

# Variation of Global Sagittal Alignment Parameters According to Gender, Pelvic Incidence, and Age

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**Study Design:** Retrospective cross-sectional study.

**Objective:** The aim was to describe existing global sagittal alignment parameters across ages and to analyze differences according to gender and pelvic incidence (PI).

**Summary of Background Data:** Variability with age has been reported. It remains unclear how gender and spinopelvic morphology could additionally influence global alignment parameters.

**Materials and Methods:** Radiographs of 2599 individuals (5–93 y) were analyzed. Translation parameters were: Sagittal Vertical Axis (SVA)-C7, SVA-C2, SVA-Center Acoustic Meatus (CAM), C7/Sacrofemoral Distance (SFD) ratio. Inclination parameters were: C7-Vertical Tilt (VT), T1-VT and T9-VT, Odontoid-Hip Axis (OD-HA), OD-CAM. Pelvic compensation parameters were: T1-Pelvic Angle (TPA), Global Tilt (GT), Spino-Sacral Angle (SSA). Global sagittal alignment (GSA) was considered

among formulae. The distribution of parameters was analyzed using a Bayesian inference. Correlations with spinopelvic parameters were investigated.

**Results:** SVA-C7, SVA-C2, SVA-CAM were larger in males and high PI, and increased significantly after 50 years ( $P > 0.9999$ ). C7/SFD decreased during growth and was larger in low PI ( $P = 0.951$ ). There was no correlation with spinopelvic parameters. Age-related variations of inclination parameters were non-significant. T1-VT and T9-VT increased with PI and were significantly larger in high PI ( $P > 0.95$ ). C7-VT was significantly larger in low PI ( $P > 0.9999$ ). OD-HA and OD-CAM were constant and increased after 80 years. TPA and GT increased with PI ( $P > 0.9999$ ) and age after 35 years ( $P > 0.9999$ ). SSA decreased nonsignificantly after 50 years. TPA correlated with PI ( $\rho = 0.6130$ ) and pelvic tilt (PT) ( $\rho = 0.8375$ ). GT correlated with PI ( $\rho = 0.5961$ ) and PT ( $\rho = 0.8996$ ). SSA correlated with sacral slope ( $\rho = 0.9026$ ). GSA was larger in high PI ( $P > 0.9999$ ) and

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increased after 35 years ( $P > 0.9999$ ). GSA correlated with PT ( $\rho = 0.7732$ ).

**Conclusion:** Translation parameters increase with age, more prominently in males and high PI. Variations of inclination parameters are smaller. Pelvic compensation parameters and GSA increase with age and are closely related to PT and spinopelvic morphology.

**Level of Evidence:** Level III.

**Key Words:** sagittal alignment, global alignment, radiographic parameters, age, gender, pelvic incidence, spinopelvic morphology

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Global sagittal alignment is analyzed when treating spinal deformities. In the dynamic condition of standing, walking and during daily activities, the patient requires a balanced trunk, which involves cognitive, neurosensory, and motor control. In clinical practice, alignment parameters are used for surgical planning and follow-up, although radiographic assessment represents only a snapshot in standing position. Accurate planning requires age-related target values, since a physiological increase of thoracic kyphosis (TK), a decrease of lumbar lordosis (LL) and adaptive phenomena with variations of spinopelvic and global alignment parameters were described.<sup>1–4</sup> Therefore, age-related thresholds were suggested for adult spinal deformity correction because sagittal overcorrection might lead to mechanical complications such as proximal junctional kyphosis.<sup>5,6</sup> Moreover, a proportionate kyphosis and lordosis distribution according to the spinopelvic configuration based on pelvic incidence (PI) should be considered.<sup>7,8</sup> The use of Roussouly alignment types<sup>9,10</sup> can be helpful in young adults, but the occurrence of degenerative changes and deformities make the use of this classification more difficult in elderly patients.<sup>3,11</sup> Legaye<sup>4</sup> demonstrated that aging was associated with loss of LL, pelvic retroversion, anterior C7 plumbline migration, and subsequent PI increase.

Global sagittal alignment parameters can be classified into 4 groups: plumbline translation, trunk inclination, pelvic compensation parameters, and mathematic formulae. The Sagittal Vertical Axis (SVA) of C7 measures the plumbline distance related to S1,<sup>12</sup> like the SVA of C2 or of the Cranial Auditory Meatus (CAM). The C7/Sacrofemoral Distance (C7/SFD) ratio is similar to the SVA-C7 measurement.<sup>13</sup> Translation parameters allow an assessment of global alignment changes in a patient between follow-up visits, but they do not take spinopelvic compensation mechanisms into account. T1-Vertical Tilt and T9-Vertical Tilt (VT) reflect global trunk inclination around the femoral heads,<sup>14</sup> like C7-VT<sup>15</sup> which originates from the sacrum. The Odontoid-Hip Axis (OD-HA) and CAM-HA both measure trunk inclination including the cervical spine.<sup>16</sup> Parameters that include pelvic version are: T1-Pelvic Angle (TPA),<sup>17</sup> Global Tilt (GT)<sup>15</sup> and Spino-Sacral Angle (SSA).<sup>18</sup> The global sagittal axis includes 2 compensation mechanisms, hip extension and knee flexion, and requires

full-body radiographs.<sup>19</sup> Among formulae, Global Sagittal Alignment (GSA) sets a normal threshold below 45 degrees using the equation  $GSA = TK - LL + PI$ .<sup>20</sup>

To date it remains unclear to what extent global alignment varies according to gender, PI, and age. We hypothesize that normal variations exist in individuals without spinal deformity.

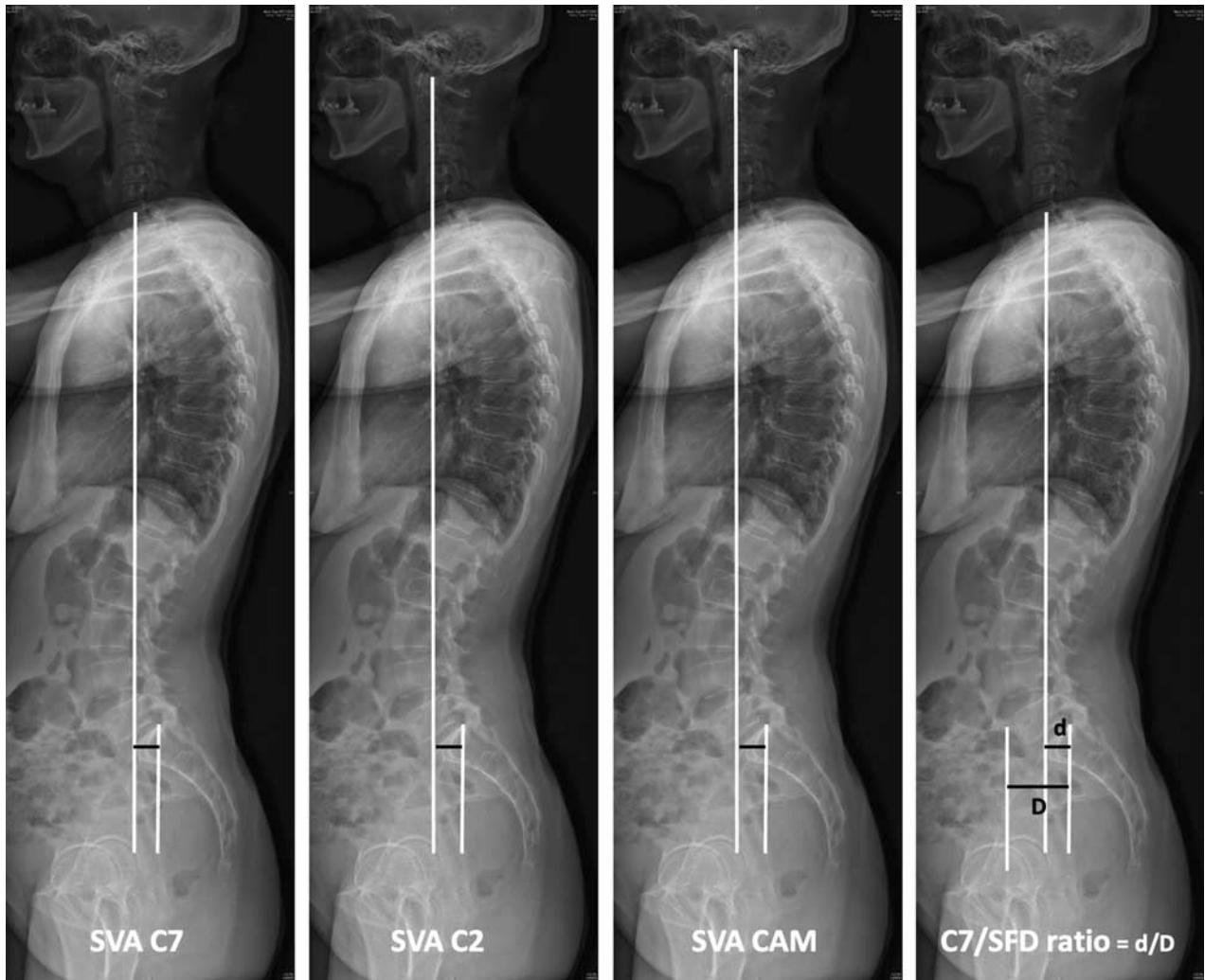
The purpose of this observational study was to describe existing parameters across ages from childhood to the elderly, and to analyze differences in gender and spinopelvic alignment types.

## MATERIALS AND METHODS

Institutional review board approval (FC/2019-91) was obtained for this retrospective cross-sectional study on full spine radiographs that were prospectively collected in a national spine registry involving 16 centers. Sagittal radiographs (EOS Imaging, Paris, France) performed from September 2019 to March 2020 performed on children, adolescents, and young adults with limb length inequality below 2 cm, spondylolysis, screening in children with positive family history of scoliosis. In adults, radiographs were collected from patients with common low back, neck or radicular pain presenting moderate symptoms, and from geriatric patients with lumbar stenosis. Radiographs and clinical charts were screened at each center. Exclusion criteria were: spinal deformity on radiographs including scoliosis (Cobb angle  $> 15$  degrees), anterior malalignment with loss of LL and pelvic retroversion ( $PI - LL > 20$  degrees and  $TPA > 25$  degrees), Scheuermann's kyphosis, or spondylolisthesis more than grade 1, traumatic or osteoporotic fractures, spinal tumors or metastases, spondylodiscitis, neuromuscular diseases, previous spine surgery (except microdiscectomy), severe degenerative changes leading to thoracolumbar deformity. Intervertebral disc degeneration, facet joint osteoarthritis and degenerative spondylolisthesis were considered to belong to the normal aging process and did not represent exclusion criteria.

Segmental anatomical landmarks were reconstructed on sagittal radiographs from the femoral heads to the CAM by a trained operator per center using KEOPS software (SMAIO, Lyon, France). The accuracy of each reconstruction was then checked by a group of 5 senior spine surgeons. This method was described as reliable with interobserver and intraobserver intraclass correlation coefficients  $> 0.9$ .<sup>21</sup> The following spinopelvic parameters were assessed: PI, pelvic tilt (PT) and sacral slope (SS), cervical lordosis (CL) between caudal C2 and C7 endplates, TK between cranial T1 and caudal T12 endplates, LL between cranial L1 and S1 endplates. Kyphosis was expressed as positive values and lordosis as negative values.

Global sagittal alignment parameters are demonstrated in Figures 1–3. The SVA was measured in mm between the plumblines of C7, C2, and the midpoint between both CAM and the posterior corner of S1 respectively. The C7/SFD ratio was determined as  $SVA - C7 / \text{distance from midpoint of femoral head centers to posterior corner of S1}$ . T1-VT and T9-VT were determined as the angle between the vertical axis originating from the midpoint of femoral head centers



**FIGURE 1.** Translation parameters: the Sagittal Vertical Axis (SVA) is measured as the distance between the posterior corner of S1 and the plumb lines of C7 (SVA-C7), C2 (SVA-C2) and of the Cranial Auditory Meatus (SVA-CAM) in mm. The C7/Sacrofemoral Distance ratio is calculated as  $C7/SFD = d/D$ .

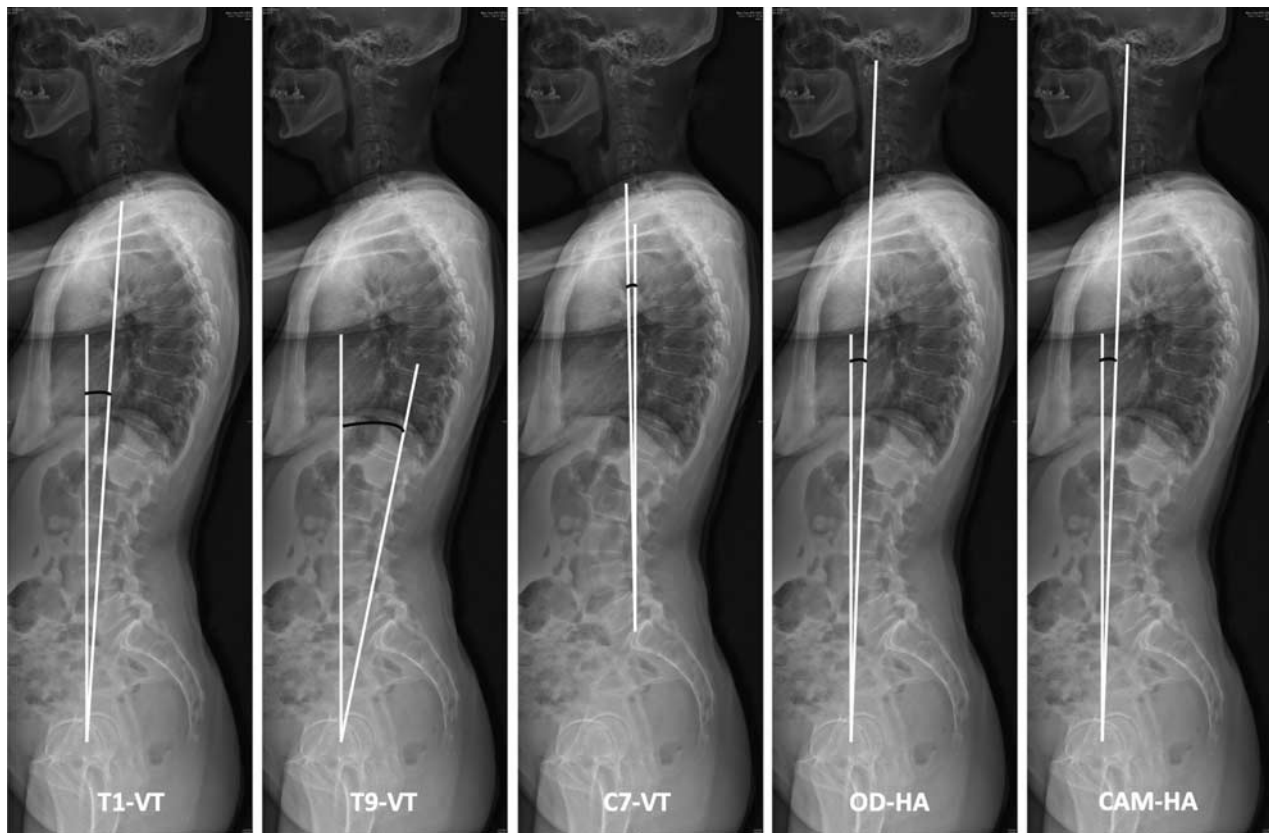
and the axis joining the center of T1 and T9, respectively. For C7-VT, the axes originated from the middle of the S1 endplate. The OD-HA and CAM-HA determined the angle between the vertical axis originating from the midpoint between femoral heads and the axis joining the odontoid tip and the CAM, respectively. The TPA was measured as the angle formed by T1 to midpoint of femoral heads and femoral head to middle of S1 endplate. The GT was determined as the sum of PT and C7-VT. The SSA represented the angle between C7-S1 axis and S1 endplate. The GSA was calculated as  $GSA = TK - ILLI + PI$ .

Statistical evaluation was performed with R Software Version 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria). A Bayesian inference using the Markov chain Monte Carlo techniques with low informative priors was used. To infer the mean of indices and correlation coefficients between 2 indices, point estimates correspond to the median of posterior distributions and credibility intervals to their 2.5 and 97.5

percentiles. Global sagittal alignment parameters were compared by gender, age groups and PI. The thresholds for PI were determined according to 25th and 75th percentiles: low PI <45 degrees, medium PI 45–60 degrees, high PI > 60 degrees. Significance tests were based on the probability of superiority for the difference between 2 means and for correlation coefficients (strong if  $\rho < -0.5$  or  $\rho > 0.5$ ). For PI the medium group and for ages the group 20–34 years were considered as references. The significance level was set at a 0.95 probability of superiority.

## RESULTS

A total of 2599 individuals were analyzed using a single radiograph at one time point. There were 1488 females (57.3%) and 1111 males (42.7%). The distribution by PI was: low PI n=972 (37.4%), medium PI n=1123 (43.2%), high PI n=504 (19.4%). The distribution by age



**FIGURE 2.** Inclination parameters: the Vertical Tilt (VT) is measured as the angle between vertical axis and the inclination of T1 (T1-VT) and T9 (T9-VT) related to the femoral heads. The axes for C7-VT originate from the sacrum. The Odontoid-Hip Axis (OD-HA) and the Cranial Auditory Meatus-Hip Axis (CAM-HA) are measured as angles formed with the vertical axis originating from the midpoint between femoral heads.

group was: 5–9 years  $n=94$  (3.6%), 10–14 years  $n=516$  (19.9%), 15–19 years  $n=448$  (17.2%), 20–34 years  $n=224$  (8.6%), 35–49 years  $n=424$  (16.3%), 50–64 years  $n=449$  (17.3%), 65–79 years  $n=340$  (13.1%), > 80 years  $n=104$  (4.0%). Table 1 gives an overview of CL, TK, LL, PI, PT, and SS per gender, PI and age groups.

### Translation Parameters

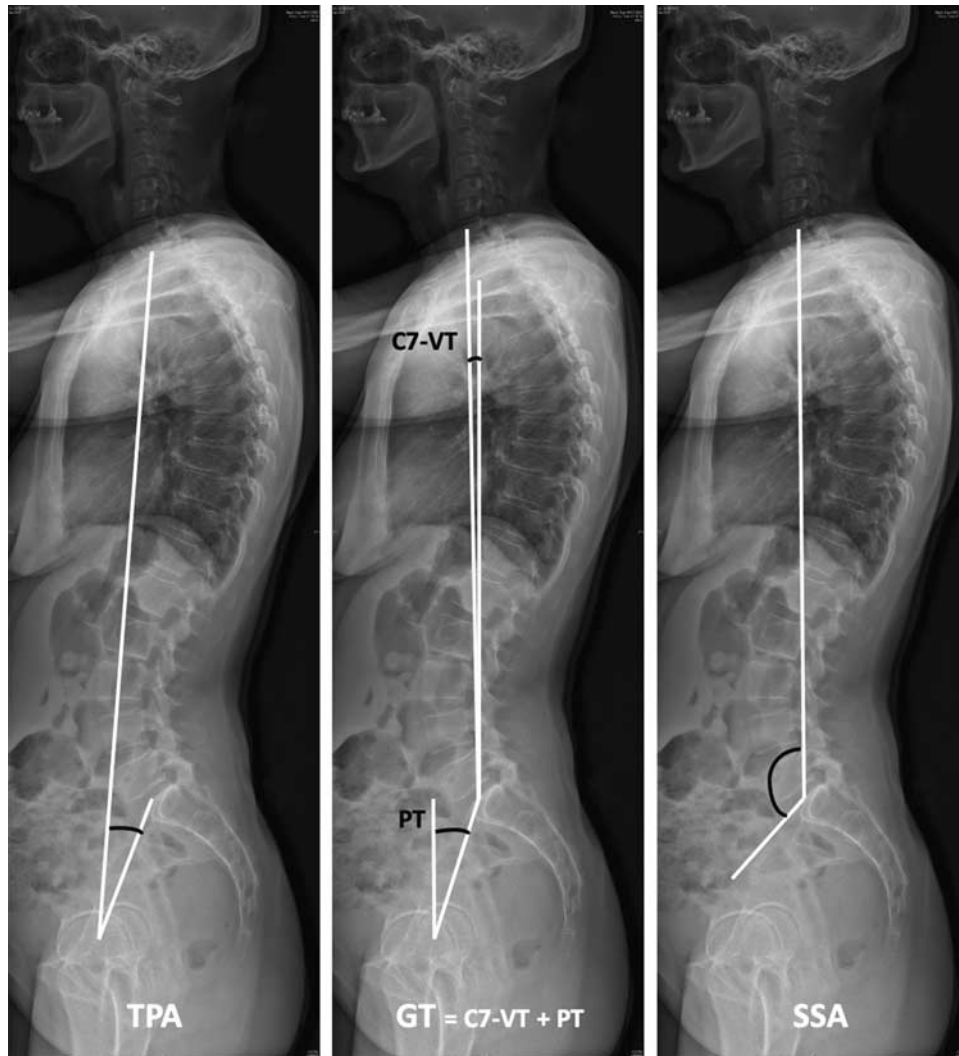
The distribution of translation parameters by gender, PI, and age are demonstrated in Table 2. SVA-C7, SVA-C2, and SVA-CAM were larger in males and increased with PI. In the high PI group, each parameter was significantly larger compared with the medium PI group ( $Pr > 0.9999$ ). SVA-C7, SVA-C2, and SVA-CAM increased significantly ( $Pr > 0.9999$ ) after the age of 50 years compared with the young adult group of 20–34 years. The SVA-C7 was significantly larger in children from 5 to 9 years ( $Pr=0.995$ ) and decreased during the growth period. The C7/SFD ratio was significantly larger in the small PI group ( $Pr=0.951$ ). Differences between males and females, and between age groups were small and nonsignificant, except for children from 5 to 9 years ( $Pr > 0.9999$ ).

### Inclination Parameters

Table 3 displays inclination parameters by gender, PI, and age. T1-VT, T9-VT, C7-VT, OD-HA, and CAM-HA were nonsignificantly smaller in males than in females. T1-VT and T9-VT increased with PI and were significantly larger in the high PI group ( $Pr=0.982$  and  $Pr=0.995$ ). C7-VT was significantly larger in the small PI group ( $Pr > 0.9999$ ). Small differences were nonsignificant for OD-HA and CAM-HA. Although variations were nonsignificant, all inclination parameters demonstrated similar distributions across age groups: an increase during the growth period and a progressive decrease with aging in adults, except for T9-VT which kept stable in adult age groups (Fig. 4).

### Parameters Including Pelvic Version

There were no significant differences between genders for TPA, GT, and SSA (Table 4). Each parameter increased with PI and their differences were significantly larger in the high PI group compared with medium PI ( $Pr > 0.9999$ , respectively). TPA and GT increased with age and differences were significant after the age of 35 years ( $Pr > 0.9999$  and  $Pr > 0.95$ ). The SSA decreased after the age of 50 years.



**FIGURE 3.** Parameters including pelvic version: the T1-Pelvic Angle (TPA) is measured between T1-femoral axis and sacrofemoral axis. The Global Tilt represents the sum of C7-Vertical Tilt and Pelvic Tilt:  $GT = C7-VT + PT$ . The Spino-Sacral Angle (SSA) is measured between S1 endplate axis and C7-sacral axis.

**TABLE 1.** Overview of Distribution of Spinopelvic Parameters Per Gender Pelvic Incidence (PI) and Age Groups: Mean ± SD (Degrees)

Groups	Cervical Lordosis	Thoracic Kyphosis	Lumbar Lordosis	Pelvic Incidence	Pelvic Tilt	Sacral Slope
Female	-29.1 ± 16.3	42.5 ± 14.0	-55.9 ± 12.3	50.2 ± 12.6	12.6 ± 10.0	37.6 ± 8.9
Male	-31.7 ± 15.8	44.6 ± 13.4	-52.2 ± 12.6	48.8 ± 11.5	12.5 ± 8.9	36.2 ± 8.8
Low PI	-28.7 ± 15.4	40.7 ± 13.0	-48.3 ± 11.6	37.5 ± 5.6	5.9 ± 7.7	31.5 ± 7.5
Medium PI	-31.4 ± 16.8	44.7 ± 14.0	-55.2 ± 11.1	51.9 ± 4.2	14.1 ± 7.3	37.8 ± 6.9
High PI	-30.7 ± 15.6	45.7 ± 14.1	-64.3 ± 10.7	67.9 ± 6.3	21.9 ± 7.8	45.9 ± 7.6
5-9 y	-29.0 ± 16.1	37.5 ± 12.1	-50.8 ± 11.2	39.9 ± 8.7	3.5 ± 7.7	3.5 ± 7.7
10-14 y	-25.8 ± 15.5	38.0 ± 12.2	-54.1 ± 11.5	44.0 ± 10.6	6.0 ± 8.1	6.0 ± 8.1
15-19 y	-29.2 ± 15.4	40.3 ± 12.4	-55.3 ± 11.7	45.5 ± 12.0	8.2 ± 8.1	8.2 ± 8.1
20-34 y	-25.5 ± 15.1	43.3 ± 12.0	-58.2 ± 12.0	50.1 ± 11.3	11.8 ± 7.0	11.8 ± 7.0
35-49 y	-28.4 ± 15.0	43.5 ± 11.9	-55.8 ± 12.8	52.7 ± 12.5	15.0 ± 8.2	15.0 ± 8.2
50-64 y	-32.3 ± 15.9	45.7 ± 13.4	-53.6 ± 13.2	53.1 ± 10.8	16.7 ± 7.5	16.7 ± 7.5
65-79 y	-38.3 ± 15.5	51.5 ± 14.9	-52.1 ± 13.5	55.4 ± 10.5	20.2 ± 7.7	20.2 ± 7.7
> 80 y	-40.3 ± 16.4	52.7 ± 17.6	-50.7 ± 14.5	55.6 ± 11.7	20.6 ± 8.6	20.6 ± 8.6

Lordosis is expressed as negative value and kyphosis as positive value.

**TABLE 2.** Distribution of Translation Parameters (Mean ± SD) and Prediction of Significant Difference (Pr > 0.95) Between Median of Posterior Distributions and Credibility Intervals (95% CI)

Parameter	Variable	Mean ± SD	Median	95% CI	Pr(d > 0)	
SVA-C7 (mm)	Female	11.7 ± 35.2	11.8	[10.0; 13.6]	Reference	
	Male	24.2 ± 36.1	24.1	[22.0; 26.1]	< 6.7×10 <sup>-5</sup>	
	Low PI	7.8 ± 31.6	8.0	[5.8; 10.2]	< 6.7×10 <sup>-5</sup>	
	Medium PI	19.4 ± 35.4	19.4	[17.4; 21.4]	Reference	
	High PI	29.2 ± 41.0	28.9	[25.9; 32.1]	> 0.9999	
	5–9 y	15.7 ± 34.6	14.7	[8.5; 21.0]	0.995	
	10–14 y	8.8 ± 29.6	8.8	[6.0; 11.6]	0.920	
	15–19 y	5.8 ± 26.4	5.9	[2.8; 8.9]	0.577	
	20–34 y	−0.2 ± 33.7	5.4	[1.7; 9.1]	Reference	
	35–49 y	12.3 ± 33.3	12.2	[9.0; 15.3]	0.996	
	50–64 y	22.6 ± 32.7	22.3	[19.3; 25.4]	> 0.9999	
	65–79 y	40.6 ± 37.7	39.6	[36.1; 43.1]	> 0.9999	
	> 80 y	61.8 ± 31.4	56.4	[50.3; 62.6]	> 0.9999	
	SVA-C2 (mm)	Female	26.7 ± 35.2	28.1	[26.0; 30.2]	Reference
		Male	41.1 ± 36.1	42.1	[39.6; 44.5]	< 6.7×10 <sup>-5</sup>
Low PI		22.3 ± 36.0	22.6	[20.0; 25.2]	< 6.7×10 <sup>-5</sup>	
Medium PI		37.4 ± 41.8	37.3	[34.9; 39.7]	Reference	
High PI		49.3 ± 50.0	48.9	[45.0; 52.2]	> 0.9999	
5–9 y		26.1 ± 38.0	25.8	[18.6; 33.0]	0.703	
10–14 y		23.5 ± 31.9	23.5	[20.3; 26.8]	0.493	
15–19 y		21.5 ± 29.5	21.6	[18.1; 25.1]	0.235	
20–34 y		16.5 ± 36.3	23.6	[19.5; 27.8]	Reference	
35–49 y		27.8 ± 37.9	27.7	[24.0; 31.4]	0.928	
50–64 y		39.0 ± 40.1	38.6	[35.1; 42.2]	> 0.9999	
65–79 y		63.4 ± 47.0	61.8	[57.7; 65.9]	> 0.9999	
> 80 y		94.2 ± 64.5	85.3	[78.2; 92.4]	> 0.9999	
SVA-CAM (mm)		Female	27.9 ± 40.6	26.9	[24.7; 29.1]	Reference
		Male	42.3 ± 44.6	40.4	[38.3; 43.4]	> 0.9999
	Low PI	21.1 ± 36.7	21.4	[18.7; 24.1]	< 6.7×10 <sup>-5</sup>	
	Medium PI	36.6 ± 42.5	36.5	[34.0; 39.0]	Reference	
	High PI	46.6 ± 51.8	46.2	[42.4; 50.0]	> 0.9999	
	5–9 y	25.0 ± 37.2	24.8	[17.4; 32.4]	0.641	
	10–14 y	23.7 ± 31.9	23.8	[20.3; 27.2]	0.572	
	15–19 y	22.3 ± 30.0	22.4	[18.6; 26.1]	0.378	
	20–34 y	15.9 ± 37.8	23.3	[19.1; 27.6]	Reference	
	35–49 y	23.8 ± 38.6	23.9	[20.0; 27.7]	0.584	
	50–64 y	36.6 ± 42.5	36.2	[32.5; 39.9]	> 0.9999	
	65–79 y	60.7 ± 48.8	59.0	[54.8; 63.3]	> 0.9999	
	> 80 y	92.2 ± 66.4	82.8	[75.5; 90.2]	> 0.9999	
	C7/SFD ratio	Female	0.7 ± 11.4	0.7	[0.1; 1.2]	Reference
		Male	0.9 ± 10.8	0.9	[0.3; 1.6]	0.730
Low PI		1.2 ± 18.1	1.2	[0.5; 1.9]	0.951	
Medium PI		0.4 ± 1.7	0.4	[−0.1; 1.1]	Reference	
High PI		0.5 ± 0.8	0.5	[−0.4; 1.5]	0.531	
5–9 y		5.7 ± 39.1	5.7	[3.5; 7.9]	> 0.9999	
10–14 y		0.5 ± 14.0	0.5	[−0.5; 1.4]	0.728	
15–19 y		1.3 ± 12.7	1.3	[0.2; 2.3]	0.9321	
20–34 y		−0.1 ± 1.2	−0.1	[−1.5; 1.4]	Reference	
35–49 y		0.2 ± 1.3	0.2	[−0.9; 1.2]	0.603	
50–64 y		0.5 ± 1.4	0.5	[−0.5; 1.6]	0.736	
65–79 y		0.8 ± 0.7	0.8	[−0.4; 2.0]	0.845	
> 80 y		1.3 ± 1.1	1.3	[−0.9; 3.4]	0.846	

CAM indicates Cranial Auditory Meatus; PI, Pelvic Incidence; SFD, Sacrofemoral Distance; SVA, Sagittal Vertical Axis.

### Global Sagittal Alignment

Values for the formula GSA are demonstrated in Table 4. GSA was larger in males (Pr = 0.999) and increased with PI. In the high PI group, GSA was significantly larger compared with the medium PI group (Pr > 0.9999). Figure 4 shows the progressive increase across age groups with significant differences after the age of 35 years (Pr > 0.9999).

### Correlation Between Global and Spinopelvic Alignment

Table 5 displays correlation coefficients ρ between each global alignment parameter and CL, TK, LL, PI, PT, and SS. No correlation was observed for translation and inclination parameters, except for T9-VT which correlated nonsignificantly with TK (ρ = 0.5011) and SS (ρ = 0.5005). Among parameters including pelvic version, TPA correlated with PI (ρ = 0.6130);

**TABLE 3.** Distribution of Inclination Parameters (Mean ± SD) and Prediction of Significant Difference (Pr > 0.95) Between Median of Posterior Distributions and Credibility Intervals (95% CI)

Parameter	Variable	Mean ± SD	Median	95% CI	Pr(d > 0)
T1-VT (degrees)	Female	3.3 ± 3.3	3.3	[3.2; 3.5]	Reference
	Male	2.2 ± 3.3	2.2	[2.0; 2.4]	< 6.7 × 10 <sup>-5</sup>
	Low PI	2.6 ± 3.2	2.6	[2.3; 2.8]	0.006
	Medium PI	2.9 ± 3.3	2.9	[2.7; 3.1]	Reference
	High PI	3.3 ± 3.6	3.3	[2.9; 3.6]	0.982
	5–9 y	1.1 ± 3.3	1.1	[0.5; 1.8]	< 6.7 × 10 <sup>-5</sup>
	10–14 y	2.2 ± 3.3	2.2	[2.0; 2.5]	< 6.7 × 10 <sup>-5</sup>
	15–19 y	2.9 ± 2.5	2.9	[2.7; 3.2]	< 6.7 × 10 <sup>-5</sup>
	20–34 y	4.3 ± 3.0	4.3	[3.9; 4.7]	Reference
	35–49 y	3.8 ± 2.9	3.9	[3.5; 4.2]	0.040
	50–64 y	3.2 ± 3.2	3.2	[2.9; 3.5]	< 6.7 × 10 <sup>-5</sup>
	65–79 y	2.2 ± 3.7	2.2	[1.8; 2.5]	< 6.7 × 10 <sup>-5</sup>
	> 80 y	0.6 ± 4.6	0.6	[0.0; 1.2]	< 6.7 × 10 <sup>-5</sup>
	T9-VT (degrees)	Female	9.2 ± 4.3	9.2	[8.9; 9.4]
Male		8.7 ± 4.0	8.7	[8.5; 9.0]	0.007
Low PI		8.2 ± 4.1	8.2	[7.9; 8.4]	< 6.7 × 10 <sup>-5</sup>
Medium PI		9.3 ± 4.1	9.3	[9.1; 9.5]	Reference
High PI		9.9 ± 4.2	9.9	[9.5; 10.2]	0.995
5–9 y		5.3 ± 3.9	5.3	[4.6; 6.1]	< 6.7 × 10 <sup>-5</sup>
10–14 y		6.8 ± 4.0	6.8	[6.5; 7.2]	< 6.7 × 10 <sup>-5</sup>
15–19 y		7.9 ± 3.6	7.9	[7.6; 8.3]	< 6.7 × 10 <sup>-5</sup>
20–34 y		10.1 ± 3.6	10.1	[9.6; 10.6]	Reference
35–49 y		10.1 ± 3.4	10.1	[9.8; 10.5]	0.577
50–64 y		10.3 ± 3.9	10.3	[9.9; 10.6]	0.718
65–79 y		10.5 ± 4.4	10.5	[10.1; 10.9]	0.900
> 80 y		9.8 ± 4.9	9.8	[9.0; 10.6]	0.268
C7-VT (degrees)		Female	0.1 ± 4.3	0.1	[0.0; 0.3]
	Male	-1.2 ± 4.0	-1.2	[-1.5; -1.0]	< 6.7 × 10 <sup>-5</sup>
	Low PI	0.8 ± 3.8	0.8	[0.5; 1.1]	> 0.9999
	Medium PI	-0.8 ± 4.2	-0.8	[-1.1; -0.6]	Reference
	High PI	-2.0 ± 4.5	-2.0	[-2.4; -1.7]	< 6.7 × 10 <sup>-5</sup>
	5–9 y	-0.3 ± 4.3	-0.3	[-1.1; 0.5]	< 6.7 × 10 <sup>-5</sup>
	10–14 y	0.5 ± 3.8	0.5	[0.2; 0.8]	< 6.7 × 10 <sup>-5</sup>
	15–19 y	0.9 ± 3.0	0.9	[0.5; 1.2]	< 6.7 × 10 <sup>-5</sup>
	20–34 y	1.6 ± 3.8	1.6	[1.1; 2.1]	Reference
	35–49 y	0.2 ± 3.7	0.2	[-0.2; 0.6]	< 6.7 × 10 <sup>-5</sup>
	50–64 y	-1.1 ± 3.8	-1.1	[-1.4; -0.7]	< 6.7 × 10 <sup>-5</sup>
	65–79 y	-3.4 ± 4.4	-3.4	[-3.8; -3.0]	< 6.7 × 10 <sup>-5</sup>
	> 80 y	-5.6 ± 5.2	-5.5	[-6.3; -4.8]	< 6.7 × 10 <sup>-5</sup>
	OD-HA (degrees)	Female	0.7 ± 3.0	0.7	[0.5; 0.9]
Male		-0.4 ± 3.2	0.4	[-0.6; -0.2]	< 6.7 × 10 <sup>-5</sup>
Low PI		0.3 ± 2.9	0.3	[0.1; 0.5]	0.821
Medium PI		0.2 ± 3.2	0.2	[0.0; 0.4]	Reference
High PI		0.3 ± 3.5	0.3	[0.0; 0.6]	0.787
5–9 y		-0.5 ± 3.1	-0.5	[-1.1; 0.1]	< 6.7 × 10 <sup>-5</sup>
10–14 y		0.1 ± 2.8	0.1	[-0.2; 0.3]	< 6.7 × 10 <sup>-5</sup>
15–19 y		0.6 ± 2.2	0.6	[0.3; 0.9]	< 6.7 × 10 <sup>-5</sup>
20–34 y		1.5 ± 2.8	1.5	[1.1; 1.9]	Reference
35–49 y		1.2 ± 2.8	1.2	[0.9; 1.5]	0.117
50–64 y		0.5 ± 3.3	0.5	[0.2; 0.8]	< 6.7 × 10 <sup>-5</sup>
65–79 y		-1.1 ± 3.7	-1.1	[-1.4; -0.8]	< 6.7 × 10 <sup>-5</sup>
> 80 y		-3.1 ± 4.2	-3.1	[-3.7; -2.6]	< 6.7 × 10 <sup>-5</sup>
CAM-HA (degrees)		Female	0.7 ± 3.0	0.8	[0.6; 1.0]
	Male	-0.3 ± 3.3	-0.3	[-0.5; -0.1]	< 6.7 × 10 <sup>-5</sup>
	Low PI	0.4 ± 3.1	0.4	[0.2; 0.6]	0.876
	Medium PI	0.2 ± 3.2	0.2	[0.0; 0.4]	Reference
	High PI	0.4 ± 3.6	0.4	[0.1; 0.7]	0.845
	5–9 y	-0.5 ± 3.0	-0.5	[-1.1; 0.1]	< 6.7 × 10 <sup>-5</sup>
	10–14 y	0.0 ± 2.7	0.0	[-0.2; 0.3]	< 6.7 × 10 <sup>-5</sup>
	15–19 y	0.5 ± 2.2	0.5	[0.2; 0.8]	< 6.7 × 10 <sup>-5</sup>
	20–34 y	1.5 ± 2.7	1.5	[1.1; 1.9]	Reference
	35–49 y	1.4 ± 3.3	1.4	[1.1; 1.7]	0.436
	50–64 y	0.6 ± 3.3	0.6	[0.3; 0.9]	< 6.7 × 10 <sup>-5</sup>
	65–79 y	-0.8 ± 3.7	-0.9	[-1.2; -0.5]	< 6.7 × 10 <sup>-5</sup>
	> 80 y	-2.8 ± 4.3	-2.8	[-3.4; -2.1]	< 6.7 × 10 <sup>-5</sup>

CAM-HA indicates Cranial Auditory Meatus-Hip Axis; OD-HA, Odontoid-Hip Axis; PI, Pelvic Incidence; VT, Vertical Tilt.

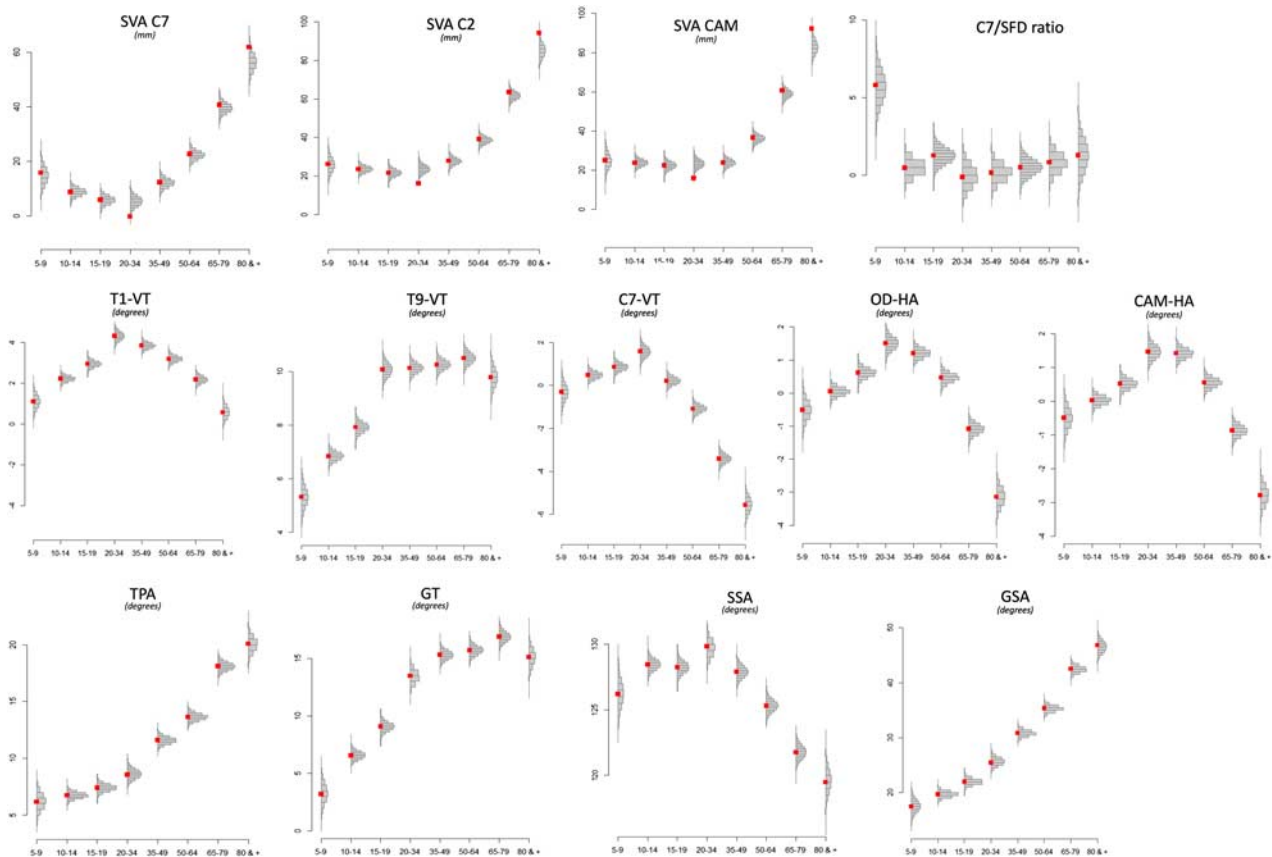


FIGURE 4. Distribution of global alignment parameters per age group. Red squares indicate median values. [full color online](#)

Pr > 0.9999) and PT ( $\rho = 0.8375$ ; Pr > 0.9999), GT correlated with PI ( $\rho = 0.5961$ ; Pr > 0.9999) and PT ( $\rho = 0.8996$ ; Pr > 0.9999), and SSA correlated with SS ( $\rho = 0.9026$ ; Pr > 0.9999). The formula GSA correlated with PT ( $\rho = 0.7732$ ; Pr > 0.9999).

## DISCUSSION

When analyzing sagittal alignment and spinal deformity, SVA-C7 represents a commonly used translation parameter in clinical practice, and values below 50 mm are considered as normal.<sup>12</sup> SVA-C2 and SVA-CAM represent similar parameters including the cervical segment and head position. SVA measurements based on radiographic plumbines do not correlate with the gravity line determined by force platforms.<sup>22</sup> Vaz et al<sup>23</sup> demonstrated that the average gravity line was 9 mm anterior to the midpoint between femoral heads in young healthy adults. Steffen et al<sup>24</sup> confirmed that the average gravity line was close to the hip axis, 16 mm posterior to the CAM and 28 mm posterior to the T1 plumbines in asymptomatic volunteers. Radiographic SVA parameters remain a description of global alignment changes in a patient between different time points. Translation parameters might not be compared between different patients because they do not include spinopelvic compensation mechanisms into account. A full description of sagittal alignment using

translation parameters requires additional assessment of kyphosis and lordosis distribution as well as PT. Furthermore, SVA parameters vary according to gender, PI, and age. In the present study, SVA-C7, SVA-C2, and SVA-CAM were larger in males, who had larger mean values for TK and LL. However, there was no direct correlation between translation parameters and TK or LL. Hu et al<sup>2</sup> and Bassani et al<sup>3</sup> described similar results for SVA-C7. In addition, SVA values increased with PI, which reflects an increase of pelvic width in the sagittal plane. Protosaltis et al<sup>8</sup> reported SVA-C7 thresholds that increased proportionally to PI in adult spinal deformity patients, which should be considered preoperatively. A progressive increase of SVA-C7 with age was reported for adult populations without spinal deformity,<sup>1-3</sup> which is consistent with our findings. Lafage et al<sup>5,6</sup> suggested age-related thresholds when operating patients with adult spinal deformity. Larger variations for SVA-C7 existed in children and adolescents, where values were generally smaller. Vedantam et al<sup>25</sup> reported smaller and even negative values in adolescents compared with adults. This might be linked to erector spinae muscle strength which decreases with muscular dystrophy during aging. A large variability was also observed for the C7/SFD ratio during growth, similar to SVA-C7. This parameter appears even more sensitive to pelvic morphology. Mac-Thiong et al<sup>26</sup> demonstrated that PI increased during childhood and

**TABLE 4.** Distribution of Global Alignment Parameters Including Pelvic Version and Global Sagittal Alignment Formula (Mean ± SD) and Prediction of Significant Difference (Pr > 0.95) Between Median of Posterior Distributions and Credibility Intervals (95% CI)

Parameter	Variable	Mean ± SD	Median	95% CI	Pr(d > 0)
TPA (degrees)	Female	10.8 ± 8.1	10.8	[10.4; 11.2]	Reference
	Male	11.3 ± 7.5	11.3	[10.8; 11.7]	0.930
	Low PI	6.4 ± 4.9	6.4	[6.0; 6.9]	< 6.7 × 10 <sup>-5</sup>
	Medium PI	11.5 ± 6.9	11.5	[11.2; 11.9]	Reference
	High PI	18.7 ± 8.0	18.7	[18.2; 19.3]	> 0.9999
	5–9 y	6.2 ± 5.1	6.2	[4.9; 7.5]	0.001
	10–14 y	6.7 ± 5.1	6.7	[6.2; 7.3]	< 6.7 × 10 <sup>-5</sup>
	15–19 y	7.4 ± 5.6	7.4	[6.8; 8.0]	0.013
	20–34 y	8.5 ± 5.9	8.4	[7.8; 9.5]	Reference
	35–49 y	11.6 ± 7.7	11.6	[11.0; 12.2]	> 0.9999
	50–64 y	13.6 ± 7.1	13.6	[13.0; 14.3]	> 0.9999
	65–79 y	18.1 ± 7.7	18.1	[17.4; 18.8]	> 0.9999
	> 80 y	20.1 ± 8.1	20.1	[18.8; 21.3]	> 0.9999
	GT (degrees)	Female	12.8 ± 9.4	12.8	[12.3; 13.2]
Male		11.3 ± 8.8	11.3	[10.8; 11.9]	< 6.7 × 10 <sup>-5</sup>
Low PI		6.8 ± 8.0	6.8	[6.3; 7.3]	< 6.7 × 10 <sup>-5</sup>
Medium PI		13.3 ± 7.5	13.3	[12.9; 13.8]	Reference
High PI		20.0 ± 8.2	20.0	[19.3; 20.7]	> 0.9999
5–9 y		3.2 ± 7.9	3.3	[1.7; 4.9]	< 6.7 × 10 <sup>-5</sup>
10–14 y		6.6 ± 8.6	6.6	[5.9; 7.3]	< 6.7 × 10 <sup>-5</sup>
15–19 y		9.1 ± 7.9	9.1	[8.3; 9.8]	< 6.7 × 10 <sup>-5</sup>
20–34 y		13.5 ± 7.0	13.4	[12.4; 14.5]	Reference
35–49 y		15.3 ± 8.0	15.3	[14.5; 16.1]	0.996
50–64 y		15.7 ± 8.0	15.7	[14.9; 16.5]	0.999
65–79 y		16.9 ± 8.3	16.9	[16.0; 17.8]	> 0.9999
> 80 y		15.1 ± 10.3	15.1	[13.5; 16.7]	0.958
SSA (degrees)		Female	127.7 ± 9.9	127.7	[127.2; 128.2]
	Male	125.0 ± 9.5	125.0	[124.5; 125.6]	< 6.7 × 10 <sup>-5</sup>
	Low PI	122.3 ± 8.3	122.3	[121.8; 122.9]	< 6.7 × 10 <sup>-5</sup>
	Medium PI	127.0 ± 8.7	127.0	[126.5; 127.5]	Reference
	High PI	133.9 ± 9.4	133.9	[133.1; 134.7]	> 0.9999
	5–9 y	126.2 ± 9.3	126.2	[124.4; 128.1]	0.001
	10–14 y	128.4 ± 9.1	128.5	[127.4; 129.3]	0.048
	15–19 y	128.2 ± 9.4	128.2	[127.4; 129.1]	0.028
	20–34 y	129.8 ± 9.5	129.7	[128.5; 130.9]	Reference
	35–49 y	127.9 ± 9.8	127.9	[127.0; 128.8]	0.001
	50–64 y	125.3 ± 9.3	125.3	[124.4; 126.2]	< 6.7 × 10 <sup>-5</sup>
	65–79 y	121.8 ± 9.4	121.8	[120.8; 122.8]	< 6.7 × 10 <sup>-5</sup>
	> 80 y	119.5 ± 10.1	119.6	[117.8; 121.4]	< 6.7 × 10 <sup>-5</sup>
	GSA (degrees)	Female	28.3 ± 15.2	28.3	[27.6; 29.0]
Male		30.2 ± 12.9	30.2	[29.4; 31.1]	0.999
Low PI		21.7 ± 12.0	21.7	[20.9; 22.5]	< 6.7 × 10 <sup>-5</sup>
Medium PI		31.1 ± 13.1	31.1	[30.4; 31.9]	Reference
High PI		38.9 ± 13.7	38.9	[37.8; 40.0]	> 0.9999
5–9 y		17.5 ± 12.0	17.6	[15.4; 19.9]	< 6.7 × 10 <sup>-5</sup>
10–14 y		19.7 ± 11.3	19.7	[18.7; 20.7]	< 6.7 × 10 <sup>-5</sup>
15–19 y		22.0 ± 11.3	22.0	[20.9; 23.0]	< 6.7 × 10 <sup>-5</sup>
20–34 y		25.5 ± 11.0	25.7	[24.2; 27.1]	Reference
35–49 y		30.9 ± 11.6	30.8	[29.7; 31.9]	> 0.9999
50–64 y		35.3 ± 10.8	35.3	[34.3; 36.4]	> 0.9999
65–79 y		42.5 ± 12.0	42.5	[41.3; 43.7]	> 0.9999
> 80 y		46.8 ± 12.2	46.6	[44.6; 48.8]	> 0.9999

GSA indicates Global Sagittal Alignment; GT, Global Tilt; PI, Pelvic Incidence; SSA, Spino-Sacral Angle; TPA, T1-Pelvic Angle.

adolescence before stabilizing into adulthood. This might influence the sacrofemoral distance and thus the C7/SFD ratio. Barrey et al<sup>13</sup> described variations of this ratio related to disc hernia, discopathy and degenerative spondylolisthesis compared with asymptomatic adults. In the present study, however, this parameter kept relatively stable after skeletal maturity and variations were non-significant during aging.

Inclination parameters reflect global trunk version around the hip axis (T1-VT and T9-VT) or around the midpoint of the S1 endplate (C7-VT). The ranges in adults were consistent with average values from previous studies for T1-VT and T9-VT<sup>14,27</sup> and for C7-VT.<sup>15</sup> Small differences existed between males and females and the amount of PI influenced inclination parameters. A similar increase was observed for each parameter during the

**TABLE 5.** Correlation Between Global Alignment and Spinopelvic Parameters: Correlation Coefficients  $\rho$  Strong if  $\rho < -0.5$  or  $\rho > 0.5$ , and Prediction of Significance only if  $Pr > 0.95$  Indicated Below Each Coefficient

Parameters	Cervical Lordosis	Thoracic Kyphosis	Lumbar Lordosis	Pelvic Incidence	Pelvic Tilt	Sacral Slope
SVA-C7	-0.2978 < 6.7×10 <sup>-5</sup>	0.1125 < 6.7×10 <sup>-5</sup>	0.2681 < 6.7×10 <sup>-5</sup>	0.2314 < 6.7×10 <sup>-5</sup>	0.3040 < 6.7×10 <sup>-5</sup>	-0.0094 < 6.7×10 <sup>-5</sup>
SVA-C2	-0.2731 < 6.7×10 <sup>-5</sup>	0.2102 < 6.7×10 <sup>-5</sup>	0.2091 < 6.7×10 <sup>-5</sup>	0.2479 < 6.7×10 <sup>-5</sup>	0.3124 < 6.7×10 <sup>-5</sup>	0.0040 < 6.7×10 <sup>-5</sup>
SVA-CAM	-0.2108 < 6.7×10 <sup>-5</sup>	0.1918 < 6.7×10 <sup>-5</sup>	0.2015 < 6.7×10 <sup>-5</sup>	0.2324 < 6.7×10 <sup>-5</sup>	0.2884 < 6.7×10 <sup>-5</sup>	0.0083 < 6.7×10 <sup>-5</sup>
C7/SFD ratio	-0.0359 < 6.7×10 <sup>-5</sup>	-0.0064 < 6.7×10 <sup>-5</sup>	0.0130 < 6.7×10 <sup>-5</sup>	-0.0285 < 6.7×10 <sup>-5</sup>	-0.0566 < 6.7×10 <sup>-5</sup>	0.0218 < 6.7×10 <sup>-5</sup>
T1-VT	0.1786 < 6.7×10 <sup>-5</sup>	0.0671 < 6.7×10 <sup>-5</sup>	-0.2024 < 6.7×10 <sup>-5</sup>	0.1052 < 6.7×10 <sup>-5</sup>	-0.1227 < 6.7×10 <sup>-5</sup>	0.2491 < 6.7×10 <sup>-5</sup>
T9-VT	-0.1376 < 6.7×10 <sup>-5</sup>	0.5011 < 6.7×10 <sup>-5</sup>	-0.2024 < 6.7×10 <sup>-5</sup>	0.1787 < 6.7×10 <sup>-5</sup>	-0.2915 < 6.7×10 <sup>-5</sup>	0.5005 < 6.7×10 <sup>-5</sup>
C7-VT	0.3118 < 6.7×10 <sup>-5</sup>	-0.1144 < 6.7×10 <sup>-5</sup>	-0.2590 < 6.7×10 <sup>-5</sup>	-0.2648 < 6.7×10 <sup>-5</sup>	-0.3144 < 6.7×10 <sup>-5</sup>	-0.0247 < 6.7×10 <sup>-5</sup>
OD-HA	0.2110 < 6.7×10 <sup>-5</sup>	-0.1543 < 6.7×10 <sup>-5</sup>	-0.1534 < 6.7×10 <sup>-5</sup>	0.0102 < 6.7×10 <sup>-5</sup>	0.1111 < 6.7×10 <sup>-5</sup>	-0.1048 < 6.7×10 <sup>-5</sup>
CAM-HA	0.1639 < 6.7×10 <sup>-5</sup>	-0.1327 < 6.7×10 <sup>-5</sup>	-0.1358 < 6.7×10 <sup>-5</sup>	0.0108 < 6.7×10 <sup>-5</sup>	0.1231 < 6.7×10 <sup>-5</sup>	-0.1165 < 6.7×10 <sup>-5</sup>
TPA	-0.2051 < 6.7×10 <sup>-5</sup>	0.1528 < 6.7×10 <sup>-5</sup>	0.1542 < 6.7×10 <sup>-5</sup>	0.6130 > 0.9999	0.8375 > 0.9999	-0.0596 < 6.7×10 <sup>-5</sup>
GT	-0.0062 < 6.7×10 <sup>-5</sup>	0.1182 < 6.7×10 <sup>-5</sup>	0.0095 < 6.7×10 <sup>-5</sup>	0.5961 > 0.9999	0.8996 > 0.9999	-0.1492 < 6.7×10 <sup>-5</sup>
SSA	0.2125 < 6.7×10 <sup>-5</sup>	-0.0183 < 6.7×10 <sup>-5</sup>	-0.8459 < 6.7×10 <sup>-5</sup>	0.4648 < 6.7×10 <sup>-5</sup>	-0.2559 < 6.7×10 <sup>-5</sup>	0.9026 > 0.9999
GSA	-0.3366 < 6.7×10 <sup>-5</sup>	0.4313 < 6.7×10 <sup>-5</sup>	0.1233 < 6.7×10 <sup>-5</sup>	0.4936 < 6.7×10 <sup>-5</sup>	0.7732 > 0.9999	-0.1687 < 6.7×10 <sup>-5</sup>

CAM indicates Cranial Auditory Meatus; CAM-HA, Cranial Auditory Meatus-Hip Axis; GSA, Global Sagittal Alignment; GT, Global Tilt; OD-HA, Odontoid-Hip Axis; SFD, Sacrofemoral Distance; SSA, Spino-Sacral Angle; SVA, Sagittal Vertical Axis; TPA, T1-Pelvic Angle; VT, Vertical Tilt.

growth period. The maximum in young adults could be related to strong erector spinae muscles in this age group. A progressive decrease with aging was then mainly observed for T1-VT and C7-VT in parallel to TK increase in the cranial thoracic segment. Vialle et al<sup>27</sup> demonstrated a correlation between TK, SS, and T9-VT, which was confirmed in the present study. T9-VT was anatomically influenced by the amount of TK, which increased with PI. However, variations of T9-VT were smaller during aging which might be explained by a cranial TK increase in elderly individuals. Amabile et al<sup>16</sup> described OD-HA and CAM-HA as quasi-invariant inclination parameters including the cervical spine. This was based on the rationale that the gravity line was close to the hip axis and CAM, and that the head remains positioned above the femoral heads in a balanced standing position.<sup>24,28</sup> Variations of these parameters kept small in adults older than 49 years, even if SVA-C7 and PT increased. The present study confirms that both parameters keep relatively constant across age groups and that only small change occurs after the age of 65 years. Progressively negative values might reflect anterior head inclination and decompensation of horizontal gaze.

TPA, GT and SSA represent parameters that include pelvic compensation mechanisms such as retroversion. Iyer et al<sup>1</sup> and Hu et al<sup>2</sup> demonstrated that TPA and PT increased with age in individuals without spinal pathology. Lafage et al<sup>3,6</sup> and Ryan et al<sup>17</sup> described the relationship between TPA, age, PT, and PI-LL in adult spinal

deformity. Protosaltis et al<sup>8</sup> further demonstrated that TPA correlated with age and PI. Likewise, Boissière et al<sup>29</sup> showed that GT was linked to PT, PI-LL, and LL distribution with an influence on quality of life in adult deformity patients. Our results on individuals without deformity are in line with these findings, and the correlation with PT and PI was confirmed. TPA and GT increase with age in parallel to PT. In addition, individuals with large PI, classified as Roussouly type 4,<sup>9</sup> have a larger PT and thus a larger TPA and GT. Therefore, the spinopelvic configuration should be considered when evaluating these parameters. Similarly, SSA decreased after 50 years and correlated with SS as a consequence of progressive pelvic retroversion and more vertical position of the sacrum. This observation is in line with physiological changes of SSA described by Roussouly and Nnadi.<sup>18</sup>

The formula GSA includes the amount of TK, LL, and PI. Yagi et al<sup>20</sup> and Rose et al<sup>30</sup> used a threshold below 45 degrees for this global alignment parameter when treating patients with adult spinal deformity. Our study demonstrated that GSA increased progressively in parallel to TK, LL, and PI changes with age. Furthermore, GSA correlated with PT, which indicates a link of this parameter with pelvic retroversion. Like for TPA, GT, and SSA, differences existed between PI groups, suggesting that the spinopelvic configuration needs to be analyzed when considering thresholds for GSA.

This cross-sectional study has limitations as the evolution of alignment parameters cannot be assessed over

a lifetime. Quality of life scores were not assessed, although clinical symptoms and pain might influence radiographic alignment. Furthermore, degenerative changes represented an inevitable phenomenon of aging. Intervertebral disc degeneration, facet joint osteoarthritis, degenerative spondylolisthesis, coxarthrosis, and hip flexion contractures might influence sagittal alignment, which was not analyzed retrospectively. Although severe degenerative changes leading to thoracolumbar deformity were excluded, it remained difficult to define the exact threshold between physiological compensation mechanisms in the elderly and mild anterior malalignment.

## CONCLUSION

This observational study demonstrates that values for global alignment parameters vary with age, gender and spinopelvic alignment type. An anterior plumbline displacement of C7, C2, and CAM is observed with age and more prominent in males and large PI. Trunk inclination parameters show smaller variations, but differences exist according age and PI. Parameters including pelvic version and GSA increase with age and are closely related to PT and the spinopelvic morphology.

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