European Spine Journal (2022) 31:1228–1240
https://doi.org/10.1007/s00586-021-07102-w

ORIGINAL ARTICLE

# Variation of cervical sagittal alignment parameters according to gender, pelvic incidence and age

Yann Philippe Charles[1] · Solène Prost[2] · Sébastien Pesenti[3] · Brice Ilharreborde[4] · Eloïse Bauduin[5] · Féthi Laouissat[6] · Guillaume Riouallon[7] · Stéphane Wolff[7] · Vincent Challier[8] · Ibrahim Obeid[9] · Louis Boissière[9] · Emmanuelle Ferrero[10] · Federico Solla[11] · Jean-Charles Le Huec[12] · Stéphane Bourret[12] · Joe Faddoul[13] · Georges Naïm Abi Lahoud[13] · Vincent Fière[14] · Michiel Vande Kerckhove[14] · Matthieu Campana[4] · Jonathan Lebhar[15] · Hadrien Giorgi[16] · Aymeric Faure[16] · Erik André Sauleau[17] · Benjamin Blondel[2] · The French Spine Surgery Society (SFCR)

Received: 30 September 2021 / Revised: 3 December 2021 / Accepted: 20 December 2021 / Published online: 6 January 2022


## Abstract

**Purpose** The aim was to describe radiographic cervical sagittal alignment variations according to age, gender and pelvic incidence (PI) and to investigate relationships with thoracic alignment.

**Methods** A total of 2599 individuals (5–93 years) without spinal deformity were studied. Cranial cervical parameters were: McGregor slope, occipita-C2 angle, McGregor-C2 lordosis and C1–C2 lordosis. Caudal cervical parameters were: C2–C7, cranial arch and caudal arch lordosis and C7- and T1-slope. A Bayesian inference compared parameter distributions. Correlations with spinopelvic and global alignment parameters were investigated.

**Results** Among cranial cervical parameters, variations of McGregor slope were non-significant. McGregor-C2 lordosis and C1–C2 lordosis were smaller in males and increased significantly during growth, whereas the occipito-C2 angle decreased ($Pr > 0.95$). The occipito-C2 angle was larger and McGregor-C2 lordosis was smaller in low PI ($Pr > 0.95$). Among caudal cervical parameters, C2–C7 lordosis and C7- and T1-slope were larger in males and increased after 50 years ($Pr > 0.95$). Lordosis changes were non-significant in the cranial arch, whereas values increased in the caudal arch after 35 years ($Pr > 0.95$). Caudal parameter differences were non-significant between PI groups. Strong correlations existed between C2–C7, caudal arch lordosis, C7-slope, T1-slope and thoracic kyphosis. The sagittal vertical axis C2 correlated with caudal arch lordosis and T1-slope ($\rho > 0.5$; $Pr > 0.95$).

**Conclusion** Cervical alignment parameters vary according to age, gender and PI. In the cranial cervical spine, changes occur mainly during growth. In the caudal cervical spine, lordosis increases in the caudal arch, which is related to thoracic kyphosis increase with age. The caudal cervical arch acts as a compensatory segment by progressive extension, allowing horizontal gaze.

**Keywords** Sagittal alignment · Cervical spine · Radiographic parameters · Age · Gender · Pelvic incidence

## Introduction

The cervical spine represents a mobile segment between the head and trunk. Its sagittal alignment involves cognitive, neurosensory and motor control to maintain horizontal gaze during standing, walking and daily activities. In clinical practice, radiographic parameters are used when analyzing cervical alignment, which represents a single momentum in static position. Radiographic alignment is considered when planning multiple-level subaxial or occipitocervical fusion [1, 2]. Cervical alignment is further considered in adolescent idiopathic scoliosis, where a relationship between thoracic hypokyphosis and decreased cervical lordosis exists [3–6]. In adult spinal deformity, cervical deformity might occur if the ability to maintain compensatory lordosis decreases. This results in anterior C2-plumbline migration and deterioration of health-related quality of life [7]. Although cervical and thoracolumbar relationships were described in deformed

✉ Yann Philippe Charles
YannPhilippe.CHARLES@chru-strasbourg.fr

Extended author information available on the last page of the article

spine, there is a lack of normative values that could be used when treating spinal deformities.

Normal cervical and thoracic alignment is linked: Cervical lordosis correlates with T1-slope and thoracic kyphosis in children and adults [8–11]. The amount of cervical lordosis increases with age [12, 13]. In the thoracolumbar segment, an age-related thoracic kyphosis increase, lumbar lordosis decrease and spinopelvic adaptive phenomena were described [14, 15]. The physiologic amount of lumbar lordosis and thoracic kyphosis and the shape of thoracolumbar curvatures are related to the spinopelvic configuration [16].

It remains unclear how cervical alignment varies according to gender, age and spinopelvic alignment types. The amount of pelvic incidence influences thoracolumbar lordosis and kyphosis distribution, which might influence cervical alignment. We hypothesize that normal variations exist in individuals without spinal deformity.

The purpose of this cross-sectional study was to describe cervical parameters across age groups from the growth period to the elderly and to analyze differences by gender and pelvic incidence.

## Materials and methods

Institutional review board approval (FC/2019-91) was obtained. Sagittal full spine radiographs (EOS Imaging, Paris, France) performed in 16 pediatric and adult spine centers were prospectively collected in a national registry from September 2019 to March 2020 and analyzed retrospectively. Clinical charts were screened, and radiographs of patients with limb length discrepancy less than 2 cm, spondylolysis, common low back or radicular leg pain were used. If several radiographs were available, the most recent image was selected. One radiograph was analyzed per patient. Exclusion criteria were: spinal deformity such as scoliosis, Scheuermann's kyphosis or spondylolisthesis more than grade 1, spinal or pelvic fractures, tumors, infection and neuromuscular disorders, previous spine surgery other than microdiscectomy and severe degenerative changes or osteoporosis leading to thoracolumbar deformity. Intervertebral disc degeneration, facet joint osteoarthritis and degenerative spondylolisthesis without thoracolumbar malalignment did not represent exclusion criteria since these radiographic changes commonly occur during aging.

In each center, a trained operator reconstructed radiographic landmarks between the cranial auditory meatus and femoral heads using KEOPS software (SMAIO, Lyon, France) (Fig. 1). Five senior spine surgeons then checked each reconstruction to minimize inter-rater errors. This method is reliable and superior to manual measurements [17]. Spinopelvic parameters were assessed: pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS), thoracic kyphosis

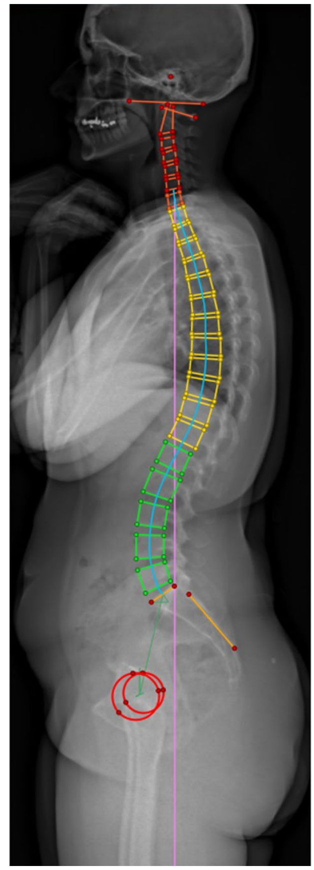

**Fig. 1** KEOPS software reconstruction of each vertebra from C1 to the sacrum, cranial auditory meatus, McGregor line and femoral heads on lateral full spine EOS radiograph

(TK) between cranial T1 and caudal T12 endplates and lumbar lordosis (LL) between cranial L1 and S1 endplates. TK and LL were expressed as positive values. Among global alignment parameters, sagittal vertical axis (SVA) of C7 and C2 measured the distances between vertebral plumblines and the posterior corner of S1 [18]. The odontoid-hip axis (OD-HA) determined the angle between the vertical axis originating from the midpoint between femoral heads and the axis joining the odontoid tip [19].

Cervical parameters were divided into cranial (C0–C2) and caudal (C3–C7) measurements. Among cranial parameters, McGregor slope represented the angle between the horizontal axis and McGregor line: the tangent to the caudal occiput joining the hard palate. Positive values reflected head flexion and negative values extension. The occipito-C2 angle was measured between McGregor line and the posterior odontoid cortical margin. McGregor-C2 lordosis was determined between McGregor line and C2 endplate. C1–C2 lordosis was measured between the anterior–posterior atlas axis and C2 endplate (Fig. 2). Among caudal parameters, C2–C7 lordosis was measured between caudal

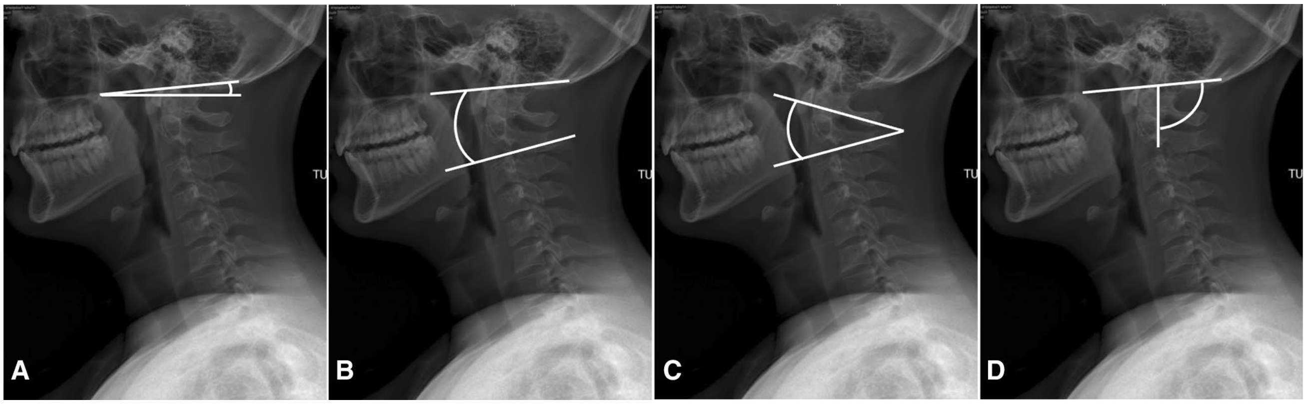


**Fig. 2** Cranial cervical parameters: McGregor slope (**A**), occipito-C2 angle (**B**), McGregor-C2 lordosis (**C**) and C1–C2 lordosis (**D**)

C2 and C7 endplates. Cervical lordosis was then divided into a cranial arch between C2 and cervical apex (inflexion point in sigmoid alignment types) and into a caudal arch between cervical apex and cervicothoracic inflexion point. Segmental cervical lordosis was expressed as positive value and kyphosis as negative value. C7-slope and T1-slope were determined as angles between cranial endplates and the horizontal axis (Fig. 3). The cervical morphology was analyzed by counting the number of vertebrae included from C1 to cervicothoracic inflexion point. Cervical alignment patterns were described: global lordosis, global kyphosis, sigmoid shape with proximal kyphosis and distal lordosis, sigmoid shape with proximal lordosis and distal kyphosis (Fig. 4).

Statistical evaluation was performed with R software, version 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria). A Bayesian inference using Markov chain Monte Carlo techniques with low informative priors was used. To infer the mean of indices and correlation coefficients between two indices, point estimates corresponded to the median of posterior distributions and credibility intervals to their 2.5 and 97.5 percentiles. Cervical alignment parameters were compared by gender, age groups and PI. Ages were grouped by 5-year spans in children and adolescents, as growth-related changes might occur, and by 15-year spans in adults. The thresholds for PI were determined according to first and third quartiles: low PI $<45°$, medium PI 45°–60° and high PI $>60°$. 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, 1488 females and 1111 males, were included. The ages ranged from 5 to 93 years. The distribution by age was: 5–9 years $n=94$, 10–14 years $n=516$, 15–19 years $n=448$, 20–34 years $n=224$, 35–49 years $n=424$, 50–64 years $n=449$, 65–79 years $n=340$ and $>80$ years $n=104$. The distribution by PI was: low PI

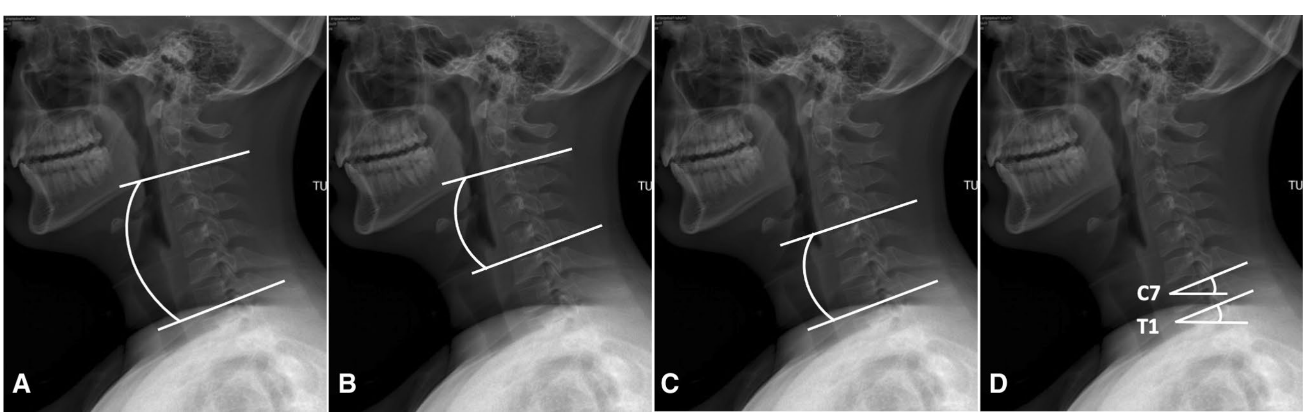


**Fig. 3** Caudal cervical parameters: C2–C7 lordosis (**A**), cranial arch lordosis (**B**), caudal arch lordosis (**C**), C7- and T1-slope (**D**)

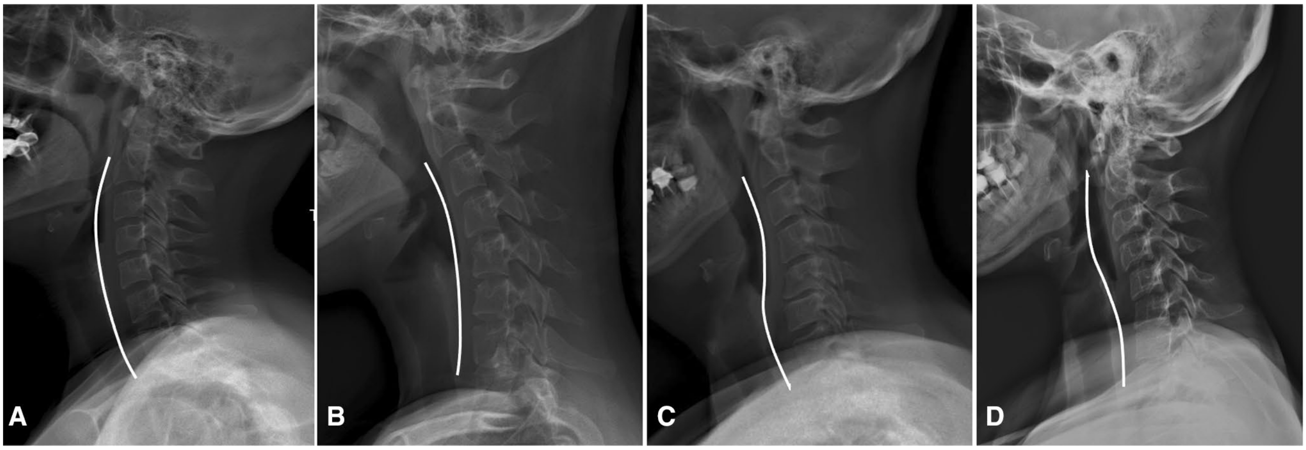


**Fig. 4** Morphologic variations of cervical alignment patterns: global lordosis (**A**), global kyphosis (**B**), sigmoid shape with proximal kyphosis and distal lordosis (**C**), sigmoid shape with proximal lordosis and distal kyphosis (**D**)

$n = 972$, medium PI $n = 1123$ and high PI $n = 504$. Table 1 gives an overview of SVA-C7, SVA-C2, OD-HA, TK, LL, PI, PT and SS per gender, PI and age groups.

## Cranial cervical parameters

Table 2 demonstrates the distribution of cranial cervical parameters by gender, PI and age. Variations of McGregor slope were small without significant differences between gender and age groups. Individuals with low PI had larger values (Pr = 0.9606). The occipito-C2 angle was similar in males and females. This parameter was significantly higher in low PI (Pr > 0.9999) and in adolescents from 10 to 19 years compared to young adults aged 20–34 years (Pr > 0.95). A progressive decrease was observed with age. McGregor-C2 lordosis was significantly smaller in males (Pr > 0.9999) and in low PI (Pr = 0.9732). A progressive increase with age was observed. Values were significantly smaller in individuals younger than 15 years (Pr > 0.95). C1–C2 lordosis was significantly smaller in males (Pr > 0.9999). This parameter was similar in PI groups. C1–C2 lordosis increased during growth with significantly smaller values in children younger than 10 years (Pr > 0.9999), and it then kept constant in adults (Fig. 5).

## Caudal cervical parameters

Table 3 displays caudal cervical parameters by gender, PI and age. Differences of C2–C7 lordosis were non-significant between males and females. Individuals with low PI

**Table 1** Overview of distribution of global alignment and spinopelvic parameters per gender pelvic incidence and age groups: mean ± SD

| Groups | SVA-C7 (mm) | SVA-C2 (mm) | OH-HA (°) | Thoracic kyphosis (°) | Lumbar lordosis (°) | Pelvic incidence (°) | Pelvic tilt (°) | Sacral slope (°) |
|---|---|---|---|---|---|---|---|---|
| Female | 11.7 ± 35.2 | 26.7 ± 35.2 | 0.7 ± 3.0 | 42.5 ± 14.0 | 55.9 ± 12.3 | 50.2 ± 12.6 | 12.6 ± 10.0 | 37.6 ± 8.9 |
| Male | 24.2 ± 36.1 | 41.1 ± 36.1 | − 0.4 ± 3.2 | 44.6 ± 13.4 | 52.2 ± 12.6 | 48.8 ± 11.5 | 12.5 ± 8.9 | 36.2 ± 8.8 |
| Low PI | 7.8 ± 31.6 | 22.3 ± 36.0 | 0.3 ± 2.9 | 40.7 ± 13.0 | 48.3 ± 11.6 | 37.5 ± 5.6 | 5.9 ± 7.7 | 31.5 ± 7.5 |
| Medium PI | 19.4 ± 35.4 | 37.4 ± 41.8 | 0.2 ± 3.2 | 44.7 ± 14.0 | 55.2 ± 11.1 | 51.9 ± 4.2 | 14.1 ± 7.3 | 37.8 ± 6.9 |
| High PI | 29.2 ± 41.0 | 49.3 ± 50.0 | 0.3 ± 3.5 | 45.7 ± 14.1 | 64.3 ± 10.7 | 67.9 ± 6.3 | 21.9 ± 7.8 | 45.9 ± 7.6 |
| 5–9 years | 15.7 ± 34.6 | 26.1 ± 38.0 | − 0.5 ± 3.1 | 37.5 ± 12.1 | 50.8 ± 11.2 | 39.9 ± 8.7 | 3.5 ± 7.7 | 3.5 ± 7.7 |
| 10–14 years | 8.8 ± 29.6 | 23.5 ± 31.9 | 0.1 ± 2.8 | 38.0 ± 12.2 | 54.1 ± 11.5 | 44.0 ± 10.6 | 6.0 ± 8.1 | 6.0 ± 8.1 |
| 15–19 years | 5.8 ± 26.4 | 21.5 ± 29.5 | 0.6 ± 2.2 | 40.3 ± 12.4 | 55.3 ± 11.7 | 45.5 ± 12.0 | 8.2 ± 8.1 | 8.2 ± 8.1 |
| 20–34 years | − 0.2 ± 33.7 | 16.5 ± 36.3 | 1.5 ± 2.8 | 43.3 ± 12.0 | 58.2 ± 12.0 | 50.1 ± 11.3 | 11.8 ± 7.0 | 11.8 ± 7.0 |
| 35–49 years | 12.3 ± 33.3 | 27.8 ± 37.9 | 1.2 ± 2.8 | 43.5 ± 11.9 | 55.8 ± 12.8 | 52.7 ± 12.5 | 15.0 ± 8.2 | 15.0 ± 8.2 |
| 50–64 years | 22.6 ± 32.7 | 39.0 ± 40.1 | 0.5 ± 3.3 | 45.7 ± 13.4 | 53.6 ± 13.2 | 53.1 ± 10.8 | 16.7 ± 7.5 | 16.7 ± 7.5 |
| 65–79 years | 40.6 ± 37.7 | 63.4 ± 47.0 | − 1.1 ± 3.7 | 51.5 ± 14.9 | 52.1 ± 13.5 | 55.4 ± 10.5 | 20.2 ± 7.7 | 20.2 ± 7.7 |
| > 80 years | 61.8 ± 31.4 | 94.2 ± 64.5 | − 3.1 ± 4.2 | 52.7 ± 17.6 | 50.7 ± 14.5 | 55.6 ± 11.7 | 20.6 ± 8.6 | 20.6 ± 8.6 |

*PI* pelvic incidence, *SVA* sagittal vertical axis, *OD-HA* odontoid-hip axis

**Table 2** Distribution of cranial cervical 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($d > 0$) |
|---|---|---|---|---|---|
| McGregor slope (°) | Female | − 0.5 ± 13.7 | − 0.5 | [− 1.2; 0.1] | Reference |
| | Male | − 0.1 ± 11.6 | − 0.1 | [− 0.9; 0.7] | 0.8016 |
| | Low PI | 0.3 ± 10.7 | 0.3 | [− 0.6; 1.1] | 0.9606 |
| | Medium PI | − 0.7 ± 12.8 | − 0.7 | [− 1.5; 0.0] | Reference |
| | High PI | − 0.6 ± 16.1 | − 0.6 | [− 1.7; 0.5] | 0.5803 |
| | 5–9 years | − 0.6 ± 10.1 | − 0.6 | [− 3.1; 1.9] | 0.2133 |
| | 10–14 years | 2.1 ± 9.1 | 2.1 | [1.0; 3.2] | 0.9258 |
| | 15–19 years | 1.5 ± 12.0 | 1.5 | [0.3; 2.7] | 0.8013 |
| | 20–34 years | 0.7 ± 14.2 | 0.6 | [− 1.0; 2.3] | Reference |
| | 35–49 years | − 0.4 ± 11.7 | − 0.4 | [− 1.6; 0.8] | 0.1603 |
| | 50–64 years | − 2.7 ± 16.6 | − 2.7 | [− 3.9; − 1.5] | 0.0003 |
| | 65–79 years | − 3.5 ± 9.5 | − 3.5 | [− 4.9; − 2.2] | 0.0001 |
| | > 80 years | − 0.9 ± 20.6 | − 0.8 | [− 3.3; 1.6] | 0.1659 |
| Occipito-C2 angle (°) | Female | 91.6 ± 14.5 | 91.6 | [90.8; 92.4] | Reference |
| | Male | 92.4 ± 15.4 | 92.4 | [91.6; 93.3] | 0.9191 |
| | Low PI | 94.1 ± 14.2 | 94.1 | [93.1; 95.0] | > 0.9999 |
| | Medium PI | 90.9 ± 15.2 | 90.9 | [90.0; 91.8] | Reference |
| | High PI | 90.3 ± 15.1 | 90.3 | [89.0; 91.6] | 0.2097 |
| | 5–9 years | 94.8 ± 16.2 | 94.8 | [92.0; 97.7] | 0.8015 |
| | 10–14 years | 95.7 ± 13.0 | 95.7 | [94.4; 96.9] | 0.9780 |
| | 15–19 years | 95.4 ± 14.1 | 95.5 | [94.5; 97.2] | 0.9847 |
| | 20–34 years | 93.5 ± 14.4 | 93.4 | [91.5; 95.2] | Reference |
| | 35–49 years | 91.5 ± 14.7 | 91.5 | [90.1; 92.9] | 0.3569 |
| | 50–64 years | 88.0 ± 14.6 | 88.0 | [86.7; 89.4] | $< 6.7 \times 10^{-5}$ |
| | 65–79 years | 88.1 ± 15.6 | 88.1 | [86.6; 89.7] | $< 6.7 \times 10^{-5}$ |
| | > 80 years | 82.8 ± 15.2 | 83.0 | [80.2; 85.8] | $< 6.7 \times 10^{-5}$ |
| McGregor-C2 lordosis (°) | Female | 18.5 ± 10.1 | 18.5 | [18.0; 19.0] | Reference |
| | Male | 16.6 ± 9.7 | 16.6 | [16.3; 17.2] | > 0.9999 |
| | Low PI | 17.0 ± 10.0 | 17.0 | [16.4; 17.7] | 0.9732 |
| | Medium PI | 17.9 ± 9.8 | 17.9 | [17.3; 18.5] | Reference |
| | High PI | 18.7 ± 10.1 | 18.7 | [17.8; 19.5] | 0.0718 |
| | 5–9 years | 13.6 ± 10.3 | 13.6 | [17.4; 32.4] | 0.9995 |
| | 10–14 years | 15.7 ± 9.4 | 15.7 | [20.3; 27.2] | 0.9890 |
| | 15–19 years | 17.1 ± 10.3 | 17.1 | [18.6; 26.1] | 0.6804 |
| | 20–34 years | 17.4 ± 8.3 | 17.4 | [19.1; 27.6] | Reference |
| | 35–49 years | 17.8 ± 9.6 | 17.8 | [20.0; 27.7] | 0.3569 |
| | 50–64 years | 19.1 ± 9.4 | 19.1 | [32.5; 39.9] | 0.0209 |
| | 65–79 years | 19.6 ± 10.7 | 19.6 | [54.8; 63.3] | 0.0049 |
| | > 80 years | 22.4 ± 12.0 | 22.4 | [75.5; 90.2] | $< 6.7 \times 10^{-5}$ |

**Table 2** (continued)

| Parameter | Variable | Mean ± SD | Median | 95% CI | Pr(*d* > 0) |
|---|---|---|---|---|---|
| C1–C2 lordosis (°) | Female | 30.3 ± 8.4 | 30.3 | [29.1; 30.8] | Reference |
| | Male | 28.4 ± 8.4 | 28.4 | [27.9; 28.9] | > 0.9999 |
| | Low PI | 29.3 ± 8.6 | 29.3 | [28.7; 29.8] | 0.8409 |
| | Medium PI | 29.6 ± 8.2 | 29.6 | [29.1; 30.1] | Reference |
| | High PI | 29.7 ± 8.8 | 29.7 | [29.0; 30.5] | 0.4191 |
| | 5–9 years | 25.1 ± 9.7 | 25.1 | [23.4; 26.8] | > 0.9999 |
| | 10–14 years | 29.0 ± 8.4 | 29.0 | [28.2; 29.7] | 0.9132 |
| | 15–19 years | 30.6 ± 8.9 | 30.6 | [29.8; 31.4] | 0.1405 |
| | 20–34 years | 29.9 ± 8.1 | 29.9 | [28.8; 31.0] | Reference |
| | 35–49 years | 29.2 ± 7.8 | 29.2 | [28.4; 30.0] | 0.8380 |
| | 50–64 years | 29.8 ± 8.1 | 29.8 | [28.0; 30.6] | 0.5287 |
| | 65–79 years | 29.5 ± 8.7 | 29.5 | [28.5; 30.4] | 0.7266 |
| | > 80 years | 30.6 ± 8.5 | 30.6 | [28.9; 32.2] | 0.2499 |

*PI* pelvic incidence

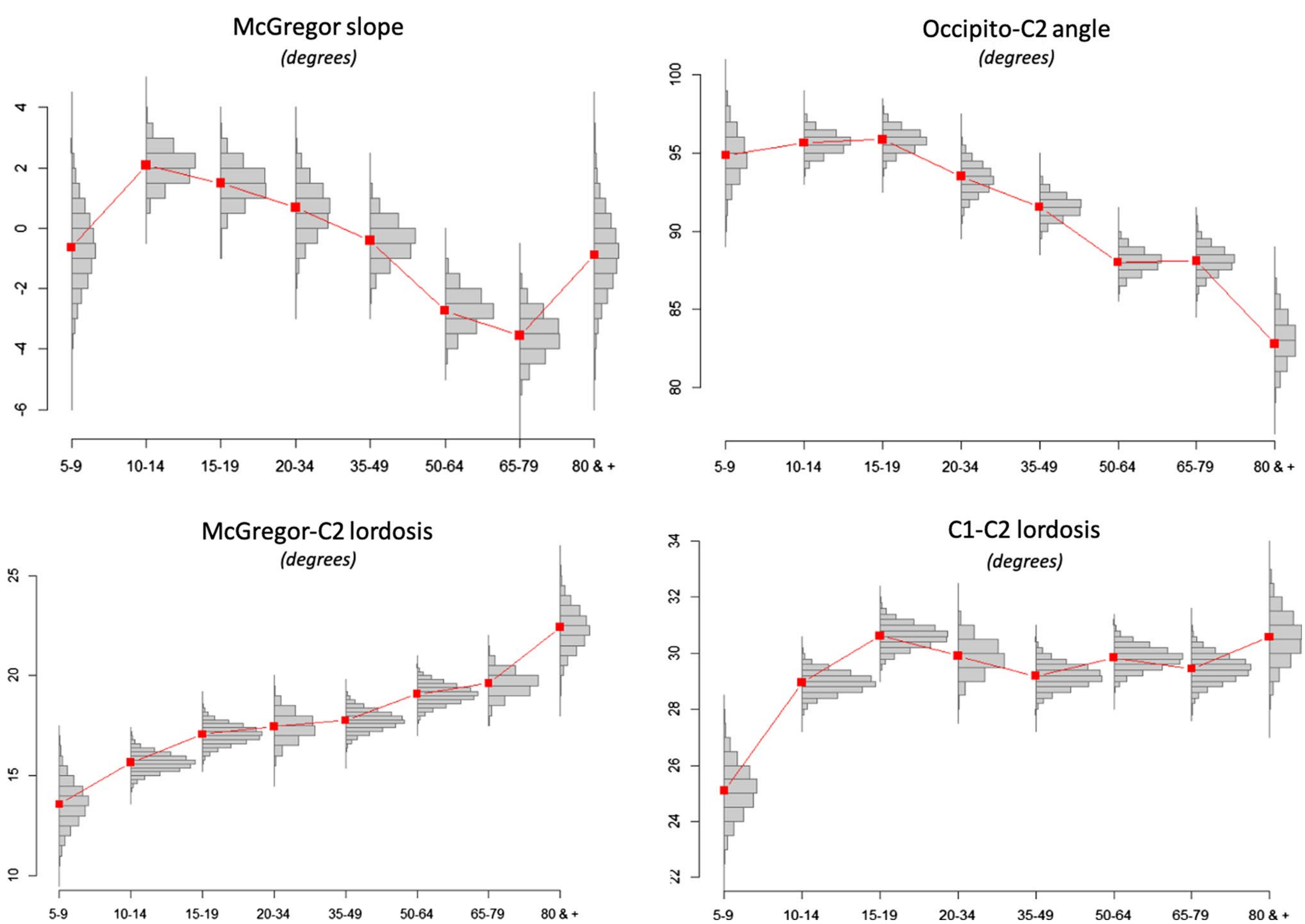


**Fig. 5** Distribution of cranial cervical parameters per age group. Red squares indicate median values

**Table 3** Distribution of caudal cervical 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($d > 0$) |
|---|---|---|---|---|---|
| C2–C7 lordosis (°) | Female | 29.1 ± 13.7 | 29.1 | [28.3; 29.9] | Reference |
| | Male | 31.7 ± 11.6 | 31.7 | [30.8; 32.7] | $< 6.7 \times 10^{-5}$ |
| | Low PI | 28.7 ± 15.4 | 28.7 | [27.6; 29.7] | > 0.9999 |
| | Medium PI | 31.3 ± 16.8 | 31.3 | [30.4; 32.3] | Reference |
| | High PI | 30.7 ± 15.6 | 30.7 | [29.3; 32.1] | 0.2097 |
| | 5–9 years | 28.9 ± 16.1 | 28.9 | [25.8; 31.9] | 0.0571 |
| | 10–14 years | 25.8 ± 15.5 | 25.8 | [24.4; 27.1] | 0.5359 |
| | 15–19 years | 29.2 ± 15.4 | 29.2 | [27.8; 30.6] | 0.0031 |
| | 20–34 years | 25.4 ± 15.1 | 25.9 | [23.9; 27.8] | Reference |
| | 35–49 years | 28.4 ± 15.0 | 28.4 | [26.9; 29.9] | 0.0203 |
| | 50–64 years | 32.3 ± 15.9 | 32.3 | [30.8; 33.7] | $< 6.7 \times 10^{-5}$ |
| | 65–79 years | 38.3 ± 15.5 | 38.2 | [36.5; 39.8] | $< 6.7 \times 10^{-5}$ |
| | > 80 years | 40.3 ± 16.3 | 40.0 | [37.0; 43.0] | $< 6.7 \times 10^{-5}$ |
| Cranial arch lordosis (°) | Female | 7.2 ± 14.9 | 7.2 | [6.5; 8.0] | Reference |
| | Male | 5.9 ± 13.3 | 5.9 | [5.1; 6.8] | 0.9901 |
| | Low PI | 7.7 ± 12.6 | 7.7 | [6.8; 8.6] | 0.0050 |
| | Medium PI | 6.1 ± 15.2 | 6.1 | [5.3; 6.9] | Reference |
| | High PI | 5.9 ± 14.8 | 5.9 | [4.6; 7.1] | 0.6189 |
| | 5–9 years | 8.6 ± 10.5 | 8.5 | [5.7; 11.3] | 0.0109 |
| | 10–14 years | 6.7 ± 12.1 | 6.7 | [5.4; 7.9] | 0.0343 |
| | 15–19 years | 10.0 ± 13.0 | 9.9 | [8.6; 11.3] | $< 6.7 \times 10^{-5}$ |
| | 20–34 years | 4.5 ± 12.3 | 4.6 | [2.8; 6.4] | Reference |
| | 35–49 years | 5.1 ± 13.7 | 5.1 | [3.7; 6.4] | 0.3581 |
| | 50–64 years | 6.8 ± 16.8 | 6.8 | [5.4; 8.1] | 0.0307 |
| | 65–79 years | 5.7 ± 17.3 | 5.7 | [4.2; 7.2] | 0.1870 |
| | > 80 years | 4.6 ± 13.2 | 4.6 | [1.9; 7.3] | 0.5121 |
| Caudal arch lordosis (°) | Female | 23.1 ± 10.1 | 23.1 | [22.6; 23.6] | Reference |
| | Male | 26.8 ± 10.2 | 26.8 | [26.2; 27.4] | > 0.9999 |
| | Low PI | 22.9 ± 9.1 | 22.9 | [22.3; 23.6] | 0.9732 |
| | Medium PI | 25.5 ± 10.7 | 25.5 | [24.9; 26.1] | Reference |
| | High PI | 26.2 ± 11.3 | 26.2 | [25.3; 27.1] | 0.0718 |
| | 5–9 years | 21.8 ± 9.8 | 21.8 | [19.9; 23.6] | 0.2440 |
| | 10–14 years | 20.8 ± 8.8 | 20.8 | [20.0; 21.6] | 0.0095 |
| | 15–19 years | 20.8 ± 8.4 | 20.8 | [19.9; 21.6] | 0.0085 |
| | 20–34 years | 22.5 ± 10.3 | 22.6 | [21.4; 23.8] | Reference |
| | 35–49 years | 24.0 ± 8.6 | 24.0 | [23.1; 24.9] | 0.9693 |
| | 50–64 years | 27.0 ± 8.8 | 27.0 | [26.1; 27.8] | > 0.9999 |
| | 65–79 years | 32.5 ± 9.8 | 32.4 | [31.5; 33.5] | > 0.9999 |
| | > 80 years | 35.6 ± 14.9 | 35.5 | [33.7; 37.3] | > 0.9999 |

**Table 3** (continued)

| Parameter | Variable | Mean ± SD | Median | 95% CI | Pr($d>0$) |
|---|---|---|---|---|---|
| C7-slope (°) | Female | 19.6 ± 11.1 | 19.6 | [19.1; 20.2] | Reference |
| | Male | 23.8 ± 11.0 | 23.8 | [23.1; 24.4] | > 0.9999 |
| | Low PI | 19.3 ± 10.1 | 19.3 | [18.6; 20.0] | $< 6.7 \times 10^{-5}$ |
| | Medium PI | 22.6 ± 11.7 | 22.6 | [21.9; 23.2] | Reference |
| | High PI | 23.0 ± 11.7 | 23.0 | [22.0; 23.9] | 0.7289 |
| | 5–9 years | 20.3 ± 11.1 | 20.3 | [18.3; 22.4] | 0.9106 |
| | 10–14 years | 17.5 ± 10.0 | 17.5 | [16.7; 18.4] | 0.0864 |
| | 15–19 years | 17.3 ± 9.1 | 17.3 | [16.4; 18.3] | 0.0540 |
| | 20–34 years | 18.5 ± 9.8 | 18.6 | [17.3; 20.0] | Reference |
| | 35–49 years | 20.6 ± 9.1 | 20.6 | [19.6; 21.6] | 0.9885 |
| | 50–64 years | 23.2 ± 11.1 | 23.2 | [22.2; 24.1] | > 0.9999 |
| | 65–79 years | 29.9 ± 11.0 | 29.8 | [28.7; 30.4] | > 0.9999 |
| | > 80 years | 33.7 ± 12.7 | 33.6 | [31.6; 35.6] | > 0.9999 |
| T1-slope (°) | Female | 23.2 ± 11.3 | 23.2 | [22.6; 23.8] | Reference |
| | Male | 27.7 ± 11.0 | 27.7 | [27.0; 28.3] | > 0.9999 |
| | Low PI | 23.0 ± 10.4 | 23.0 | [22.3; 23.8] | $< 6.7 \times 10^{-5}$ |
| | Medium PI | 26.5 ± 11.8 | 26.5 | [25.8; 27.1] | Reference |
| | High PI | 26.1 ± 11.8 | 26.1 | [25.1; 27.1] | 0.2914 |
| | 5–9 years | 22.3 ± 10.6 | 22.3 | [20.2; 24.3] | 0.4159 |
| | 10–14 years | 20.1 ± 9.8 | 20.1 | [20.0; 21.7] | 0.0195 |
| | 15–19 years | 21.2 ± 9.5 | 21.2 | [20.2; 22.1] | 0.0502 |
| | 20–34 years | 22.4 ± 10.1 | 22.5 | [21.2; 23.9] | Reference |
| | 35–49 years | 24.2 ± 9.6 | 24.2 | [23.2; 25.2] | 0.9714 |
| | 50–64 years | 27.4 ± 10.4 | 27.4 | [26.5; 28.4] | > 0.9999 |
| | 65–79 years | 33.9 ± 11.4 | 33.8 | [32.7; 35.0] | > 0.9999 |
| | > 80 years | 37.2 ± 13.7 | 37.1 | [35.1; 39.1] | > 0.9999 |

*PI* pelvic incidence

had significantly smaller C2–C7 lordosis (Pr > 0.9999). A progressive increase was observed after 50 years. Cranial arch lordosis was significantly smaller in males (Pr = 0.9901). Differences between PI groups were non-significant. This parameter kept constant during adulthood. Caudal arch lordosis was significantly larger in males (Pr > 0.9999). Differences between PI groups were non-significant. This parameter increased progressively during adulthood. When compared to young adults, there was a significant difference in the age group between 35 and 49 years (Pr = 0.9693) and after 50 years (Pr > 0.9999). Similar observations were made for C7- and T1-slope. Both parameters were significantly larger in males (Pr > 0.9999). Differences between PI groups were non-significant. A significant increase with aging was observed for both parameters in the group 35–49 years (Pr > 0.95) and after 50 years (Pr > 0.9999) (Fig. 6).

## Cervical morphology

Cervicothoracic inflexion levels were at C6 in 526 (20.2%), C7 in 978 (37.6%), T1 in 768 (29.6%), T2 in 256 (9.9%) and T3 in 71 (2.7%) individuals. Variations in number of vertebrae from C1 to the cervicothoracic inflexion were small (Table 4). The cervical segment included more vertebrae in low PI (Pr > 0.9999) and in the group 10–14 years (Pr = 0.9813). The distribution by cervical alignment patterns (Fig. 4) was: global lordosis $n = 1323$ (50.9%), global kyphosis $n = 34$ (1.3%), sigmoid shape with proximal kyphosis and distal lordosis $n = 894$ (34.4%) and sigmoid shape with proximal lordosis and distal kyphosis $n = 348$ (13.4%).

## Correlation between cervical, global and spinopelvic alignment

Table 5 displays correlation coefficients $\rho$ between cervical and global alignment parameters. SVA-C2

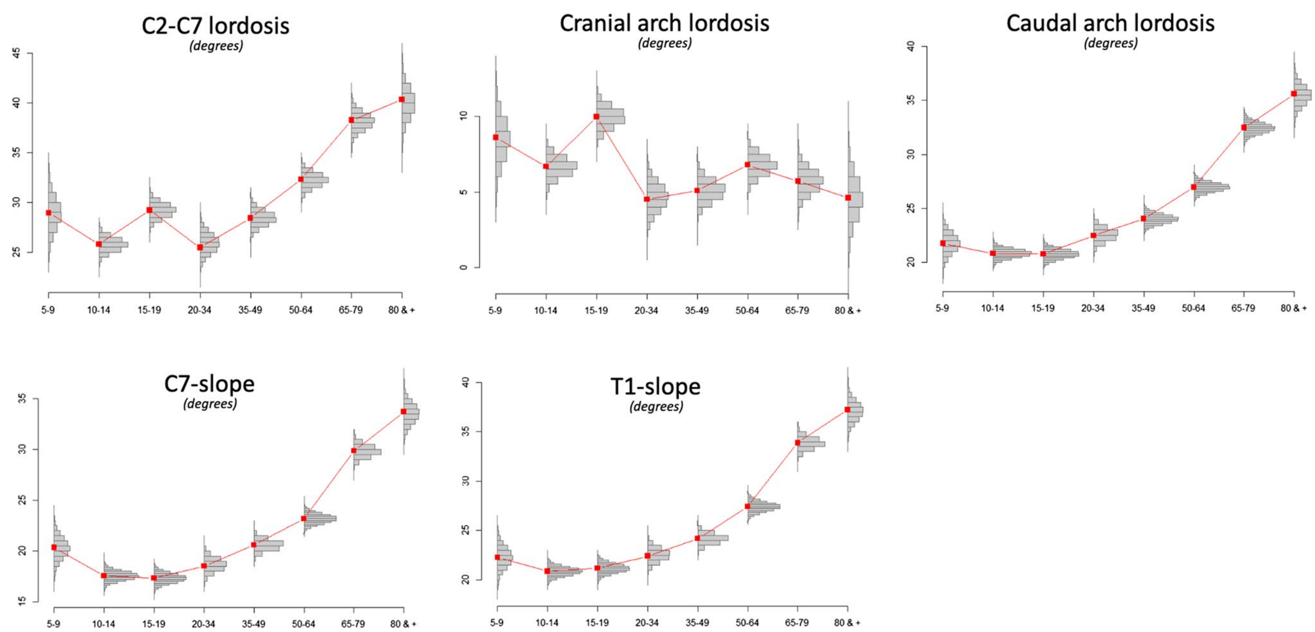


**Fig. 6** Distribution of caudal cervical parameters per age group. Red squares indicate median values

**Table 4** Distribution of number of cervical vertebrae from C1 to the cervicothoracic inflexion point (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) |
|---|---|---|---|---|---|
| Number of cervical vertebrae | Female | 7.5 ± 1.1 | 7.5 | [7.4; 7.5] | Reference |
| | Male | 7.2 ± 1.1 | 7.2 | [7.2; 7.3] | $< 6.7 \times 10^{-5}$ |
| | Low PI | 7.5 ± 1.1 | 7.5 | [7.4; 7.6] | > 0.9999 |
| | Medium PI | 7.3 ± 1.0 | 7.3 | [7.2; 7.4] | Reference |
| | High PI | 7.3 ± 1.2 | 7.3 | [7.2; 7.4] | 0.2914 |
| | 5–9 years | 7.3 ± 1.0 | 7.3 | [7.0; 7.5] | 0.2546 |
| | 10–14 years | 7.5 ± 0.9 | 7.5 | [7.4; 7.6] | 0.9813 |
| | 15–19 years | 7.4 ± 1.0 | 7.4 | [7.3; 7.5] | 0.7785 |
| | 20–34 years | 7.3 ± 1.1 | 7.3 | [7.2; 7.5] | Reference |
| | 35–49 years | 7.4 ± 1.1 | 7.4 | [7.3; 7.5] | 0.6385 |
| | 50–64 years | 7.3 ± 1.2 | 7.3 | [7.2; 7.4] | 0.2190 |
| | 65–79 years | 7.2 ± 1.1 | 7.2 | [7.0; 7.3] | 0.0224 |
| | > 80 years | 7.2 ± 1.3 | 7.2 | [7.0; 7.4] | 0.1801 |

*PI* pelvic incidence

correlated significantly with caudal arch lordosis ($\rho = 0.5526$; Pr = 0.9997) and non-significantly with T1-slope ($\rho = 0.5217$; Pr = 0.9337) and C7-slope ($\rho = 0.5001$; Pr = 0.5026). No correlation was observed for SVA-C7 and OD-HA. Table 6 demonstrates correlation coefficients between cervical and spinopelvic parameters. TK correlated significantly with C2–C7 lordosis ($\rho = 0.5359$; Pr = 0.9943), caudal arch lordosis ($\rho = 0.7267$; Pr > 0.9999), C7-slope ($\rho = 0.7073$; Pr > 0.9999) and T1-slope ($\rho = 0.8491$; Pr > 0.9999). There was no correlation between cervical parameters and LL, PI, PT or SS.

## Discussion

Analyzing cervical alignment in spinal deformity has gained interest [3–7]. Cervical malalignment represents a consequence of thoracolumbar deformity as interactions with the mobile cervical segment exist [11, 20]. Although age-related changes of cervical parameters have been reported on the one hand [11–13] and spinopelvic and global alignment parameters on the other hand [14, 15], there is a lack of knowledge about the interaction of both. PI- and age-related alignment targets have been defined in adult spinal deformity [21], seeking for optimal thoracolumbar alignment, thus

**Table 5** Correlation between cervical and global alignment 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 | SVA-C7 | SVA-C2 | OD-HA |
|---|---|---|---|
| McGregor slope | − 0.0529 | − 0.0003 | − 0.0455 |
| | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ |
| Occipito-C2 angle | 0.0592 | − 0.1489 | 0.2479 |
| | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ |
| McGregor-C2 lordosis | 0.0186 | 0.1306 | 0.1216 |
| | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ |
| C1–C2 lordosis | 0.0342 | 0.0488 | 0.0548 |
| | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ |
| C2–C7 lordosis | 0.2978 | 0.2730 | 0.2120 |
| | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ |
| Cranial arch lordosis | 0.0045 | 0.0914 | 0.1171 |
| | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ | $<6.7\times10^{-5}$ |
| Caudal arch lordosis | 0.4916 | 0.5526 | 0.4961 |
| | 0.2816 | 0.9997 | 0.3936 |
| C7-slope | 0.4132 | 0.5001 | − 0.4498 |
| | $<6.7\times10^{-5}$ | 0.5026 | 0.0006 |
| T1-slope | 0.4587 | 0.5217 | − 0.4667 |
| | 0.0032 | 0.9337 | 0.0128 |

*SVA* sagittal vertical axis, *OD-HA* odontoid-hip axis

limiting the risk of secondary cervical decompensation [7]. Therefore, the present study aimed to provide a comprehensive description of cranial and caudal cervical alignment according to gender, PI and age, to provide a repository of reference parameters when treating spinal deformity.

Cranial parameters are mainly influenced by head position, which is often analyzed by the chin-brow vertical angle. Moses et al. [22] demonstrated a correlation with McGregor slope. Le Huec et al. [9] reported a mean value of 1.59° (range − 18° to 16°) in adults. Abelin-Genevois et al. [8] reported a mean McGregor-C2 lordosis of 15.2° in children and 18.3° in adolescents, with larger values in girls. In asymptomatic adults, mean values range from 12.7° to 22.4° [9, 23–26]. Our results are in line with these findings. Gender-specific differences exist for McGregor-C2 lordosis, and a progressive increase with age was observed. McGregor slope and occipito-C2 angle decreased with age, describing a progressive head extension. Significant differences existed between pediatric and young adult populations, which might be explained by a lower muscle tone of cervicothoracic erector spinae and trapezius muscles in children and adolescents. The amount of PI influenced the occipitocervical orientation, especially in low PI, which is associated lower TK and LL. Positive McGregor slope values indicated a flexed head position, which resulted in larger occipito-C2 angles and smaller McGregor-C2 lordosis. C1–C2 lordosis accounts for the main part of cervical lordosis. Mean values range from 26.0° to 30.3° in children and adolescents [8] and 20.8°–31.9° in adults [9, 12, 24–28]. Our findings fit within these ranges. C1–C2 lordosis increased during growth, whereas values kept stable during

**Table 6** Correlation between cervical 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 | Thoracic kyphosis | Lumbar lordosis | Pelvic incidence | Pelvic tilt | Sacral slope |
|---|---|---|---|---|---|
| McGregor slope | − 0.0853 | 0.0171 | − 0.0248 | − 0.0620 | 0.0326 |
| | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| Occipito-C2 angle | − 0.0578 | 0.0259 | − 0.1017 | − 0.1255 | − 0.0036 |
| | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| McGregor-C2 lordosis | 0.0420 | 0.0115 | 0.0698 | 0.1029 | − 0.0149 |
| | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| C1–C2 lordosis | 0.0265 | − 0.0242 | 0.0413 | 0.0355 | 0.0181 |
| | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| C2–C7 lordosis | 0.5359 | 0.0175 | 0.0534 | 0.1478 | 0.0854 |
| | 0.9943 | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| Cranial arch lordosis | 0.0091 | 0.0220 | 0.0646 | 0.0430 | − 0.0423 |
| | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| Caudal arch lordosis | 0.7267 | 0.0047 | 0.1293 | 0.2558 | 0.0970 |
| | > 0.9999 | $< 6.7\times10^{-5}$ | 0.3936 | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| C7-slope | 0.7073 | 0.0010 | 0.1439 | 0.2307 | − 0.0502 |
| | > 0.9999 | $< 6.7\times10^{-5}$ | 0.0006 | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |
| T1-slope | 0.8491 | 0.0223 | 0.1233 | 0.2465 | − 0.0951 |
| | > 0.9999 | $< 6.7\times10^{-5}$ | 0.0128 | $< 6.7\times10^{-5}$ | $< 6.7\times10^{-5}$ |

adulthood. Gender-specific differences existed with smaller values in males.

The literature indicates a large variability of C2–C7 lordosis, due to varying measurement methods, different alignment patterns and age-related changes. In children and adolescents, mean values of 6.5° and 0.7° were reported [8]. In adults, means range from 4.9° to 40.0° [9–13, 20, 22–28]. In our study, values were higher in the pediatric population, but similar in adults. Scheer et al. [11] described a C2–C7 lordosis increase from 9.4° at 20–34 years to 22.2° over 60 years. Hardacker et al. [12] demonstrated an increase from 37° at 20–30 years to 47° at 61–70 years. Iyer et al. [13] showed an increase from 4.5° at 21–30 years to 15.7° over 71 years. Our results showed that this lordosis increase mainly occurred in the caudal arch, whereas the cranial arch kept stable. Caudal arch lordosis increased with age in parallel to C7-slope, T1-slope and TK. An age-related TK increase was described by Iyer et al. [14] and Hu et al. [15]. This suggests that progressive caudal cervical hyperextension compensating increasing proximal TK to maintain horizontal gaze. This phenomenon was more prominent in males and individuals with high PI. C7-slope and T1-slope represent similar parameters. Mean C7-slope values were 21.3° and 17.4° in children and adolescents [8] and 19.64° in adults [9]. Iyer et al. [13] described a T1-slope increase from 21.7° at 21–30 years to 35.3° over 71 years. Chen et al. [28] demonstrated an increase from 23.0° under 21 years to 28.7° at 41–60 years, like our findings.

Correlation analyses confirmed a strong relationship between C2–C7 lordosis, C7-slope, T1-slope and TK in pediatric and adult populations [8–11, 13, 20, 24]. Núñez-Pereira et al. [24] found a weak ($r = -0.3$) but significant correlation between C7-slope and SS. Lee et al. [10] and Scheer et al. [11] investigated correlation chains between cervical, thoracolumbar and spinopelvic parameters. Correlations exist between cervical and thoracic parameters around the cervicothoracic junction, between TK and LL and between LL and spinopelvic parameters. A direct correlation between cervical parameters, LL and spinopelvic parameters was not evidenced. Among global alignment parameters, Iyer et al. [13] demonstrated weak but significant correlations for SVA-C2–C7 with T1-slope ($r = 0.306$) and C2–C7 lordosis ($r = 0.221$). In our study, only SVA-C2 correlated with caudal arch lordosis and T1-slope. Global alignment results showed that SVA-C2 and TK increased with age. This indicates a relationship between progressive anterior C2-plumbline migration, TK changes and compensatory hyperextension of the caudal cervical arch. This phenomenon might influence cervical morphology and the level of cervicothoracic inflexion point which varied from C6 to T3. In our population, 50.9% presented an evenly distributed cervical lordosis. Kyphotic alignment represented only 1.3%. This pattern is more common in patients with scoliosis and thoracic hypokyphosis [3–6]. Yu et al. [4] and Charles et al. [5] described sigmoid shapes in scoliosis, which represented compensation phenomena of thoracic malalignment. Sigmoid patterns were also found in our asymptomatic population. Proximal kyphosis and distal lordosis represented 34.4%, possibly related to degenerative changes, adaptive C2–plumbline translation and caudal arch increase with age. Proximal lordosis and distal kyphosis represented 13.4%, where TK extended into the caudal cervical spine.

This cross-sectional study has limitations as the evolution of alignment parameters cannot be assessed over a lifetime. Quality-of-life scores and muscle strength were not assessed, although these clinical factors might influence radiographic alignment. Moderate intervertebral disc degeneration and osteoarthritis represent an inevitable age-related phenomenon. Severe changes leading to deformity were excluded. The influence of degenerative changes was not specifically analyzed.

## Conclusion

Cervical alignment parameters vary according to age, gender and PI. In the cranial cervical segment, the main changes occur during growth. In the caudal cervical segment, lordosis increases mainly in the lower arch during adulthood, which is strongly related to thoracic kyphosis increase with age. The caudal cervical arch acts as a compensatory segment.

**Acknowledgements** The authors would like to thank Philippe Roussouly for technical support using the KEOPS online database.

**Authors' contribution** Yann Philippe Charles designed and coordinated the study, collected and analyzed data and wrote the manuscript. Benjamin Blondel, Solène Prost, Sébastien Pesenti, Brice Ilharreborde, Eloïse Bauduin and Féthi Laouissat designed the study, collected and analyzed data and approved the manuscript. Erik André Sauleau designed the study, analyzed data and approved the manuscript. Guillaume Riouallon, Stéphane Wolff, Vincent Challier, Ibrahim Obeid, Louis Boissière, Emmanuelle Ferrero, Federico Solla, Jean-Charles Le Huec, Stéphane Bourret, Joe Faddoul, Georges Naïm Abi Lahoud, Vincent Fière, Michiel Vande Kerckhove, Matthieu Campana, Jonathan Lebhar, Hadrien Giorgi and Aymeric Faure collected and analyzed data and approved the manuscript.

**Funding** The KEOPS online database license was funded by the French Spine Surgery Society (SFCR). All the authors participated in the study with no study funding involved.

## 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. Brice Ilharreborde is consultant for Zimmer Biomet, Medtronic and Implanet. Féthi Laouissat is consultant for Spineart and SMAIO. Guillaume Riouallon is consultant for Medtronic, Stryker and NewClip; he received royalties from Euros. Vincent Challier is shareholder of Follow Health SA and consultant for Clariance. Ibrahim Obeid is consultant for Medtronic and DePuy Synthes; he received grants from DePuy Synthes unrelated to this study and royalties from Clariance, Alphatec and Spineart. Louis Boissière is consultant for Neo and Euros; he received grants from DePuy Synthes unrelated to this study. Federico Solla received funding to attend meetings from Medicrea, Medtronic and Euros. Jean-Charles Le Huec is consultant for Medtronic and BD Bard; he received royalties and grants unrelated to this study from Medtronic. Vincent Fière is consultant for Clariance; he received royalties Medicrea and Clariance. Aymeric Faure is consultant for OSD. Benjamin Blondel is associate editor for OTSR Elsevier-Masson and consultant for Medicrea, Medtronic, Implanet, Vexim Stryker and M. Solène Prost, Sébastien Pesenti, Eloïse Bauduin, Stéphane Wolff, Emmanuelle Ferrero, Stéphane Bourret, Joe Faddoul, Georges Naïm Abi Lahoud, Michiel Vande Kerckhove, Matthieu Campana, Jonathan Lebhar, Hadrien Giorgi and Erik André Sauleau have no conflict of interest.

**Ethics approval** Institutional review board approval (FC/2019-91) was obtained. The study was declared at ClinicalTrials.gov ID: NCT04467775.

**Consent to participate** Informed consent was obtained from study participants.

**Consent for publication** Informed consent for publication of results was obtained from study participants.

## References


1. Inada T, Furuya T, Kamiya K, Ota M, Maki S, Suzuki T, Takahashi K, Yamazaki M, Aramomi M, Mannoji C, Koda M (2016) Postoperative increase in occiput-C2 Angle negatively impacts subaxial lordosis after occipito-upper cervical posterior fusion surgery. Asian Spine J 10:744–747. https://doi.org/10.4184/asj.2016.10.4.744
2. Matsubayashi Y, Shimizu T, Chikuda H, Takeshita K, Oshima Y, Tanaka S (2016) Correlations of cervical sagittal alignment before and after occipitocervical fusion. Global Spine J 6:362–369. https://doi.org/10.1055/s-0035-1563725
3. Hilibrand AS, Tannenbaum DA, Graziano GP, Loder RT, Hensinger RN (1995) The sagittal alignment of the cervical spine in adolescent idiopathic scoliosis. J Pediatr Orthop 15:627–632. https://doi.org/10.1097/01241398-199509000-00015
4. Yu M, Silvestre C, Mouton T, Rachkidi R, Zeng L, Roussouly P (2013) Analysis of the cervical spine sagittal alignment in young idiopathic scoliosis: a morphological classification of 120 cases. Eur Spine J 22:2372–2381. https://doi.org/10.1007/s00586-013-2753-1
5. Charles YP, Sfeir G, Matter-Parrat V, Sauleau EA, Steib JP (2015) Cervical sagittal alignment in idiopathic scoliosis treated by posterior instrumentation and in situ bending. Spine (Phila Pa 1976) 40:E419–E427. https://doi.org/10.1097/BRS.0000000000000767
6. Ilharreborde B, Vidal C, Skalli W, Mazda K (2013) Sagittal alignment of the cervical spine in adolescent idiopathic scoliosis treated by posteromedial translation. Eur Spine J 22:330–337. https://doi.org/10.1007/s00586-012-2493-7
7. Passias PG, Soroceanu A, Smith J, Boniello A, Yang S, Scheer JK, Schwab F, Shaffrey C, Kim HJ, Protopsaltis T, Mundis G, Gupta M, Klineberg E, Lafage V, Ames C; International Spine Study Group (2015) Postoperative cervical deformity in 215 thoracolumbar patients with adult spinal deformity: prevalence, risk factors, and impact on patient-reported outcome and satisfaction at 2-year follow-up. Spine (Phila Pa 1976) 40:283–291. https://doi.org/10.1097/BRS.0000000000000746
8. Abelin-Genevois K, Idjerouidene A, Roussouly P, Vital JM, Garin C (2014) Cervical spine alignment in the pediatric population: a radiographic normative study of 150 asymptomatic patients. Eur Spine J 23:1442–1448. https://doi.org/10.1007/s00586-013-3150-5
9. Le Huec JC, Demezon H, Aunoble S (2015) Sagittal parameters of global cervical balance using EOS imaging: normative values from a prospective cohort of asymptomatic volunteers. Eur Spine J 24:63–71. https://doi.org/10.1007/s00586-014-3632-0
10. Lee SH, Son ES, Seo EM, Suk KS, Kim KT (2015) Factors determining cervical spine sagittal balance in asymptomatic adults: correlation with spinopelvic balance and thoracic inlet alignment. Spine J 15:705–712. https://doi.org/10.1016/j.spinee.2013.06.059
11. Scheer JK, Tang JA, Smith JS, Acosta FL Jr, Protopsaltis TS, Blondel B, Bess S, Shaffrey CI, Deviren V, Lafage V, Schwab F, Ames CP; International Spine Study Group (2013) Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine 19:141–159. https://doi.org/10.3171/2013.4.SPINE12838
12. Hardacker JW, Shuford RF, Capicotto PN, Pryor PW (1997) Radiographic standing cervical segmental alignment in adult volunteers without neck symptoms. Spine (Phila Pa 1976) 22:1472–1480. https://doi.org/10.1097/00007632-199707010-00009
13. Iyer S, Lenke LG, Nemani VM, Fu M, Shifflett GD, Albert TJ, Sides BA, Metz LN, Cunningham ME, Kim HJ (2016) Variations in occipitocervical and cervicothoracic alignment parameters based on age: a prospective study of asymptomatic volunteers using full-body radiographs. Spine (Phila Pa 1976) 41:1837–1844. https://doi.org/10.1097/BRS.0000000000001644
14. Iyer S, Lenke LG, Nemani VM, Albert TJ, Sides BA, Metz LN, Cunningham ME, Kim HJ (2016) Variations in sagittal alignment parameters based on age: a prospective study of asymptomatic volunteers using full-body radiographs. Spine (Phila Pa 1976) 41:1826–1836. https://doi.org/10.1097/BRS.0000000000001642
15. Hu Z, Man GCW, Yeung KH, Cheung WH, Chu WCW, Law SW, Lam TP, Zhu Z, Qiu Y, Cheng JCY (2020) 2020 Young investigator award winner: age- and sex-related normative value of whole-body sagittal alignment based on 584 asymptomatic Chinese adult population from age 20 to 89. Spine (Phila Pa 1976) 45:79–87. https://doi.org/10.1097/BRS.0000000000003187
16. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J (2005) Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. Spine (Phila Pa 1976) 30:346–353. https://doi.org/10.1097/01.brs.0000152379.54463.65
17. Maillot C, Ferrero E, Fort D, Heyberger C, Le Huec JC (2015) Reproducibility and repeatability of a new computerized software for sagittal spinopelvic and scoliosis curvature radiologic measurements: Keops(®). Eur Spine J 24:1574–1581. https://doi.org/10.1007/s00586-015-3817-1
18. Amabile C, Pillet H, Lafage V, Barrey C, Vital JM, Skalli W (2016) A new quasi-invariant parameter characterizing the postural alignment of young asymptomatic adults. Eur Spine J 25:3666–3674. https://doi.org/10.1007/s00586-016-4552-y
19. Jackson RP, McManus AC (1994) Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. A prospective controlled clinical study. Spine (Phila Pa 1976) 19:1611–1618. https://doi.org/10.1097/00007632-199407001-00010

20. Lee SH, Hyun SJ, Jain A (2020) Cervical sagittal alignment: literature review and future directions. Neurospine 17:478–496. https://doi.org/10.14245/ns.2040392.196
21. Protopsaltis TS, Soroceanu A, Tishelman JC, Buckland AJ, Mundis GM Jr, Smith JS, Daniels A, Lenke LG, Kim HJ, Klineberg EO, Ames CP, Hart RA, Bess S, Shaffrey CI, Schwab FJ, Lafage V; International Spine Study Group (ISSG) (2020) Should sagittal spinal alignment targets for adult spinal deformity correction depend on pelvic incidence and age? Spine (Phila Pa 1976) 45:250–257. https://doi.org/10.1097/BRS.0000000000003237
22. Moses MJ, Tishelman JC, Zhou PL, Moon JY, Beaubrun BM, Buckland AJ, Protopsaltis TS (2019) McGregor's slope and slope of line of sight: two surrogate markers for Chin–Brow vertical angle in the setting of cervical spine pathology. Spine J 19:1512–1517. https://doi.org/10.1016/j.spinee.2019.04.021
23. Lee SH, Kim KT, Seo EM, Suk KS, Kwack YH, Son ES (2012) The influence of thoracic inlet alignment on the craniocervical sagittal balance in asymptomatic adults. J Spinal Disord Tech 25:E41–E47. https://doi.org/10.1097/BSD.0b013e3182396301
24. Núñez-Pereira S, Hitzl W, Bullmann V, Meier O, Koller H (2015) Sagittal balance of the cervical spine: an analysis of occipitocervical and spinopelvic interdependence, with C-7 slope as a marker of cervical and spinopelvic alignment. J Neurosurg Spine 23:16–23. https://doi.org/10.3171/2014.11.SPINE14368
25. Guo Q, Ni B, Yang J, Liu K, Sun Z, Zhou F, Zhang J (2011) Relation between alignments of upper and subaxial cervical spine: a radiological study. Arch Orthop Trauma Surg 131:857–862. https://doi.org/10.1007/s00402-011-1265-x
26. Kuntz C 4th, Levin LS, Ondra SL, Shaffrey CI, Morgan CJ (2007) Neutral upright sagittal spinal alignment from the occiput to the pelvis in asymptomatic adults: a review and resynthesis of the literature. J Neurosurg Spine 6:104–112. https://doi.org/10.3171/spi.2007.6.2.104
27. Nojiri K, Matsumoto M, Chiba K, Maruiwa H, Nakamura M, Nishizawa T, Toyama Y (2003) Relationship between alignment of upper and lower cervical spine in asymptomatic individuals. J Neurosurg 99:80–83. https://doi.org/10.3171/spi.2003.99.1.0080
28. Chen Y, Luo J, Pan Z, Yu L, Pang L, Zhong J, Li Z, Han Z, Cao K (2017) The change of cervical spine alignment along with aging in asymptomatic population: a preliminary analysis. Eur Spine J 26:2363–2371. https://doi.org/10.1007/s00586-017-5209-1




## Authors and Affiliations


**Yann Philippe Charles[1] · Solène Prost[2] · Sébastien Pesenti[3] · Brice Ilharreborde[4] · Eloïse Bauduin[5] · Féthi Laouissat[6] · Guillaume Riouallon[7] · Stéphane Wolff[7] · Vincent Challier[8] · Ibrahim Obeid[9] · Louis Boissière[9] · Emmanuelle Ferrero[10] · Federico Solla[11] · Jean-Charles Le Huec[12] · Stéphane Bourret[12] · Joe Faddoul[13] · Georges Naïm Abi Lahoud[13] · Vincent Fière[14] · Michiel Vande Kerckhove[14] · Matthieu Campana[4] · Jonathan Lebhar[15] · Hadrien Giorgi[16] · Aymeric Faure[16] · Erik André Sauleau[17] · Benjamin Blondel[2] · The French Spine Surgery Society (SFCR)**

[1] Service de Chirurgie du Rachis, Hôpitaux Universitaires de Strasbourg, Université de Strasbourg, 1 Avenue Molière, 67200 Strasbourg, France

[2] Unité de Chirurgie Rachidienne, CHU Timone, Aix-Marseille Université, Marseille, France

[3] Service d'Orthopédie Pédiatrique, CHU Timone, Aix-Marseille Université, Marseille, France

[4] Service de Chirurgie Orthopédique Pédiatrique, AP-HP, CHU Robert Debré, Université de Paris, Paris, France

[5] Service de Chirurgie Orthopédique et Traumatologie, Hôpital Maison Blanche, CHU de Reims, Reims, France

[6] Hôpital Privé de L'Est Lyonnais, Saint-Priest, France

[7] Service de Chirurgie Orthopédique et Traumatolgique, Groupe Hospitalier Paris Saint Joseph, Paris, France

[8] Hôpital Privé du Dos Francheville, Périgueux, France

[9] Clinique du Dos Jean Villar, Bruges, France

[10] Service de Chirurgie Orthopédique de la Colonne Vertébrale, AP-HP, Hôpital Européen Georges-Pompidou, Université de Paris, Paris, France

[11] Service d'Orthopédie Pédiatrique, Fondation Lenval, Nice, France

[12] Polyclinique Bordeaux Nord Aquitaine, Université de Bordeaux, Bordeaux, France

[13] Institut de la Colonne Vertébrale et des Neurosciences, Centre Médico-Chirurgical Bizet, Paris, France

[14] Centre Orthopédique Santy, Unité du Rachis, Lyon, France

[15] Institut Locomoteur de L'Ouest Rachis, Centre Hospitalier Privé Saint-Grégoire, Saint-Grégoire, France

[16] Institut Méditerranéen du Dos, Marseille, France

[17] Pôle Santé Publique, Hôpitaux Universitaires de Strasbourg, Strasbourg, France