Eur Spine J (2014) 23:1442–1448
DOI 10.1007/s00586-013-3150-5

ORIGINAL ARTICLE

Cervical spine alignment in the pediatric population: a radiographic normative study of 150 asymptomatic patients

K. Abelin-Genevois · A. Idjerouidene · P. Roussouly · J. M. Vital · C. Garin

Received: 24 June 2013 / Revised: 15 December 2013 / Accepted: 18 December 2013 / Published online: 7 January 2014

Abstract
Purpose To describe the normal cervical sagittal alignment of the pediatric spine in a normal population and to identify the changes during growth period.
Methods We randomly selected in PACS database 150 full-spine standing views. Exclusion criteria were: age >18 years, spinal deformity and any disease affecting the spine (medical charts reviewing). For cervical alignment we measured: OC-angle according to Mc Gregor, C1C7 angle, upper cervical angle, inferior cervical angle and C7 tilt. Spino pelvic parameters were analyzed: T1 tilt, thoracic kyphosis, lumbar lordosis, pelvic incidence, sacral slope and pelvic tilt. We compared two age subgroups (juvenile and adolescent). Differences between age groups and gender were tested using Student's *t* test. Correlations between sagittal spinal parameters were evaluated using Pearson's test.
Results Cervical spine shape was correlated to cranio cervical orientation to maintain horizontal gaze ($r = 0.60$) and to thoracic kyphosis ($r = -0.46$). Cervical spine alignment was significantly different between the two age groups except for the global C1C7 cervical lordosis, which remained stable. A significant gender difference was found for all the cervical sagittal angles ($p < 0.01$) whereas no differences were demonstrated for the spino pelvic parameters, except the lumbar lordosis ($p = 0.047$).
Conclusions This study is the first to report the cervical spinal alignment in a normal pediatric Caucasian population. Even though cervical lordosis is the common shape, our results showed variability in cervical sagittal alignment. Cervical spine is a junctional area that adjusts its alignment to the head position and to the underlying spinal alignment.

Keywords Cervical spine · Child · Spine radiography · Sagittal balance · Posture

K. Abelin-Genevois (✉) · A. Idjerouidene · C. Garin
Department of Pediatric Orthopedic Surgery, Hôpital Femme Mère Enfant, Université Claude Bernard Lyon I, Hospices Civils de Lyon, 59, Boulevard Pinel, Bron Cedex, 69677 Lyon, France
e-mail: kariman.abelin-genevois@chu-lyon.fr

K. Abelin-Genevois · P. Roussouly · J. M. Vital · C. Garin
Cervical Spine Study Group, Groupe d'Etude sur la Scoliose (GES), Paris, France

P. Roussouly
Department of Orthopedic Surgery, Centre Médico-Chirurgical de Réadaptation des Massues, Lyon, France

J. M. Vital
Spine Surgery Unit, Pellegrin University Hospital, Bordeaux, France

Introduction

Cervical spine alignment has become over years of increasing interest, as its misalignment could be a consequence of spinal deformity. Optimal spinal balance in humans maintains the gravity line in an economic range mentioned by Dubousset [1] as the cone of economy. The goal of an adequate trunk balance in erect position is to align the head over the femoral heads and to sustain a horizontal visual gaze. Roussouly [2] emphasized the importance to assess pelvic morphology to better understand the spinal alignment. In pediatric deformity, attention has recently focused on the sagittal contour of the spine and the restoration of adequate thoracic kyphosis and lordosis. Hilibrand et al. [3] showed a significant correlation between loss of thoracic kyphosis and cervical kyphosis development. Yu et al. [4] confirmed these findings, showing a high incidence of cervical kyphosis in adolescent and young adults idiopathic scoliosis. Postoperative decrease of thoracic kyphosis was associated to cervical kyphosis. Inadequate sagittal contouring has been questioned as a cause of adjacent segment degeneration disease at the cervical and/or lumbar level.

Many studies have described the normal alignment of the spine in adults but cervical spinal alignment in the pediatric population is poorly defined in the literature. Comparable normative data are required to better understand the relationship between cervical spine and the underlying spinal deformities.

The aim of the present observational study was to describe the sagittal spinal alignment during growth in a normal pediatric Caucasian population with a special focus on the cervical spine. We performed the radiographic analysis of 150 asymptomatic children and adolescents to determine the cervical spine shape and analyzed its orientation according to their global sagittal alignment.

Materials and methods

We randomly selected from our pediatric hospital PACS database full spine standing views (AP and lateral). All radiographs were performed using a standardized protocol using EOS stereo radiographic technology (Biospace®). Patients were asked to stand in a relaxed position and to look straightforward. The position of the arms during the radiography procedure depended on the age of the child. Teenagers were asked to keep the hands at the level of their clavicles according to the standard position recommended for adults. This position was not reproducible for younger children without the help of a handle bar when using the stereo radiographic method. Indeed, children can hardly maintain the position without support, as it can cause artifacts during the time required for acquisition.

After a first radiologic screening, we excluded radiographs if any anatomical landmark was missing or not visible and/or if the osseous palate was not horizontal, presuming that the patient was not looking straight ahead. Arm positioning was also verified (arms should be placed between 30° and 60° of abduction).

Frontal radiograph were reviewed in order to exclude scoliosis (curves > 10°), limb length discrepancy exceeding 1 cm and/or inadequate position.

If the selected radiographs met all the quality criteria, patient's medical charts were reviewed. Patients related exclusion criteria were: age > 18 years, history of spinal trauma, spinal deformity and any medical condition that could affect the spine (metabolic or rheumatologic).

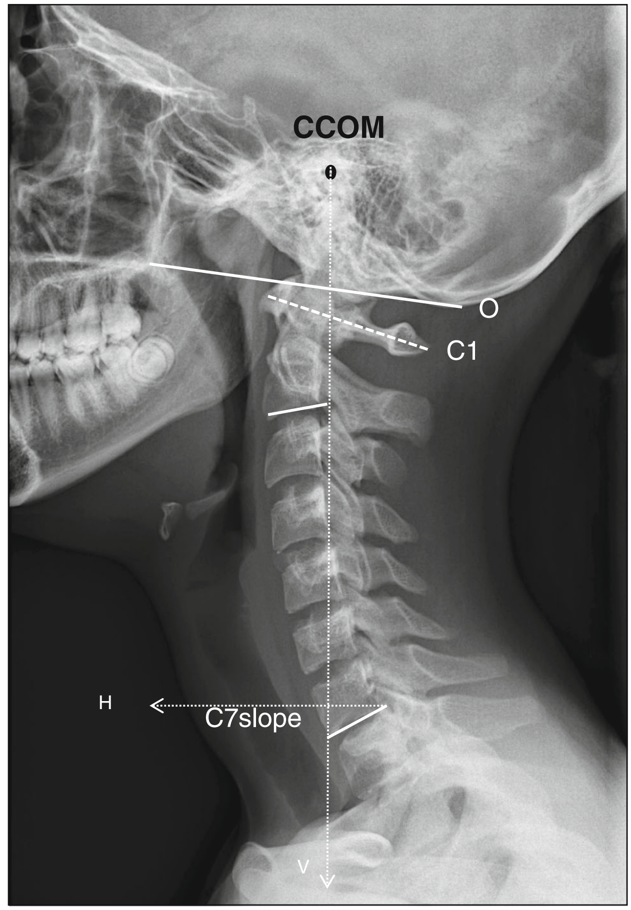

Fig. 1 Anatomical landmarks for cervical spine parameters measurement. Occipital line or Mac Gregor line (*O*) is drawn from the posterior aspect of the osseous palate and the inferior edge of the occipital bone. Center of external auditory tracts (CEA) indicates the cranial center of mass. Vertical plumb line is drawn

Two observers (one resident and one senior spine surgeon) were assigned to sagittal radiographs analysis. Measurements were made using the digital tool on the hospital viewing system (Centricity PACS, GE Healthcare®).

The following angles were measured on each lateral radiograph (Fig. 1):

- Occipito C2 angle (OC2 angle) was formed by the Mac Gregor line and the tangent to the inferior aspect of C2 body.
- Upper cervical spine (C1C2 angle) was formed by the antero posterior diameter of C1 and the inferior aspect of C2 vertebral body.
- Inferior cervical spine angle (C2C7 angle) was formed by the tangent to the inferior endplates of C2 and C7.
- Global cervical spine angle (C1C7 angle).
- C7 slope was the angle formed by the tangent to the inferior endplate of C7 and the horizontal reference line.

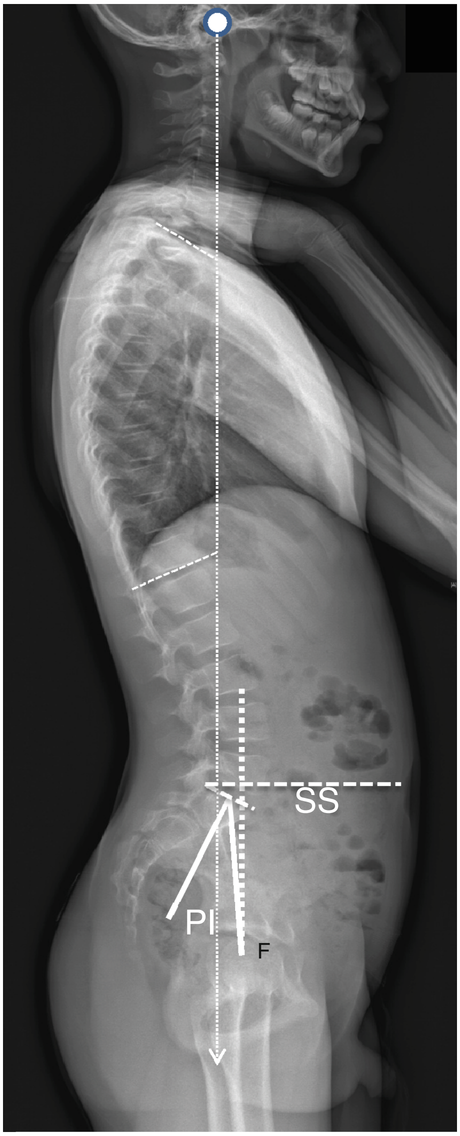

Fig. 2 Anatomical landmarks for spino pelvic parameters measurements. Thoracic kyphosis was measured according to the Cobb method between T1 upper vertebral plate and T12 inferior vertebral plate. Lumbar lordosis was measured between L1 and S1. Vertical plumb line is drawn from the center of auditory tracts (CCOM). Distance from the center of femoral heads (*F*) was measured from the vertical plumb line to assess the patient's positioning to the gravity line

Center of the external auditory tracts was chosen as the cranial center of mass. A vertical line was drawn from the center of mass. Distance from the center of femoral heads was measured from the vertical plumb line. Positive value was given when the line felt forward the femoral heads (anterior shift of the trunk).

The following spino pelvic parameters were analyzed (Fig. 2):

- TK: thoracic kyphosis (T1 T12),
- LL: lumbar lordosis (L1 S1),
- Pelvic incidence (PI) angle between the perpendicular of the sacral plate and the line joining the middle of the sacral plate and the hip axis,
- Sacral slope (SS) angle between the sacral plate and the horizontal line.
- Pelvic tilt (PT) angle between the vertical line and the line joining the middle of the sacral plate and the hip axis, which is positive when the hip axis lies in front of the middle of the sacral plate.

Statistical analysis

We separated the cohort into two age groups. Group 1 was aged less than 11 years old. Group 2 were patients aged 11 years or more. Data were analyzed using Statview software®. Differences between age groups and gender were tested using Student's *t* test. Correlation between spino-pelvic parameters was evaluated using Pearson correlation test. Level of significance was $p < 0.05$.

Intra and inter-observer reproducibility was tested using ANOVA for cervical spine angles.

Results

The mean age was 8.8 years (3.6–10.9) in group 1, 14.2 years (11–18) in group 2. Both genders were equally represented in the younger group. Group 2 presented a slight predominance of girls explained by the frequency of scoliosis screening in this population. Cervical spine alignments were significantly different between the two age groups except for the global C1C7 cervical lordosis, which remained stable.

Table 1 reports the mean cervical angles measured in the cohort. Lordotic curvatures were defined as negative values. Results were given as means and standard deviation (with 95 % confidence intervals). Cervical spine angles showed excellent intra-observer reproducibility (OC2: ICC = 0.97; C2C7: ICC = 0.98; standard error < 1°). Inter-observer reproducibility was also high (OC2: ICC = 0.94; C2C7: ICC = 0.95; standard error < 2°).

C1C2 and C1C7 angles did not vary between the two age groups. C2C7 angle significantly decreased after 10 years ($p = 0.004$), as did the C7 slope ($p = 0.001$). Concerning the global sagittal parameters, PI increased with age ($p = 0.002$), as did LL ($p = 0.046$). Gravity line from the CEA gradually tilted backward from +8.1 mm in patients less than 10 years to −6.5 mm in adolescents.

A significant gender difference was found for all the cervical parameters ($p < 0.01$) whereas no difference was observed for the thoracic kyphosis. No differences were

Table 1 Mean sagital spinal angles according to age groups

(a) Cervical angles

	O–C2 (°)	C1–C2 (°)	C2–C7 (°)	C1–C7 (°)	C7 slope (°)
Group 1 ($n = 65$)	−15.2 (±6.7) (−37.7; −1.1)	−26.0 (±6.2) (−44.4; −7.6)	−6.5 (±11.7) (−38.6; 24.8)	−32.7 (±11.3) (−68.2; 7.4)	21.3 (±6.9) (1.0; 39.8)
Group 2 ($n = 85$)	−18.3 (±6.1) (−41.4; −2.7)	−30.3 (±6.0) (−47.3; −8.7)	−0.7 (±11) (−34.2; 35.6)	−30.5 (±10.1) (−63.0; −4.7)	17.4 (±6.6) (0.9; 36.1)
P value*	0.024	0.001	0.015	0.315	0.006

(b) Spino pelvic angles

	TK T1–T12 (°)	LL L1–L5 (°)	Pelvic incidence (°)	Pelvic tilt (°)	Sacral slope (°)
Group 1 ($n = 65$)	36.6 (±7.1) (10.0; 57.6)	−42.5 (±9.1) (−75; −15.6)	40.5 (±6.2) (22; 65.8)	3.5 (±6.0) (−14.7; 21.6)	36.8 (± 6.6) (15.0; 59.0)
Group 2 ($n = 85$)	38.6 (±8.6) (13.2; 62.6)	−46.0 (±7.3) (−74.7; −23)	44.5 (±6.2) (26.9; 64.4)	5.4 (±4.6) (−9.3; 15.8)	39.2 (± 6.5) (15.5; 57.8)
p value	0.235	0.046	0.002	0.084	0.092

Group 1 represents patients aged <11 years

Group 2 represents teenagers aged 11 years or more

Values are expressed in degrees and given as means (±SD) (min–max)

* Student's *t* test comparing age groups, level of significance $p < 0.05$

demonstrated for the spino pelvic parameters except a difference at the limit of significance for LL ($p = 0.047$) (Table 2). Girls demonstrated higher values of LL while TK was slightly inferior to boys (NS). Boys had generally a more lordotic cervical spine than girls. This was mainly related to the existence of a lower cervical lordosis (−5.1° vs 3.1°; $p = 0.002$). In contrast, OC2 angle was higher among girls ($p < 0{,}001$).

Relationships between continuous variables were tested using the Pearson coefficient correlations. Table 3 presents the correlation coefficients between the radiologic sagittal parameters among the entire cohort. High correlation rates were found between the lumbo pelvic parameters. Correlation coefficients were also high among the cervical spine angles (Fig. 3). Cervical angles showed good correlation to the cranio-cervical orientation (OC2-C1C2: $r = 0.580$, $p < 0.01$; 0C2-C2C7: $r = 0.542$, $p < 0.01$). The strongest correlations were found between C1C7 (global lordosis), C2C7 (sub axial lordosis) and C7 tilt ($r = 0.726$, $p < 0.001$). Both C1C7 and TK showed strong correlation to C7 tilt ($r = 722$, $p < 0.001$; $r = 0.631$, $p = 0.002$). A weak but significant correlation rate was found between TK and LL ($r = -0.33$, $p = 0.024$). No direct correlation could be demonstrated between cervical sagittal angles and the lumbo pelvic parameters.

Discussion

The main objective of the present study was to establish normative values of cervical spine alignment in the normal pediatric population. The only available data reported in the literature showed that cervical lordosis even though commonly described is not constant in children and adolescents. Lee et al. [5] found comparable values in an Asiatic asymptomatic population of children with a mean C2 C7 angle of −4.8° ± 12°. Our data confirm this reality. Moreover our results demonstrate the large variability of cervical angles among children, especially in the sub axial cervical spine. While the lordotic shape is commonly accepted as normal, we found a high prevalence of kyphotic or straight curvatures in an asymptomatic population.

The cervical curvature pre-exists in utero [6, 7]. Cervical lordosis decreases consequently to head weight and uterine constraints. Kasai et al. [8] described the anatomical morphological changes during growth. The authors defined two periods of cervical curvature modifications. From 0 to 10 years, inferior cervical spine angle gradually decreases under the influence of an asymmetrical antero posterior growth and decrease of the facet joints angle. After 10 years, facet angles tend to stabilize while the antero superior aspect of the vertebral bodies ossify. At maturity onset, antero posterior body height index tends towards one.

Table 2 Sagittal parameters in group 2 (age ≥ 11 years): differences between males and females

(a) Cervical sagittal angles

	Mean age	OC2 (°)	C1C2 (°)	C2C7 (°)	C1C7 (°)	C7 slope (°)
Girls ($n = 45$)	14.0 years	−20.8 (−41.4; −2.7)	−30.1 (−47.3; −5.7)	3.1 (−33.6; 35.6)	−27.8 (−63; −4.7)	16.0 (0.9; 36.1)
Boys ($n = 40$)	13.5 years	−15.6 (−30.6; −4.0)	−29.4 (−45.2; −8.7)	−5.1 (−34.2; 23.3)	−33.5 (−52.7; −7.4)	19.0 (5; 32.3)
Total ($n = 85$)	13.8 ± 1.7	−18.3 ± 7.9	−29.8 ± 8.1	−0.7 ± 13.8	−30.5 ± 12.3	17.4 ± 8
p value*	0.09	<0.001	0.334	0.002	0.015	0.04

(b) Spino pelvic sagittal angles

	Mean age	TK (°)	LL (°)	PI (°)	PT (°)	SS (°)
Girls ($n = 45$)	14.0 years	38.1 (13.2; 58.2)	−47.7 (−23.9; −74.7)	43.8 (26.9; 59.2)	4.7 (−9.3; 15.8)	39.2 (15.5; 57.8)
Boys ($n = 40$)	13.5 years	39.1 (18.8; 62.6)	−44.1 (−23; −64.9)	45.3 (32.5; 64.4)	6.1 (−7.1; 14.3)	39.2 (25.8; 53.5)
Total ($n = 85$)	13.8 ± 1.7	38.6 ± 10.7	−45.1 ± 9.8	44.5 ± 7.6	5.4 ± 5.9	39.2 ± 8.1
p value*	0.09	0.323	0.047	0.191	0.137	0.465

* Student's t test comparing gender differences; level of significance $p < 0.05$

Table 3 Pearson's correlation coefficients between sagittal parameters

	OC2	C1C7	C1C2	C2C7	C7 tilt	TK	LL	PI	SS	PT	SVA
OC2	1.000	−0.233*	0.580**	−0.542**	0.183	0.064	0.245	−0.038	−0.107	0.091	−0.050
C1C7		1.000	0.202	0.811***	−0.722***	−0.485**	0.003	−0.042	−0.094	0.066	−0.013
C1C2			1.000	−0.243	0.09	0.021	0.155	−0.082	−0.170	0.122	−0.006
C2C7				1.000	−0.726***	−0.510**	−0.047	−0.029	−0.040	0.008	0.014
C7 tilt					1.000	0.631**	−0.007	−0.054	0.044	−0.120	0.280*
TK						1.000	−0.336*	0.061	0.159	−0.120	−0.092
LL							1.000	−0.501**	−0.697***	0.264	0.151
PI								1.000	0.671***	0.369*	−0.118
SS									1.000	−0.434*	0.054
PT										1.000	−0.216
SVA											1.000

* Significant change ($p < 0.05$)

** Significant change ($p < 0.01$)

*** Significant change ($p < 0.001$)

In adult population, most authors report lordotic values at C2C7 level from −6.1° to −34° with a proportion of kyphotic curvatures from 6 to 35 %. According to Yukawa et al. [9] cervical lordosis develops with aging process. C2C7 lordosis increases with age from 8° in the third decade to 20° in the eighth decade while total range of motion significantly decreases. Extension is more affected than flexion mobility. These authors also showed a significant difference between men and women whatever the age subgroup. Kyphotic alignment was more frequent in females and younger males. (19.4 % of males and 33 % of females in the second decade). Our results were slightly different as the cervical spine was straighter in our teenage girls. Even though not significantly, TK was higher in teenage boys, which may have induced more kyphosis in the lower cervical spine. In adults, TK increases with age in females, especially after menopause onset [9]. In contrast, OC2 angle was higher among girls in order to compensate for horizontal gaze.

On the organization of different cervical segments, Ames et al. [10] have shown through a comprehensive review of the literature that the majority of the cervical lordosis was consumed in the upper cervical spine (OC2). Only few degrees of lordosis were found in the lower levels. We share this conclusion in our pediatric population.

Few studies have analyzed the parameters influencing the normal cervical alignment. Lee et al. [11] reported the important role of the thoracic orientation (thoracic inlet angle and T1 slope) on the sub axial cervical spine

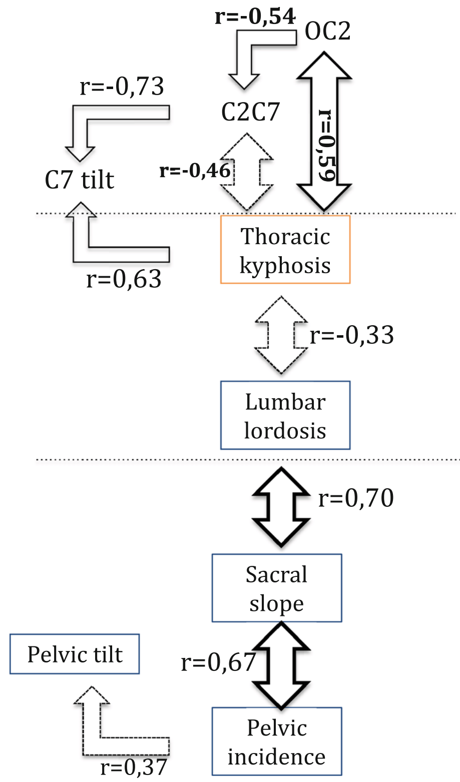

Fig. 3 Diagram of the statistically significant correlations between adjacent segments from the cervical spine to the pelvis. Correlations are moderate when $0.3 \leq r < 0.5$ (*dotted arrows*) and strong when $r \geq 0.5$

orientation (C2C7 angle). Results in terms of correlation coefficients between those parameters were strictly comparable to our findings in the pediatric population with highest coefficients relating C2C7 angle and T1 slope. C2C7 angle and C7 slope were both strongly correlated to OC2 angle in a lesser proportion.

We also analyzed the influence of the global sagittal profile on the cervical spine alignment. Only thoracic spine shape (TK) showed a strong correlation with the cervical spine shape through the C7 slope. C7 slope was both correlated to the OC2 angle and TK. In this population, PT had no influence on the cervical spine shape. Pelvic morphology strongly influences the spino pelvic organization [11] and the adaptive phenomenon in case of spinal deformity [12]. Spino pelvic parameters in our cohort were comparable to previous reported data in the pediatric population [13]. Among the studied parameters, only PI, SS and PT were influenced by age. As for adult population, pelvic incidence is strongly correlated to the sacral slope and the lumbar shape.

In spine degenerative pathology, anterior sagittal imbalance frequently occurs. Patients compensate through the pelvic orientation and knee flexion to maintain the horizontal gaze. In pediatric spinal deformity such as AIS, sagittal alignment is also disturbed. The sagittal component of the tridimensional deformity causes spinal flattening of the sagittal curves, whereas pelvic parameters have been described as comparable to the normal population [10, 13]. Thoracic hypo kyphosis reciprocally modifies the cervical spine alignment. This leads to an increase in muscle energy expenditure and consequently to cervical pain. Cervical kyphosis may accelerate degenerative changes after skeletal maturity. In AIS patients, Yu et al. [4] found a high incidence rate of cervical kyphosis (40 %). Strong correlation existed between cervical and cervico-thoracic angles ($r = 0.854$). Common knowledge advocates that cervical kyphosis is a pathologic condition. However in the normal population, Grob et al. conducted a comparative study of the cervical spinal alignment between normal and neck-pain complaining patients. The authors showed no significant difference between the two groups in relation to the global curvature, the segmental angles, or the incidence of straight-spine or kyphotic deformity ($p > 0.05$) [14].

In idiopathic scoliosis, cervical kyphosis has been described as a common feature. The incidence was 35–40 % and directly related to the subjacent thoracic alignment [4, 15]. The incidence of cervical kyphosis in the normal pediatric population is not clearly established. When categorizing the cervical sagittal morphology according to Ohara, the incidence of kyphotic cervical spine among the cohort was high [16].

During growth, the gravity line represented by the CAE projection upon the femoral heads gradually moved backward. Young patients had a cranial center of mass plumb line falling ahead the femoral heads indicating a slight tendency to anterior sagittal balance. This could first be explained by the neurological immaturity of postural integration centers. In infants, anticipatory postural control is activated around 14 months and matures throughout early childhood [17]. Postural adjustment becomes similar to adult pattern by at least age seven [18]. The second explanation could be related to the different motor activation pattern in postural control. Deffeyes et al. showed that co activation of legs muscles was higher in adolescents [19]. Sugrue et al. have shown that CCOM correlated with the C7 plumb line and could directly assess the relation between the head position and the pelvis, describing the cranio-spino-pelvic alignment [20]. Mac Thiong et al. showed that global spine balance was strongly correlated to health related quality of life scores and ODI in scoliosis patients [21].

Limits of the study

- First, precise identification of anatomical landmarks was difficult in young children due to the weak ossification of the bone (especially femoral heads, but also vertebral endplates). Inter and intra observer reliability is still in an acceptable range.

- Second, recruited individuals were asymptomatic but not healthy volunteers that would have been the ideal population to study. However such a protocol was not possible for ethical considerations (exposure to ionizing radiations).
- Third, stereo radiography is an innovative technique allowing lower exposure to radiations for high quality images. However for children the acquisition time (approx. 5 min) is long enough to create artifacts due to motion.

Conclusion

In our study, cervical spine alignment was strongly influenced by the cranio cervical orientation (occipito-C2 angle) and thoracic shape. Cervical spine is a junctional area that adjusts its alignment to the head position and to the underlying spinal alignment.

Inferior cervical spine sagittal orientation is a compromise between the cranio-cervical junction position and the underlying spino-pelvic alignment. Normal sagittal alignment is crucial to understand intimate links between sagittal curves when performing spinal segmental fusions. Two main goals should be carefully addressed depending on the location of the fusion: maintenance of a visual horizontal gaze and adequate thoraco lumbar contouring according to the pelvic morphology and preoperative orientation.

During growth, anatomical modifications explain reorientation of the sub axial cervical spine. Main lordosis is consumed in the upper cervical spine while sub axial cervical spine is hypo-lordotic or straight. Global cervical lordosis (C1C7) remains stable.

This study showed significant variations between males and females whatever the age.

Acknowledgments We thank all the members of the Cervical Spine Study Group for their collaboration in the critical analysis of our work. This work has not receive any funds or grants.

References

1. Dubousset J (1994) Three-dimensional analysis of the scoliosis deformity. In: Weinstein S (ed) The pediatric spine: principles and practice. Raven, New York, pp 479–496
2. 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 30:346–353
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
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. doi:10.1007/s00586-013-2753-1
5. Lee CS, Noh H, Lee DH, Hwang CJ, Kim H, Cho SK (2012) Analysis of sagittal spinal alignment in 181 asymptomatic children. J Spinal Disord Tech 25:259–263
6. Chansigaud JP, Criscuolo JL, Kamina P (1986) Development of the curvature of the cervical spine in utero. Attempted interpretation. Bull Assoc Anat (Nancy) 70:39–45
7. Bagnall KM, Harris PF, Jones PR (1984) A radiographic study of variations of the human fetal spine. Anat Rec 208:265–270
8. Kasai T, Ikata T, Katoh S, Miyake R, Tsubo M (1996) Growth of the cervical spine with special reference to its lordosis and mobility. Spine 21:2067–2073
9. Yukawa Y, Kato F, Suda K, Yamagata M, Ueta T (2012) Age-related changes in osseous anatomy, alignment, and range of motion of the cervical spine. Part I: radiographic data from over 1,200 asymptomatic subjects. Eur Spine J 21:1492–1498
10. Ames CP, Blondel B, Scheer JK et al (2013) Cervical radiographic alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. Spine Aug 16 [Epub ahead of print]
11. 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 25:41–47
12. Legaye J, Duval-Beaupère G, Hecquet J, Marty C (1998) Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 7:99–103
13. Roussouly P, Labelle H, Rouissi J, Bodin A (2013) Pre- and post-operative sagittal balance in idiopathic scoliosis: a comparison over the ages of two cohorts of 132 adolescents and 52 adults. Eur Spine J 22:203–215
14. Mac-Thiong JM, Berthonnaud E, Dimar JR 2nd, Betz RR, Labelle H (2004) Sagittal alignment of the spine and pelvis during growth. Spine 29:1642–1647
15. Mac-Thiong JM, Labelle H, Charlebois M, Huot MP, de Guise JA (2003) Sagittal plane analysis of the spine and pelvis in adolescent idiopathic scoliosis according to the coronal curve type. Spine 28:1404–1409
16. Grob D, Frauenfelder H, Mannion AF (2007) The association between cervical spine curvature and neck pain. Eur Spine J 16:669–678
17. Canavese F, Turcot K, De Rosa V, de Coulon G, Kaelin A (2011) Cervical spine sagittal alignment variations following posterior spinal fusion and instrumentation for adolescent idiopathic scoliosis. Eur Spine J 20:1141–1148
18. Ohara A, Miyamoto K, Naganawa T, Matsumoto K, Shimizu K (2006) Reliabilities of and correlations among five standard methods of assessing the sagittal alignment of the cervical spine. Spine 31:2585–2591
19. Hadders-Algra M (2005) Development of postural control during the first 18 months of life. Neural Plast 12:99–108
20. Girolami GL, Shiratori T, Aruin AS (2010) Anticipatory postural adjustments in children with typical motor development. Exp Brain Res 205:153–165
21. Deffeyes JE, Karst GM, Stuberg WA, Kurz MJ (2012) Coactivation of lower leg muscles during body weight-supported treadmill walking decreases with age in adolescents. Percept Mot Skills 115:241–260
22. Sugrue PA, McClendon J Jr, Smith TR, Halpin RJ, Nasr FF, O'Shaughnessy BA, Koski TR (2013) Redefining global spinal balance: normative values of cranial center of mass from a prospective cohort of asymptomatic individuals. Spine 38:484–489
23. Mac-Thiong JM, Transfeldt EE, Mehbod AA, Perra JH, Denis F, Garvey TA, Lonstein JE, Wu C, Dorman CW, Winter RB (2009) Can C7 plumb line and gravity line predict health related quality of life in adult scoliosis? Spine 34:519–527