C2-7 Cobb. The implications of excessive anterior pelvic rotation extend beyond alterations in segmental spinal angles, as evidenced by significant differences of global balance such as T1SPI and T1PA.

C7-S1 Sagittal Vertical Axis (C7-S1 SVA), T1 Spinopelvic inclination (T1SPI), and T1 Pelvic Angle (T1PA) are parameters frequently utilized in the evaluation of global sagittal balance in adults[80–82], particularly in the elderly, for diagnosing and assessing spinal pathologies. These metrics are instrumental in assessing the spinal anterior or posterior inclination, with significant implications for clinical diagnosis and therapeutic planning[83–86]. In children, due to ongoing growth and development, the normal ranges for these parameters may differ from those in adults and can be influenced by factors such as age, gender, height, and developmental stage[55,67,87]. Our study found normal values for C7-S1 SVA, T1SPI, and T1PA to be 2.89 ± 24.64 mm, -2.90 ± 3.75°, and 4.20 ± 7.10°, respectively, marking a substantial deviation from adult values. Additionally, a significant age correlation was noted, indicating that these parameters increase with age, suggesting an age-related trend towards increased anterior spinal inclination. This trend highlights a crucial link between spinal parameters and pelvic orientation in children, with both T1SPI and T1PA not only associated with pelvic parameters but also with the curvature of the cervical spine, emphasizing the interconnected nature of spinal and pelvic parameters during growth.

Overall, our research provides comprehensive normative data and establishes parameter correlations that offer an evidence-based foundation for pediatric spinal surgical decision-making and treatment planning, significantly advancing the clinical application of sagittal alignment assessment in pediatric populations.

Limitation

This study has several limitations. First, the retrospective design limits our ability to track developmental changes in spinal alignment over time. While our age-stratified analysis provides insights into age-related differences, longitudinal studies would be necessary to definitively characterize the progression of spinopelvic parameters during growth and development. Another significant challenge lies in the precise identification and measurement reliability of anatomical landmarks in pediatric populations. This limitation potentially affects the accuracy and reproducibility of our measurements, highlighting the need for pediatric-specific reliability studies. The absence of anthropometric data, particularly height and weight measurements, represents another significant limitation. The body mass index has been demonstrated to influence postural alignment and sagittal balance in children[88,89]. The lack of these measurements prevents analysis of potential relationships between body composition and spinopelvic parameters. Additionally, our analysis did not incorporate or evaluate cases with lumbosacral transitional vertebrae, a significant anatomical variation with reported prevalence rates of up to 40% in the general population. As demonstrated by Krenn et al.[90]., these vertebral variations can substantially influence sacral positioning and lumbar lordosis. The exclusion of this consideration from our study design may have impacted on our assessments of sagittal balance parameters and their relationships.

Future research should address these limitations through prospective longitudinal studies incorporating anthropometric measurements, detailed assessment of transitional vertebrae, and larger sample sizes in specific age groups. Additionally, reliability studies specifically focused on pediatric populations would enhance the validity of these measurements in clinical practice.

Conclusion

In this investigation of 307 asymptomatic Chinese pediatric subjects, we identified variations in cervical and spinopelvic parameters influenced by age and sex. These findings demonstrate that both factors play a significant role in spinal development during childhood and adolescence. The results underscore the importance of considering age and sex-specific norms in the clinical evaluation and management of pediatric spinal health, providing essential benchmarks for future research and interventions in this field.

Data availability

All raw data for the spinopelvic sagittal balance parameters measured in this study are available in the Excel files within the Supplementary Information. These data support all findings presented in the manuscript.

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Conceptualization: H.Q., D.Z.; Methodology: H.Q., Z.Z., F.Z.; Software: Z.Z., C.C.W.; Validation: H.Q., Z.Z., F.Z.; Formal analysis: H.Q., C.C.W., C.X.W.; Investigation: H.Q., Z.Z., F.Z.; Resources: H.Q., Z.H., W.C.; Data curation: J.R., R.X., Z.W.; Writing—original draft preparation: H.Q.; Writing—review and editing: D.Z., W.C.; Visualization: Z.Z.; Supervision: D.Z., Z.H., W.C.; Project administration: D.Z. All authors have read and agreed to the published version of the manuscript.

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Declarations

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish
Written informed consent for publication was obtained from all participants.

Ethical approval
This study was approved by the Ethics Committee of the Third Hospital of Hebei Medical University and all subjects enrolled provided informed consent.

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The authors declare no competing interests.

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