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ORIGINAL ARTICLE

Variation of cervical sagittal alignment parameters according to age and pelvic incidence in degenerative spinal deformity patients

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Abstract

Introduction In asymptomatic subjects, variations of cervical sagittal alignment parameters according to age and spinopelvic organization have been reported. A large range of compensation phenomena has been observed in degenerative spinal deformity in order to maintain horizontal gaze, but it remains unclear how age and spinopelvic morphology could additionally influence cervical alignment. The aim of this observational retrospective study was to describe the distribution of cervical sagittal alignment parameters according to age and pelvic incidence in subjects with and without degenerative spinal deformity in order to precisely evaluate cervical compensation phenomena in adult spinal deformity (ASD).

Material and methods Radiographs of 478 subjects (327 females and 151 males) were distributed into 235 asymptomatic and 243 deformed subjects. Occipito-cervical parameters were McGregor-C1, McGregor-C2, C1–C2 and occipito-C2 angles. The cervicothoracic inflection point (CTIP) was determined. Caudal cervical sagittal alignment parameters were: C2–C7 lordosis, C2-apex (superior arch), apex-CTIP (inferior arch), occipito-C3 and occipito-C4 angles, C7-slope and T1-slope. The distribution of parameters was analyzed using a Bayesian inference (significant when $Pr > 0.975$ or $Pr < 0.025$). Comparisons between asymptomatic and deformed subjects were done after matching on age (40–60 years; > 60 years) and on PI (< 45°; 45–60°; > 60°).

Results Among occipito-cervical parameters, there was no significant change in McGregor-C1 angle. However, McGregor-C2 angle was significantly higher in the ASD group ($Pr = 0.0029$), with influence of age ($Pr = 0.023$), but PI influence. C1–C2 lordosis was significantly higher in the ASD group compared to the asymptomatic group ($Pr < 0.0007$), without influence of age or PI noticed. C2–C7 lordosis was also higher in the ASD group ($Pr < 0.025$) with a role of age and PI ($Pr < 0.025$). Cervical lordosis in the superior arch was significantly higher in the ASD group ($Pr > 0.999$), without influence of age or PI. In the inferior arch, the lordosis angle was not modified according to the group, but there was an influence of age ($Pr < 0.0007$). C7-slope and T1-slope were higher according the age group ($Pr < 0.0012$), without influence of the group or PI.

Conclusion This observational study highlights cervical sagittal alignment adaptations in degenerative spinal deformity, matched on age and pelvic incidence. The inferior cervical spine seemed to be modified with a higher lordosis, increasing with age responding to the age-related thoracic kyphosis increase. In addition to that, the superior cervical spine hyperextends more in adult degenerative deformity to maintain horizontal gaze.

Level of evidence III.

Keywords Sagittal balance · Adult spinal deformity · Cervical spine · Pelvic incidence

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Introduction

Recent studies have proven that aging causes modifications of spinal sagittal alignment parameters. This can have consequences on health-related quality of life. In particular, cervical malalignment with anterior migration of C2-plumbline seems to have a negative impact on clinical outcomes [1, 2].

Apart from aging, spinal deformities appeared to lead to cervical sagittal alignment adaptations. In idiopathic adolescent scoliosis (AIS), there is a significant correlation between thoracic kyphosis and cervical lordosis parameters, and appropriate thoracic alignment seems crucial for surgical outcome as it determines cervical lordosis improvement [3]. Besides, cervical kyphosis in young patients with idiopathic scoliosis is correlated with global sagittal alignment [4]. This link between global sagittal alignment and cervical morphological changes is emphasized by the significant correlation between thoracic and cervical improvement following surgical correction of AIS [5].

In the aging population, additional compensation phenomena were observed such as anterior malalignment and pelvic retroversion, along with C2–C7 plumbline distance increase and cervical extension to prevent drop head [6]. Similar compensation phenomena might occur in adult spinal deformity (ASD), in order to maintain horizontal gaze, but this point remains poorly described in literature. Moreover, physiologic spinal sagittal alignment and thus the targets when planning deformity correction depends on age and spinopelvic parameters [7, 8]. We hypothesize that specific variations of cervical sagittal parameters exist in patients with degenerative scoliosis compared to individuals without spinal deformity.

The purpose of this multicenter retrospective study was to describe cervical parameters in patients with ASD and to analyze differences compared to asymptomatic individuals with similar age and pelvic incidence.

Materials and methods

Study design

Institutional review board approval (FC-2019-91, CE-2020-153) was obtained for this retrospective cross-sectional study on full spine radiographs that were prospectively collected in a national spine database involving two centers. First, sagittal radiographs (EOS Imaging, Paris, France) performed from September 2019 to March 2020 in patients who were examined for leg length discrepancy below 2 cm, spondylolysis or mild common low back pain were collected. These patients had no symptoms in the cervical spine and the following conditions were excluded: spinal deformity (scoliosis, Scheuermann's kyphosis, spondylolisthesis ≥ grade 2), vertebral fracture, disco-ligamentous injury, spinal tumor, spondylodiscitis, neuromuscular disease and previous spine surgery except microdiscectomy, severe degenerative changes leading to deformity, and represented the asymptomatic group used as a reference. This group of individuals was defined as the reference group (R-group). Then, a population of patients with degenerative scoliosis (thoracic and/or lumbar vertebral rotation, age ≥ 40) operated on between 2012 and 2020 were identified from a prospective database in the same 2 spine centers. All patients underwent posterior deformity correction and thoraco-lumbar fusion with minimum 2-year follow-up. Exclusion criteria in the deformity group were: prior instrumentation requiring revision, posterior minimal invasive procedure, three-column osteotomies and neurologic syndromes. This group of patients was defined as the pathological group (P-group).

Radiographic assessment

Full spine radiographs of asymptomatic individuals and preoperative radiographs of ASD patients were analyzed. Radiographic measurements were performed by a single trained operator using KEOPS software (SMAIO, Lyon, France) [9], and were secondarily checked by an independent senior spine surgeon of another center: coronal Cobb angles, pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), thoracic kyphosis (TK) measured between cranial T1 and caudal T12 endplates and expressed as negative value, lumbar lordosis (LL) between cranial L1 and S1 endplates.

Cranial cervical sagittal alignment parameters were: McGregor slope, McGregor-C2, C1–C2 and posterior occipito-C2 angles. For McGregor slope, negative values mean flexion of the head, whereas positive values mean extension of the head. Among caudal cervical sagittal alignment parameters, cervical lordosis (CL) was measured between caudal C2 and C7 endplates. CL was then divided into a cranial arch between C2 and cervical apex (inflection point in sigmoid alignment types), and into a caudal arch between cervical apex and cervicothoracic inflection point. C7-slope and T1-slope were determined as angles between cranial endplate and the horizontal axis. Figure 1 gives an overview of cervical parameters measured on lateral X-rays.

Statistical analysis

Statistical evaluation was performed using Markov chain Monte Carlo techniques for Bayesian inference with R Software and ad hoc packages (R Foundation for Statistical

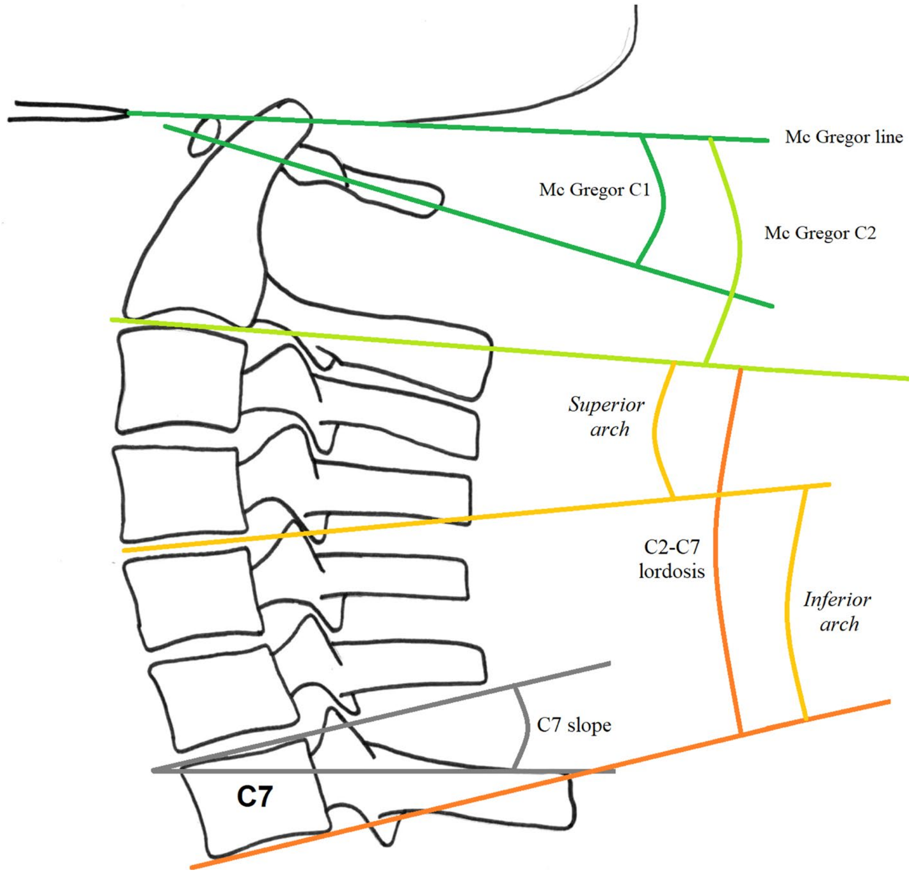

Fig. 1 Overview of cervical parameters measured on lateral X-ray

Computing, Vienna, Austria). Sensitivity analyses were carried out to assess the robustness of models. To infer the value of quantity, point estimates corresponded to the median of posterior distribution and the credible interval to its 2.5 and 97.5 percentiles. The probability (Pr) that a quantity is greater or less than 0 was calculated. The test of this difference with respect to 0 was considered as significant if this probability was > 0.975 or < 0.025. Cervical alignment parameters were compared by PI (low PI < 45°, medium PI 45–60°, high PI > 60°) and age groups (40–60 years; > 60 years).

Results

A total of 478 individuals, 327 females and 151 males, were included. There were 235 asymptomatic individuals (N-group) and 243 patients with adult scoliosis (P-group): 171 had a lumbar curve and 72 had a thoraco-lumbar curve. The ages ranged from 40 to 88 years. The distributions by age in the N-group and the P-group were, respectively: 40–60 years $n = 136$, > 60 years $n = 99$, and 40–60 years $n = 72$, > 60 $n = 171$. The distributions by PI in the N-group and the P-group were, respectively: low PI $n = 31$, medium PI $n = 126$, high PI $n = 78$ and low PI $n = 57$, medium PI $n = 107$, high PI $n = 79$. In the P-group, the average preoperative Cobb angle was 52.9 ± 20.7° [28; 97].

Global alignment and spinopelvic parameters

Table 1 gives an overview of SVA-C7, SVA-C2, TK, LL, PT and SS according to age and PI in each group. The SVA-C2 was significantly higher in the P-group compared to the R-group ($P > 0.999$). This parameter increased with age (Pr > 0.999). Differences between PI groups were nonsignificant. The results for SVA-C7 were similar with influence of the group and age. Differences in the delta SVA-C2-SVA-C7 were nonsignificant.

Cranial cervical parameters

Table 2 demonstrates the distribution of cranial cervical parameters by age and PI among the R-group and the P-group, and Table 3 indicates the probability of effect of the group, age and PI on each parameter. Among occipito-cervical parameters, there was no significant change in McGregor slope according to the group (Pr = 0.69), age (Pr = 0.83) or PI (Pr = 0.81). The McGregor-C2 angle was significantly higher in the P-group (Pr = 0.0029) compared to the R-group, with influence of age (Pr = 0.023), but no

Table 1 Overview of general and pelvic parameters: mean ± standard deviation and symmetric 95% credible intervals

Group	Reference (N = 235)						Pathologi (N = 243)					
Age (years)	40–60 (N = 136)			> 60 (N = 99)			40–60 (N = 72)			> 60 (N = 171)		
Pelvic incidence	Low < 45° (N = 26)	Medium 45–60° (N = 75)	High > 60° (N = 35)	Low < 45° (N = 5)	Medium 45–60° (N = 51)	High > 60° (N = 43)	Low < 45° (N = 22)	Medium 45–60° (N = 32)	High > 60° (N = 18)	Low < 45° (N = 35)	Medium 45–60° (N = 75)	High > 60° (N = 61)
SVA-C7 (mm)	20.9 ± 31.7 [5.4;28.3]	26.9 ± 33.2 [17.8;34.3]	40.6 ± 33.6 [32.3;52.0]	27.5 ± 17.4 [19.5;45.7]	42.4 ± 37.3 [32.9;50.9]	52.5 ± 47.3 [48.0;67.5]	46.4 ± 61.1 [41.7;64.8]	63.5 ± 59.0 [52.3;72.5]	75.5 ± 70.4 [66.9;90.0]	68.3 ± 48.6 [58.1;80.1]	76.8 ± 55.7 [70.1;86.5]	101.0 ± 58.3 [85.3;103.2]
SVA-C2 (mm)	39.1 ± 34.8 [23.8;49.3]	47.1 ± 40.3 [37.8;55.9]	60.5 ± 41.8 [51.3;72.9]	54.7 ± 9.2 [40.6;69.7]	65.5 ± 42.4 [55.8;75.6]	78.1 ± 58.0 [70.0;94.4]	55.2 ± 51.3 [51.3;77.3]	83.8 ± 70.0 [63.4;85.8]	78.9 ± 56.2 [77.0;103]	83.5 ± 53.4 [70.7;95.7]	89.8 ± 59.0 [84.4;103]	116 ± 66.2 [98.6;119]
Delta SVAC2–C7 (mm)	18.2 ± 10.5 [15.8;24.0]	20.2 ± 15.6 [17.5;23.2]	20.0 ± 15.4 [18.0;24.8]	27.2 ± 18.2 [17.7;27.1]	23.1 ± 13.7 [19.8;26.0]	25.6 ± 18.7 [20.5;27.2]	16.5 ± 15.7 [11.3;19.6]	19.3 ± 20.5 [12.3;19.4]	15.8 ± 17.8 [12.8;20.9]	18.0 ± 17.4 [14.0;22.0]	17.0 ± 16.4 [15.6;21.3]	19.3 ± 18.2 [16.2;22.5]
Sacral slope (degrees)	29.7 ± 5.0 [27.2;31.3]	35.7 ± 6.8 [35.0;37.8]	45.7 ± 7.8 [43.5;46.9]	19.9 ± 7.1 [24.2;28.8]	34.2 ± 7.3 [32.1;35.2]	42.9 ± 7.9 [40.7;44.1]	22.7 ± 6.8 [19.3;23.4]	27.7 ± 7.4 [26.7;30.3]	38.0 ± 7.1 [35.3;39.3]	18.4 ± 10.8 [16.7;20.6]	26.3 ± 10.2 [24.4;27.2]	33.7 ± 9.1 [33.0;36.1]
Pelvic tilt (degrees)	12.0 ± 5.0 [8.7;12.5]	16.3 ± 6.5 [15.2;17.8]	23.4 ± 8.3 [22.0;25.2]	17.2 ± 5.9 [10.9;15.2]	19.4 ± 6.3 [17.5;20.4]	24.6 ± 7.4 [24.5;27.6]	16.5 ± 6.1 [16.2;20.0]	25.0 ± 8.9 [22.4;25.7]	30.3 ± 7.2 [29.3;33.0]	19.9 ± 8.4 [18.8;22.4]	26.0 ± 9.9 [25.2;27.8]	35.0 ± 7.3 [32.2;35.0]
Lumbar lordosis (degrees)	46.7 ± 10.2 [53.1;45.7]	55.7 ± 11.6 [59.0;53.7]	66.0 ± 12.6 [67.5;61.2]	42.4 ± 10.9 [49.9;41.4]	53.1 ± 15.1 [55.4;49.7]	62.1 ± 9.8 [63.7;57.5]	29.6 ± 14.6 [33.0;25.5]	36.1 ± 16.3 [39.4;32.9]	47.4 ± 19.6 [47.9;40.5]	27.5 ± 18.2 [29.0;21.8]	32.8 ± 18.7 [35.0;29.8]	37.5 ± 17.9 [43.2;37.5]
Thoracic kyphosis (degrees)	40.4 ± 12.8 [40.5;48.7]	46.2 ± 13.1 [43.7;49.4]	48.6 ± 10.8 [43.9;50.8]	54.6 ± 17.2 [42.3;51.6]	49.7 ± 17.2 [45.8;52.12]	50.2 ± 15.6 [46.3;53.1]	31.3 ± 15.8 [28.0;36.1]	34.7 ± 18.9 [30.5;37.6]	40.1 ± 22.0 [30.8;38.8]	37.0 ± 22.3 [30.6;38.4]	36.0 ± 17.3 [33.6;39.3]	34.6 ± 17.7 [34.1;40.3]

Negative values represent lordosis

Table 2 Distribution of cranial cervical parameters by age and pelvic incidence among the reference and pathologic groups: mean ± standard deviation and symmetric 95% credible intervals

Group	Reference						Pathologic					
Age (years)	40–60			> 60			40–60			> 60		
Pelvic incidence	Low < 45°	Medium 45–60°	High > 60°	Low < 45°	Medium 45–60°	High > 60°	Low < 45°	Medium 45–60°	High > 60°	Low < 45°	Medium 45–60°	High > 60°
McGregor slope* (degrees)	− 0.33 ± 6.7 [− 1.3;3.3]	− 1.21 ± 8.1 [− 2.2;2.0]	4.29 ± 30.6 [− 0.1;4.9]	− 0.38 ± 9.4 [− 0.9;5.3]	2.57 ± 8.1 [− 1.3;3.5]	2.45 ± 8.7 [1.0;6.1]	0.78 ± 9.1 [− 1.3;4.4]	0.72 ± 13.8 [− 2.3;3.1]	4.26 ± 12.1 [− 0.1;6.0]	3.62 ± 6.8 [− 0.0;5.6]	1.66 ± 10.2 [− 0.5;3.8]	3.42 ± 10.7 [1.8;6.5]
McGregor C2 angle (degrees)	16.9 ± 7.8 [19.4;14.6]	16.5 ± 9.1 [17.2;13.9]	14.1 ± 8.2 [18.6;14.6]	18.4 ± 12.9 [21.7;16.2]	16.9 ± 9.9 [19.3;15.6]	19.6 ± 11.5 [20.6;16.6]	20.7 ± 12.1 [22.1;17.2]	18.0 ± 10.4 [20.3;16.2]	19.3 ± 9.2 [21.6;16.9]	21.0 ± 8.3 [23.9;19.3]	19.6 ± 10.0 [21.9;18.4]	22.0 ± 8.4 [23.1;19.3]
C1–C2 lordosis (degrees)	26.7 ± 8.6 [30.3;26.3]	29.7 ± 7.9 [30.1;27.4]	28.4 ± 7.9 [30.4;27.1]	30.3 ± 4.4 [30.5;25.9]	28.7 ± 6.8 [30.2;27.1]	28.0 ± 10.1 [30.2;27.0]	33.8 ± 10.4 [34.5;30.5]	32.1 ± 6.2 [34.8;31.3]	32.3 ± 5.6 [35.0;31.0]	32.5 ± 8.1 [34.4;30.4]	32.3 ± 8.5 [34.3;31.5]	33.9 ± 7.5 [34.5;31.4]
Posterior occipito C2 angle (degrees)	91.7 ± 15.8 [91.9;98.6]	101.5 ± 13.4 [97.3;101.9]	99.9 ± 10.4 [96.1;101.6]	94.8 ± 20.1 [90.0;97.7]	96.6 ± 11.3 [95.8;100.9]	97.5 ± 11.5 [94.7;100.2]	92.1 ± 12.5 [87.3;94.1]	90.7 ± 12.1 [92.2;98.0]	95.2 ± 14.5 [91.0;97.6]	91.4 ± 14.0 [86.1;92.6]	94.8 ± 15.0 [91.4;94.1]	92.0 ± 13.4 [90.3;95.5]

Negative values represent lordosis; positive values represent kyphosis for McGregor C2 angle and C1–C2 lordosis

*Negative values indicate head flexion, whereas positive values indicate head extension

Table 3 Probability of effect of the group, age and PI on parameters

Parameter	SVA-C7	SVA-C2	Delta SVA C2/C7	Sacral slope	Pelvic tilt	Lumbar lordosis	Thoracic kyphosis	McGregor slope	McGregor C2 angle	C1–C2 lordosis	Posterior occipito C2 angle	C2–C7 lordosis	Superior arch lordosis	Inferior arch lordosis	C7 slope
Group effect	**1.00**	**1.00**	**0.00**	**0.00**	**1.00**	**1.00**	**0.00**	0.67	**0.00**	**0.00**	**0.00**	**0.02**	**0.99**	0.03	0.45
Age effect	0.99	0.99	0.94	**0.00**	**0.99**	**0.99**	0.93	0.83	**0.02**	0.54	0.15	**0.00**	0.87	**0.00**	**0.00**
PI effect	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Low versus medium	0.94	0.94	0.58	**0.01**	**1.00**	**0.01**	0.82	0.22	0.87	0.33	**0.99**	**0.01**	0.94	0.49	0.44
Low versus high	**0.99**	**0.99**	0.73	**0.01**	**1.00**	**0.00**	0.88	0.81	0.61	0.34	0.97	**0.00**	0.97	0.25	0.24
Medium versus high	**0.99**	**0.99**	0.72	**0.01**	**1.00**	**0.00**	0.67	0.97	0.16	0.50	0.29	0.23	0.76	0.20	0.23

Bold values represent significant results

influence of PI. C1–C2 lordosis was significantly higher in the P-group compared to the R-group (Pr < 0.0007), without influence of age (Pr = 0.54) or PI (Pr = 0.33).

Caudal cervical parameters

Table 4 displays caudal cervical parameters by age and PI among the R-group and the P-group. C2–C7 lordosis was higher in the P-group compared to the R-group (Pr < 0.025). There was a role of age with an increase of C2–C7 lordosis with aging (Pr < 0.0001). C2–C7 lordosis was significantly higher in high PI (Pr < 0.025).

Cervical lordosis in the superior arch was significantly higher in the P-group (Pr > 0.999), without influence of age (Pr = 0.87). Cervical lordosis in the superior arch was significantly higher in high PI compared to low PI (respectively, 5.10° versus 1.57° in the 40–60 age group of the R-group, 7.68° versus 4.46° in the > 60 age group of the R-group, 13.5° versus 9.19° in the 40–60 age group of the P-group, 11.8° versus 7.8° in the > 60 age group of the P-group) with Pr > 0.97. In the inferior arch, the lordosis angle was not modified according to the group or PI. A significant increase with aging was observed for lordosis in the inferior arch (Pr < 0.0007).

The posterior C2 angle was significantly lower in the P-group compared to the R-group ($P < 0.0001$). Differences between age and PI groups were nonsignificant.

C7-slope and T1-slope were both significantly increased with aging (Pr < 0.0012). Differences between groups and PI were nonsignificant.

Discussion

Spinal sagittal alignment has gained interest within the last decade [10–12]. Thus, evaluation of sagittal parameters compared to normative values has gain interest in spinal deformity. Cervical modifications and correlations with thoracic parameters were particularly described in idiopathic adolescent scoliosis [3–5, 13]. As the cervical spine allows the widest range of motion of the spine, it is influenced by the thoraco-lumbar spine to maintain horizontal gaze which is the ultimate goal of sagittal balance [12]. Besides, the implication of cervical spine alignment in health-related quality of life has been widely described [2, 14–17]. Moreover, specific variations of sagittal parameters have been described according to age progression and spinopelvic organization [7, 8, 18]. It remains unclear how cervical spine might compensate thoraco-lumbar modifications in the field of adult degenerative deformity.

Sagittal cervical parameters are split into cranial and caudal parameters. Cranial parameters involve the occipito-cervical area and the C1–C2 segment. The position of the head

Table 4 Distribution of caudal cervical parameters by age and pelvic incidence among the reference and pathologic groups: mean ± standard deviation and symmetric 95% credible intervals

Group	Reference						Pathologic					
Age (years)	40–60			> 60			40–60			> 60		
Pelvic incidence	Low < 45°	Medium 45–60°	High > 60°	Low < 45°	Medium 45–60°	High > 60°	Low < 45°	Medium 45–60°	High > 60°	Low < 45°	Medium 45–60°	High > 60°
C2–C7 lordosis (degrees)	23.5 ± 14.0 [30.3;22.7]	32.1 ± 13.6 [33.5;28.2]	31.0 ± 15.3 [35.2;28.9]	36.1 ± 23.5 [36.6;27.8]	36.6 ± 17.3 [39.4;33.6]	37.9 ± 16.7 [40.9;34.6]	32.3 ± 14.9 [33.7;25.9]	30.1 ± 14.9 [37.4;30.8]	40.4 ± 14.3 [39.1;31.5]	35.5 ± 15.5 [39.2;31.7]	40.3 ± 13.5 [42.4;37.1]	40.0 ± 17.6 [43.9;38.1]
Superior arch lordosis (degrees)	1.57 ± 11.1 [0.3;5.9]	6.7 ± 11.2 [3.1;7.5]	7.7 ± 13.0 [5.1;10.2]	4.5 ± 16.8 [0.7;7.8]	5.8 ± 14.5 [4.4;9.1]	7.7 ± 11.9 [5.1;10.2]	9.2 ± 12.8 [3.9;10.2]	5.2 ± 13.6 [6.9;12.3]	13.5 ± 9.9 [7.4;13.4]	7.8 ± 11.6 [5.5;11.6]	12.2 ± 10.4 [8.9;13.2]	11.8 ± 16.0 [9.5;14.4]
Inferior arch lordosis (degrees)	24.9 ± 10.1 [29.2;23.8]	26.6 ± 9.7 [28.4;24.6]	29.0 ± 6.7 [29.7;25.2]	34.7 ± 8.0 [34.3;28.2]	31.4 ± 10.0 [33.3;29.2]	31.1 ± 11.9 [34.5;30.0]	25.5 ± 11.9 [31.3;25.9]	29.1 ± 11.1 [31.1;26.3]	31.1 ± 15.1 [32.2;26.9]	35.9 ± 13.0 [35.9;30.7]	32.9 ± 11.2 [35.2;31.4]	33.7 ± 11.7 [36.4;32.2]
C7 slope (degrees)	19.3 ± 8.6 [24.3;18.5]	22.5 ± 10.5 [23.6;19.6]	22.0 ± 8.8 [25.0;20.1]	25.1 ± 21.7 [28.6;22.1]	25.5 ± 10.7 [27.7;23.3]	26.7 ± 12.4 [28.9;24.1]	19.9 ± 10.8 [24.5;18.7]	22.2 ± 11.2 [24.3;19.3]	24.2 ± 11.4 [25.6;19.9]	28.1 ± 14.5 [28.2;22.7]	24.7 ± 12.0 [27.7;23.7]	26.3 ± 14.0 [28.8;24.4]

Negative values represent lordosis; positive values represent kyphosis

directly influences their alignment. The McGregor slope is reliably measured on X-rays. Le Huec et al.[19] reported a mean value of 1.59° (−18°; 16°) in adults. McGregor-C2 lordosis range from 12.7° to 22.4° in asymptomatic adults for Kuntz et al.[20]. Our results are in line with these findings. The McGregor-C2 angle was significantly higher in the P-group, meaning a larger lordosis in the very cranial part of cervical spine in ASD patients ($Pr < 0.0029$). There was also a correlation with age, with a larger lordosis between the occiput and C2 with aging ($Pr < 0.023$). A progressive head extension was already described in asymptomatic individuals [21], but this phenomenon seems to be even more in contrast in ASD patients. Figure 2 gives an illustration of this phenomenon on full spine radiographs of a patient with degenerative scoliosis and anterior malalignment.

The C1–C2 angle is involved in cervical lordosis. C1–C2 lordosis was measured in asymptomatic adults and mean values range from 20.8 to 31.9° [16, 19, 22, 23]. Our findings fit with these ranges. Charles et al.[21] described the increase of C1–C2 lordosis during growth, and a relative stability of values during adulthood. In spinal deformity, our results highlight a significant increase in C1–C2 lordosis compared to asymptomatic individuals ($Pr < 0.0007$), demonstrating a head extension thanks to the atlantoaxial segment. This phenomenon was specific of the deformation group without influence of age or PI.

The posterior C2 angle, meaning head extension when lowered, was significantly lower in the P-group compared to the R-group ($P < 0.0001$). Differences between age and PI groups were nonsignificant. Modifications of these parameters were specific to the deformity group and evidenced again a head extension involving occipito-cervical junction and atlantoaxial segment in ASD patients.

Modifications also occur in the caudal cervical segment. C2–C7 lordosis in adults range from 4.9 to 40.0° [10, 12, 16, 19, 20, 22, 24]. Hardacker et al.[16] demonstrated a correlation with aging, C2–C7 lordosis increasing from 37° at 20–30 years to 47° at 61–70°. Our results are in line with these findings, showing a progressive increase with age ($Pr < 0.0001$). The cervical lordosis angle between C2 and the cervical apex, which represents the cranial arch, was significantly higher in the P-group compared to the R-group ($Pr > 0.999$), whereas differences in the cervical lordosis in the inferior arch were nonsignificant according to the group. On the other hand, the differences in the superior arch were nonsignificant among age groups ($Pr = 0.87$), whereas cervical lordosis increase in the inferior arch was significantly correlated with age groups ($Pr < 0.0007$). These findings reveal that the increase in cervical lordosis mainly occurred in the caudal arch with aging, and in addition to this, occurred in the superior arch in degenerative scoliosis.

In this study, caudal arch lordosis increased with age in parallel to C7-slope ($Pr < 0.0012$), which is in line with

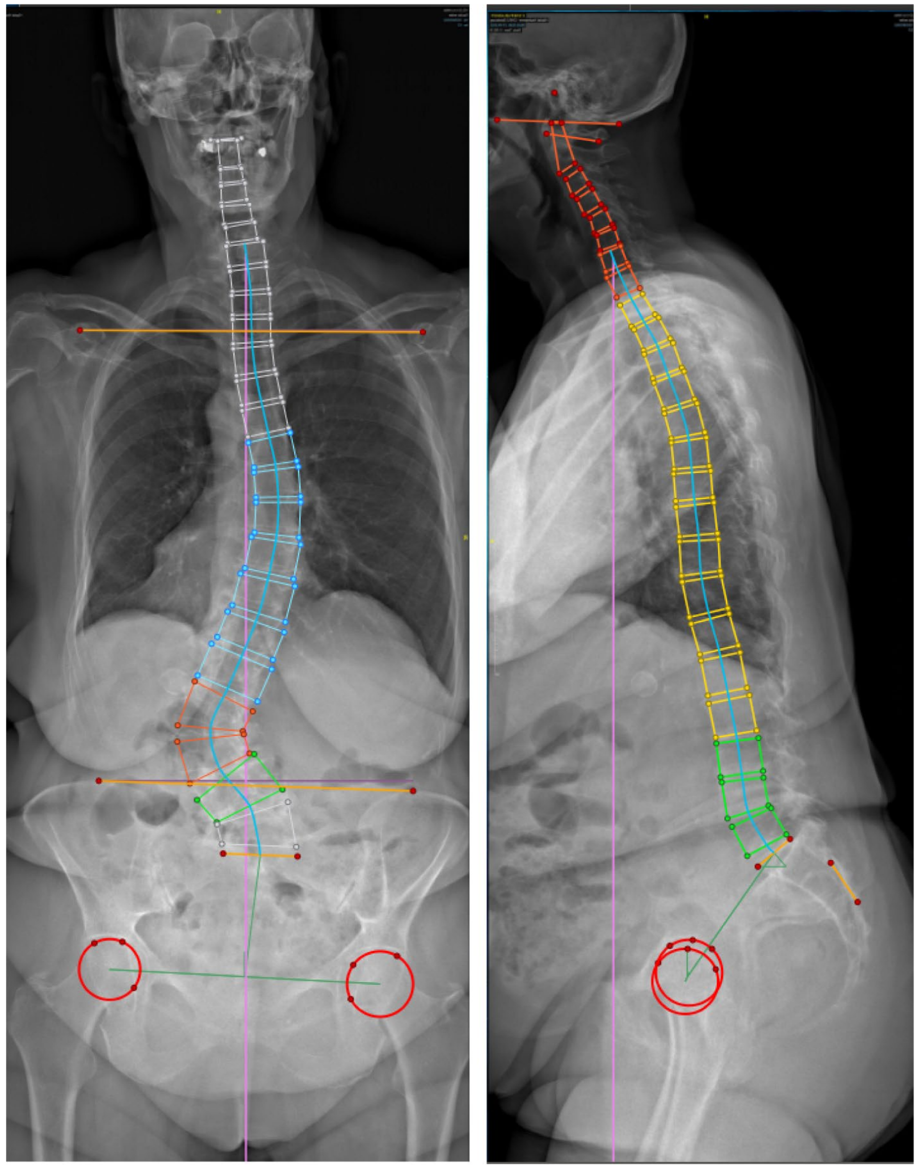

Fig. 2 Full spine radiographs of a patient with degenerative scoliosis and anterior malalignment

literature [10, 21, 25]. These results suggest that the caudal arch compensates thoracic kyphosis increase with aging, in order to maintain horizontal gaze. Significant differences were only found in age groups for this parameter.

Anterior sagittal malalignment is often assessed measuring SVA-C2 and SVA-C7 in clinical practice. In our study, SVA-C7 was significantly higher in the P-group compared to the R-group (Pr > 0.999), and significantly increased according to with age groups (Pr > 0.999). The results for SVA-C2 were similar. These findings are in line with the literature. Hardacker et al.[16] reported SVA-C7 values in adults of 15.6 ± 11.2 mm. Park et al.[26] found a progressive increase in SVA-C2 with aging, ranging from 0.59 ± 24.7 mm at 20–29 years to 13.11 ± 51.34 at 60–69 years ($p = 0.043$). Interestingly, differences in delta SVA-C2/SVA-C7 were nonsignificant. This means that delta SVA was similar in age groups and was not influenced by spinal deformity, which indicates adaptive phenomena especially in the cranial cervical spine. Figure 3 summarizes these adaptive phenomena occurring in the cervical spine. These adaptive phenomena might be taken into account in the preoperative planning of ASD surgery.

This study has some limitations due to the retrospective study design. Quality of life scores and muscle strength were not assessed, although these clinical factors might influence radiographic alignment. Degenerative cervical changes represented an inevitable age-related phenomenon. Severe changes leading to deformity were excluded. Nevertheless, intervertebral disk degeneration and osteoarthritis might influence sagittal alignment, which was not analyzed.

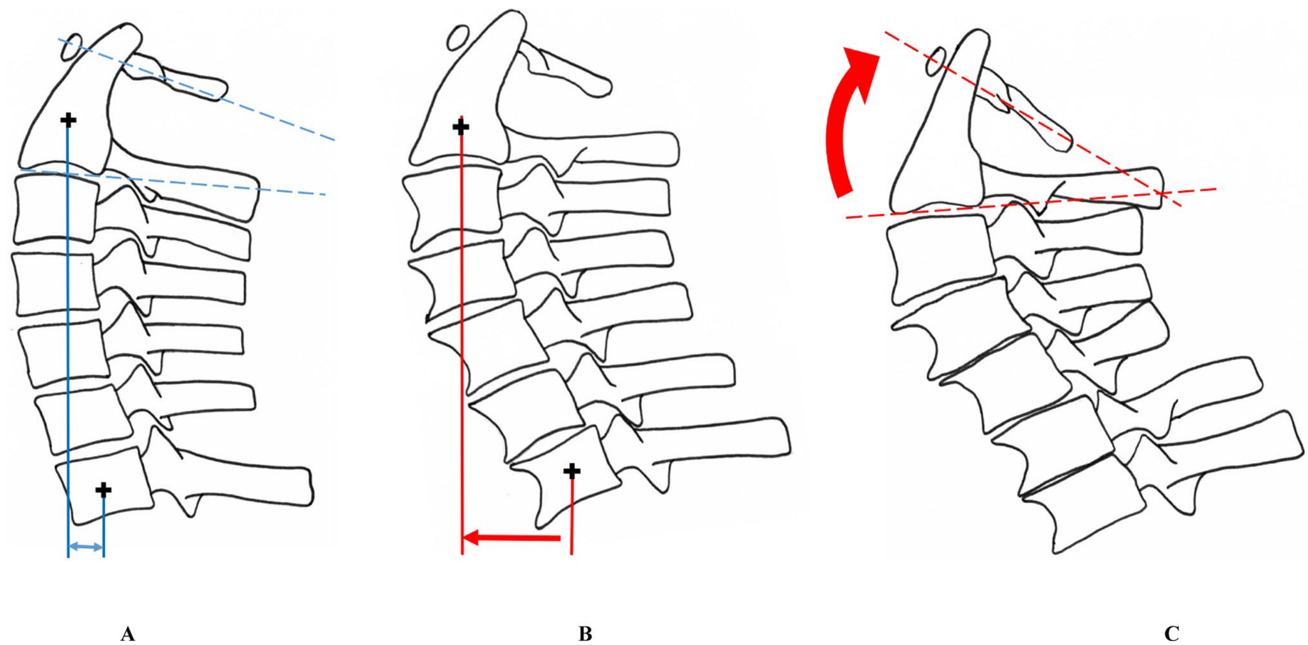

Fig. 3 Adaptive phenomena occurring in the cervical spine. **A** Normal situation; **B** Aging spine: adaptive phenomena in the lower cervical spine (SVA-C7, SVA-C2, C2–C7 lordosis and C7-tilt increase); **C** Deformity group: extension in the upper cervical spine

Conclusion

This observational study highlights cervical sagittal alignment parameters adaptations in degenerative spinal deformity, matched on age and pelvic incidence categories. The inferior cervical spine seemed to be modified with a higher lordosis according to age progress, responding to the age-related the physiologic thoracic kyphosis. In addition to that phenomenon, superior cervical spine is specifically involved in adult spinal deformity in order to maintain horizontal gaze.

Declarations

Conflict of interest Yann Philippe Charles is consultant for Stryker, Clariance, Philips and Ceraver; he received royalties and grants unrelated to this study from Stryker and Clariance. Vincent Lamas is consultant for Clariance. Renan Chapon, Erik Sauleau, Solène Prost has no conflict of interest. Benjamin Blondel is associate editor for OTSR Elsevier-Masson and consultant for Medicrea, Medtronic, Implanet, Vexim Stryker and 3M.

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