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ORIGINAL ARTICLE

The standing and sitting sagittal spinopelvic alignment of Chinese young and elderly population: does age influence the differences between the two positions?

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Abstract

Purpose To investigate the characteristics of standing and sitting spinopelvic sagittal alignment among Chinese healthy population with different age groups.

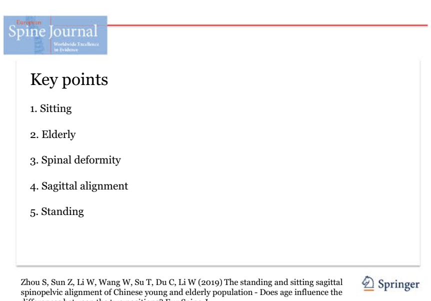
Method This cross-sectional, prospective study included a total of 235 volunteers aged 19 to 71 years. Volunteers were divided into two groups: group A (age ≤ 40 years; $n = 140$) and group B (age > 40 years, $n = 95$). Student's t test was performed to compare the sagittal parameters including sagittal vertical axis (SVA), T1 pelvic angle (TPA), cervical lordosis (CL), thoracic kyphosis (TK), lumbar lordosis (LL) and pelvic tilt (PT) between standing and sitting positions of two groups. Multiple regression was performed to explore the influence factors of differences between two positions.

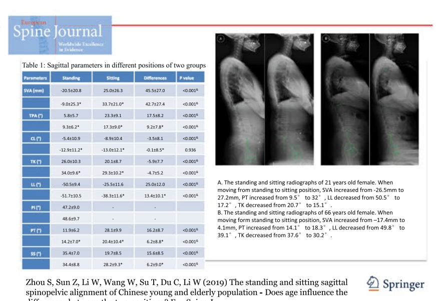
Results In the standing position, group B had larger SVA, TK, PT and TPA than group A. When moving from standing to sitting position, increased SVA and PT were found in both groups, accompanied by decreased LL and TK. However, despite similar change in SVA, group B presented with lesser changes in LL, PT and TPA than group A in sitting position. Age and gender independently influenced the difference in PT and LL.

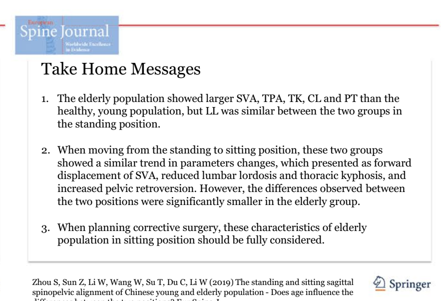
Conclusion In the standing position, the older volunteers showed larger SVA, TPA, TK, CL and PT than young population. Both groups showed similar changes when moving from standing to sitting, but the differences between the positions were smaller in older population. These characteristics in the standing and sitting positions of different age groups should be considered when planning surgical reconstruction of sagittal alignment.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







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Extended author information available on the last page of the article

Keywords Sitting · Elderly · Spinal deformity · Sagittal alignment · Standing

Introduction

It has been widely recognized that spinopelvic sagittal alignment plays a vital role in the treatment of spinal deformity and degenerative disease [1, 2]. Achieving a suitable sagittal alignment can be a predictor of better clinical outcome [3, 4] and fewer surgical complications [5, 6]. However, what the optimum alignment should be is still in debated, and it also varies between ethnic, age and even bodily position [7–9].

Current optimal values of sagittal parameters are mainly based on standing radiographs [10–12], while sitting is also a common weight-bearing position in daily life as standing [13], and there is evidence that the spine straightens with a forward displacement of the center of gravity and pelvic retroversion when moving from standing to sitting [9, 14]. Thus, restoring the sagittal alignment simply based on standing sagittal plane will make the spine bear unsuitable stress in sitting position [9], since fusion surgery renders the spine in this curvature. With respect to the increase in the incidence of proximal junctional failure associated with the rise of sagittal deformity correction [15], the present standing-only correction goals may be responsible for rising incidence of proximal junctional failure [9].

Therefore, it is necessary to characterize the normal sitting sagittal plane and explore the regulatory mechanism between the two positions. Although previous studies have attempted to characterize the differences between standing and sitting sagittal alignment, some deficiencies existed in these studies. First, most studies recruited patients who had symptoms or even spinal disease, and there still lacked the data from healthy middle aged and elderly population. Second, the sample size for some studies was relatively small. Third, some studies focused only on the lumbar–pelvic alignment, neglecting the whole spinal change [9, 16–18].

Therefore, the objectives of this study were to investigate the alignment of the entire spine and pelvis from standing to sitting position in healthy Chinese population with different age groups and then explore how age influenced this mechanism.

Materials and methods

Study design

This was a cross-sectional prospective study which was approved by the Ethics Committee of Peking University Third Hospital and was performed within the principles of the Declaration of Helsinki. All volunteers were fully informed about the methods, purposes and risks involved in the study protocol and provided their signed informed consent.

Patients

Before participating in the current study, a detailed history was taken from all volunteers and each underwent a physical examination. Finally, 235 healthy Chinese volunteers from Beijing were included in the study based on following inclusion criteria, and all volunteers had Oswestry Disability Index (ODI) and Neck Disability Index (NDI) less than 10.

1. Aged from 18 to 75.
2. No neck and back pain in the previous 6 months.
3. No history of radicular symptoms.
4. No history of chronic neck or back pain.
5. No previous history of spinal diseases and surgery.
6. No coronal deformity or lumbar spondylolisthesis.
7. No history of hip or knee arthroplasty or other realignment surgery of the lower extremities.
8. No history of neuromuscular disorders.
9. Not pregnant.

Radiographic evaluation

The lateral standing and sitting radiographs were obtained from all volunteers in standardized ways (Fig. 1). In the standing position, volunteers were requested to stand as

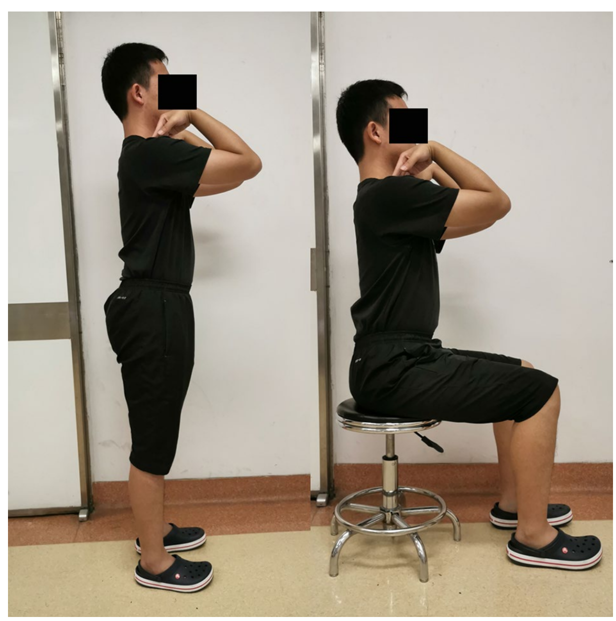

Fig. 1 Photographs to instruct the patients in standing (left) and sitting (right) positions

straight as possible, with fingers touching the homolateral collar bones. In the sitting position, volunteers were asked to flex their hips and knees to 90°, and sit as straight as possible, with fingers touching the homolateral collar bones. A height-adjustable stool without a back-rest was provided for volunteers so that they could adjust the height to reach a standardized posture and put their feet flat on the ground. If the volunteers' feet could not touch the ground after adjusting the stool height, a wooden step was provided.

All radiographic measurements were performed by two orthopedic specialists who were not otherwise involved in this study, and the average of their results was recorded. Using the PACS system (Picture Archiving and Communication System, GE Healthcare, Mount Prospect, IL, USA), the following parameters were measured. (1) Global parameters: sagittal vertical axis (SVA); T1 pelvic angle (TPA), the angle between the line from the femoral head axis to the centroid of T1 and the line from the femoral head axis to the middle of the S1 endplate [19]. (2) Local curvature: lumbar lordosis (LL); thoracic kyphosis (TK) and cervical lordosis (CL). (3) Pelvic parameters: pelvic incidence (PI); pelvic tilt (PT) and sacral slope (SS). The measurements of sagittal parameters are shown in Fig. 2.

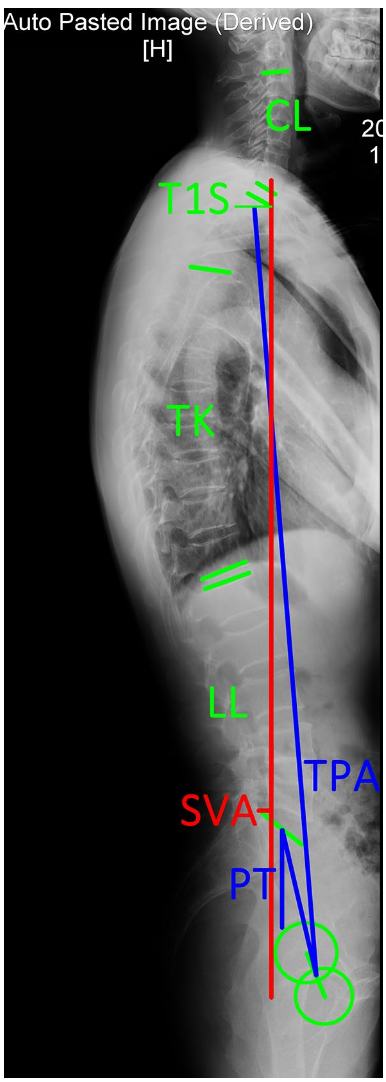

Fig. 2 The measurements of sagittal parameters

Statistical analysis

All analyses were performed using SPSS version 19.0 (SPSS Inc., Chicago, IL, USA). The continuous radiological parameters were compared in the standing and sitting positions using paired t tests. Volunteers were divided into different groups based on age to demonstrate its influence on mechanism of moving from standing to sitting position. Statistical significance was set at a level of $P < 0.05$, and Bonferroni correction was used to counteract the problem of multiple comparisons. Inter-observer reliability was assessed using intraclass correlation coefficient (ICC) and characterized as excellent (ICC ≥ 0.9), good (0.7 ≤ ICC < 0.9), acceptable (0.6 ≤ ICC < 0.7), poor (0.5 ≤ ICC < 0.6) or unpredictable (ICC < 0.5). Multifactor regression analysis was performed to explore the influence factors of differences between two positions.

Results

General profiles

Of the 235 volunteers, 89 were males and 146 were females, with ages ranging from 19 to 71 years. They were divided into two groups based on age. Group A (the young group with age ≤ 40 years) comprised 49 males and 91 females with an average age of 23.2 ± 2.6 years (range 19–39 years). The average height, weight and BMI in group A were 1.68 ± 0.08 meters (m), 60.2 ± 11.2 kilograms (kg) and 21.1 ± 2.6 kg/m^2, respectively. Group B (the older group including middle aged and elderly people with age > 40 years) comprised 40 males and 55 females with an average of 53.3 ± 6.2 years (range 42–71 years). The average height, weight and BMI in group B were 1.64 ± 0.07 m, 65.8 ± 10.1 kg and 24.5 ± 3.0 kg/m^2, respectively.

Sagittal alignment in different positions

As presented in Table 1, the inter-observer reliability ranged from good to excellent for all measured sagittal parameters.

In the standing position, group B was characterized by a larger SVA (− 9.0 mm ± 25.3 mm vs − 20.5 mm ± 20.8 mm, $P < 0.001$) and TPA (9.3° ± 6.2° vs 5.8° ± 5.7°, $P = 0.004$) than group A, accompanied by a larger CL (5.4° ± 10.9° vs 12.9° ± 11.2°, $P < 0.001$), TK (34.0° ± 9.6° vs 26.0° ± 10.3°,

Table 1 Interobserver reliability of sagittal parameters

Parameters	Inter-rater ICC	Inter-rater reliability
SVA	0.93	Excellent
TPA	0.99	Excellent
CL	0.98	Excellent
TK	0.92	Excellent
LL	0.89	Good
PI	0.89	Good
PT	0.92	Excellent
SS	0.76	Good

$P<0.001$) and PT (14.2° ± 7.0° vs 11.9° ± 6.2°, $P=0.009$). However, PI was similar between the two groups (48.6° ± 9.7° vs 47.2° ± 9.0°, $P=0.266>0.05$), and the LL of group B was also close to that of group A (51.7° ± 10.5° vs 50.5° ± 9.4°, $P=0.383>0.05$).

When moving from standing to sitting position, significant forward movement of SVA was observed in both groups ($P<0.001$), and this change was followed by straightening of the entire spine, with a significant decrease in LL and TK ($P<0.001$) in both groups. With respect to the pelvic parameters, PT increased and SS decreased in both groups, which demonstrated that pelvic retroversion occurred from standing to sitting.

Although a similar trend of measurement changes was observed in older people of group B and the young volunteers of group A when moving from standing to sitting position, the measurement differences between positions were significantly smaller in group B. As shown in Table 2, despite that similar differences between standing and sitting positions were observed for SVA in both groups (42.7 mm ± 27.4 mm vs 45.5 mm ± 27.0 mm, $P=0.441>0.05$), the differences in TPA (9.2° ± 7.8° vs 17.5° ± 8.2°, $P<0.001$), PT (6.2° ± 8.8° vs 16.2° ± 8.7°, $P<0.001$), SS (6.2° ± 9.0° vs 15.6° ± 8.5°, $P<0.001$) and LL (13.4° ± 10.1° vs 25.0° ± 12.0°, $P<0.001$) were significantly smaller in group B than in group A. With respect to TK, although the difference between standing and sitting positions in group B was not significantly smaller than that in group A (4.7° ± 5.2° vs 5.9° ± 7.7°, $P=0.145>0.05$), the percentage of decrease in TK was only 14% in group B, compared with 23% in group A. The sitting and standing values for CL remained the same in group B (13.0° ± 12.1° vs 12.9° ± 11.2°, $P=0.936$), whereas it significantly increased in group A ($P<0.001$).

Potential influence factors of the differences between two positions

As shown in Table 2, lumbopelvic parameters changed most significantly from standing to sitting, so we explored how the factors including age, gender, height, weight and body

Table 2 Sagittal parameters in different positions of two groups

Parameters	Standing	Sitting	Differences	P value
SVA (mm)	− 20.5 ± 20.8	25.0 ± 26.3	45.5 ± 27.0	< 0.001&
	− 9.0 ± 25.3*	33.7 ± 21.0*	42.7 ± 27.4	< 0.001&
TPA (°)	5.8 ± 5.7	23.3 ± 9.1	17.5 ± 8.2	< 0.001&
	9.3 ± 6.2*	17.3 ± 9.0*	9.2 ± 7.8*	< 0.001&
CL (°)	− 5.4 ± 10.9	− 8.9 ± 10.4	− 3.5 ± 8.1	< 0.001&
	− 12.9 ± 11.2*	− 13.0 ± 12.1*	− 0.1 ± 8.5*	0.936
TK (°)	26.0 ± 10.3	20.1 ± 8.7	− 5.9 ± 7.7	< 0.001&
	34.0 ± 9.6*	29.3 ± 10.2*	− 4.7 ± 5.2	< 0.001&
LL (°)	− 50.5 ± 9.4	− 25.5 ± 11.6	25.0 ± 12.0	< 0.001&
	− 51.7 ± 10.5	− 38.3 ± 11.6*	13.4 ± 10.1*	< 0.001&
PI (°)	47.2 ± 9.0	–	–	
	48.6 ± 9.7	–	–	
PT (°)	11.9 ± 6.2	28.1 ± 9.9	16.2 ± 8.7	< 0.001&
	14.2 ± 7.0*	20.4 ± 10.4*	6.2 ± 8.8*	< 0.001&
SS (°)	35.4 ± 7.0	19.7 ± 8.5	15.6 ± 8.5	< 0.001&
	34.4 ± 8.8	28.2 ± 9.3*	6.2 ± 9.0*	< 0.001&

The upper line presented the data from group A (young volunteers), and the lower line presented the data from group B (older volunteers)

*Means compared with group A, $P<0.025$ (adjusted by using Bonferroni correction)

&Compared with standing position, $P<0.025$ (adjusted by using Bonferroni correction)

Table 3 The results of multiple linear regression analysis in influence factors of ΔPT

	Regression coefficient	P value	Standardized coefficient
Intercept	73.224	0.448	0
Age	− 0.287	< 0.001	− 0.441
Gender	− 3.890	0.028	− 0.189
Height	− 31.809	0.583	− 0.250
Weight	0.521	0.490	0.578
BMI	− 1.292	0.542	− 0.411

ΔPT is equal to PT in sitting minus PT in standing

Table 4 The results of multiple linear regression analysis in influence factors of ΔLL

	Regression coefficient	P value	Standardized coefficient
Intercept	− 20.544	0.868	0
Age	0.359	< 0.001	0.439
Gender	4.781	0.035	0.184
Height	− 3.915	0.958	− 0.024
Weight	− 0.096	0.921	− 0.085
BMI	− 0.078	0.977	− 0.020

ΔLL is equal to LL in sitting minus LL in standing mass index (BMI) influenced the differences in lumbopelvic parameters between two positions.

According to Tables 3 and 4, age and gender were independently associated with Δ PT and Δ LL. With increase in age, the increase in PT and decrease in LL from standing to sitting were smaller. Males presented smaller increase in PT and decrease in LL from standing to sitting than females.

Discussion

Spinal fusion renders the spine immobile in a fixed curvature, so the spine surgeon should design this curvature referring to the normal alignment of healthy population and coordinated with patient's age [20, 21]. Previous surgical strategy only takes the standing sagittal plane into consideration, but ignores sitting, which is a position as common as standing in daily life and involves a different alignment to standing [18, 22]. In this case, the fixed "standing" spine after long fusion cannot move into a suitable alignment during sitting and have to bear abnormal stress in this position [23], which may be related with post-fusion pain and postoperative complication such as proximal junction kyphosis (PJK) [9, 24]. In order to optimize the current surgical strategy, it is necessary to characterize the standing and sitting sagittal alignment in healthy population of different age groups.

Some studies have demonstrated that LL decreases and PT increases in the sitting position, but these studies only focused on the local lumbar–pelvic sagittal alignment [18, 25, 26]. Few studies have taken the whole spinal change into account and found that TK decreased and CL increased, followed by forward-moving SVA from standing to sitting in healthy young subjects [9] and children with scoliosis [14]. Furthermore, Suzuki et al. [17] proposed that the sitting sagittal alignment might also vary between different age groups. They found that the changes in lumbar curvature and pelvic retroversion were smaller among the elderly when moving from standing to sitting position due to poor lumbar–pelvic mobility. However, the elderly patients included in their study had degenerative spinal diseases and therefore could not reflect the normal status of a healthy elderly population. Given the fact that old people may share a different sagittal alignment in sitting position compared to young adults, exploring the standard sitting sagittal plane in middle aged and elderly population is necessary for the surgical planning. The advantages of our study over others are that all recruited volunteers were strictly selected and our sample size is relatively large. To the best of our knowledge, this is the first study to demonstrate the standing and sitting spinopelvic sagittal alignment in Chinese young and older population.

This study revealed the middle aged and elderly population presented with larger CL, SVA, TK, TPA and PT in the standing position than the young population. These differences might be due to the age-related degeneration of the spine, as SVA and TK both increased with age, accompanied by an increased PT to rebalance the spine. CL increased with TK since a larger thoracic curvature demanded a larger cervical lordosis to maintain the horizontal eyesight. TPA, which is the combination of truncal inclination and pelvic retroversion, increased with SVA and PT. Our findings were consistent with another prospective study, which demonstrated that SVA, CL, TPA, TK and PT increased with age in an asymptomatic population [20]. Korovessis et al. [27] have also reported that TK increased with age in an asymptomatic Greek population. By contrast, we found that LL was similar in our older and young groups, and this contradicts a former study, suggesting that LL should be smaller in the elderly [20]. Our study only recruited few volunteers over the age of 70 years, which might explain this discrepancy, since age-related loss of LL has been reported to be significant in subjects over 70 years of age [28].

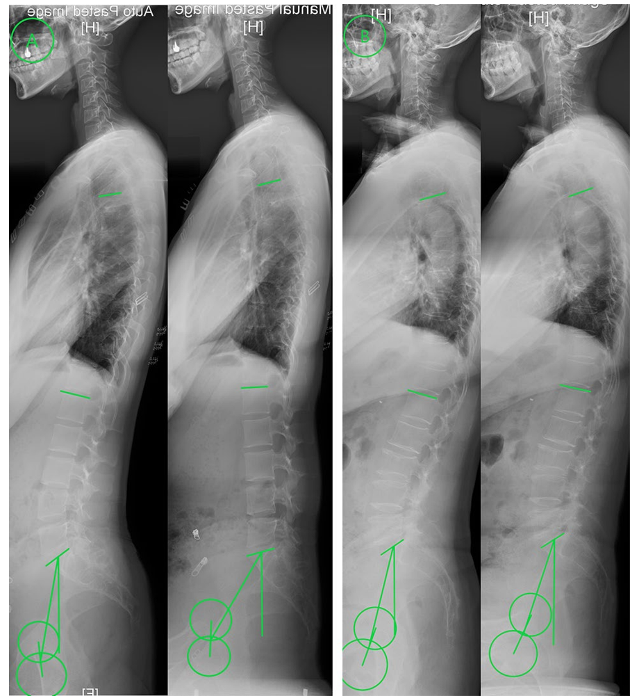

Fig. 3 **a** The standing and sitting radiographs of 21-year-old female. When moving from standing to sitting position, SVA increased from −26.5 to 27.2 mm, PT increased from 9.5° to 32°, LL decreased from 50.5° to 17.2°, and TK decreased from 20.7° to 15.1°. B. The standing and sitting radiographs of 66-year-old female. When moving from standing to sitting position, SVA increased from −17.4 mm to 4.1 mm, PT increased from 14.1° to 18.3°, LL decreased from 49.8° to 39.1°, and TK decreased from 37.6° to 30.2°

With respect to the change in each parameter from standing to sitting position, our results indicate that young people present forward-moving SVA, smaller lumbar and thoracic curvature, pelvic retroversion and larger CL. These findings are consistent with former studies [9, 14]. Our older group displayed a similar trend to that observed in the young group, but the values of differences in the two groups were significantly different (Fig. 3). Regarding standing position as reference, PT of older group increased lesser at 44% versus 136%, LL and TK decreased lesser than those of the young group in the sitting position at 26% versus 50% and 14% versus 23%, respectively. CL remained the same in the older group, as against a 65% increase in the young group in the sitting position.

Previous studies have also reported these differences. Lee et al. [16] reported that LL of an elderly group decreased less (53.9°–27.9°) than that of a young age group (52.2°–13.5°) from standing to 90° sitting. However, their sample size was too small with only 20 subjects and all subjects lay in the chair device with a back-rest. Another study found that the PT of elderly persons increased less (15°–27.5°) than that of young adults (10.3°–27.6°) [17], but the elderly persons included in that study had lumbar degenerative disease. In our opinions, there were several possible reasons for this phenomenon: first, age-related degeneration and reduced muscle strength lead to a less flexible spine [29], corresponding to reduced differences between the two positions in older population; second, the older persons might be more tolerant of increased SVA, so they showed less pelvic retroversion despite their SVA increase being similar to that of the young group in the sitting position, and the smaller decrease in SS resulted the smaller decrease in LL.

The older population has its own characteristics in the sitting position, which is different from those in the young population. As shown in Tables 3 and 4, the increase in PT and decrease in LL get smaller with the increase in age. Regarding the conception that reconstructing sagittal alignment should account for patient's age [8, 20] and the importance of sitting sagittal profile in management of spinal disorders, we cannot simply apply the conclusions drawn from the studies of sitting alignment in young population to the clinical practice of older population. The normal values of sagittal parameters in standing and sitting positions from middle aged and elderly population demonstrated in the present study are especially important, since spinal degenerative diseases and deformity are common in this population and usually need fusion surgery as well as sagittal realignment. In this case, our results fill the gaps of previous studies and serve as references when reconstructing the sagittal alignment fitting both standing and sitting positions for middle aged and elderly population.

This study has some limitations. First, all volunteers were recruited from the same city and therefore might not be representative of the entire Chinese population. Second, we only took the erect sitting position into account and did not consider the natural sitting position, so this should also be considered in further study. Despite these limitations and to our knowledge, this is still the first study to describe the spinopelvic sagittal alignment in both standing and sitting positions of healthy, Chinese populations with different ages, and could serve as a reference for sagittal alignment reconstruction.

Conclusion

The present study has demonstrated that the healthy, middle age and elderly population showed larger SVA, TPA, TK, CL and PT than the healthy, young population, but LL was similar between the two groups in the standing position. When moving from the standing to sitting position, these two groups showed a similar trend in parameters changes, which presented as forward displacement of SVA, reduced lumbar lordosis and thoracic kyphosis, and increased pelvic retroversion. However, the differences observed between the two positions were significantly smaller in the middle aged and elderly group. These characteristics of spinopelvic alignment in standing and sitting position should be fully considered in the surgical reconstruction of sagittal alignment for patients with different age groups.

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Compliance with ethical standards

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

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