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ORIGINAL ARTICLE

Sagittal parameters of global cervical balance using EOS imaging: normative values from a prospective cohort of asymptomatic volunteers

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Abstract

Objective To define reference parameters for analyzing sagittal balance of the cervical spine in asymptomatic volunteers.

Methods Prospective study after Bioethics Committee approval. Imaging performed using a low-dose radiographic system (EOS Imaging, Paris, France). The absence of pain was assessed using the Oswestry Questionnaire and VAS. 106 subjects were included of whom 55.66 % were men. The parameters measured were: pelvic incidence, pelvic tilt, sacral slope, thoracic and lumbar curvature, C7 plumb line position and the spino-sacral angle. The C7 slope and new parameters were measured: cranial incidence, defined in relation to the McGregor line and the sella turcica allowing to define cranial slope and tilt, and the spino-cranial angle (SCA).

Results This study demonstrated a close correlation between the C7 slope and the cranio-cervical system. Economic sagittal balance in the asymptomatic population was defined by a constant SCA angle of 83° ± 9°. To maintain this balance, a spine with a marked C7 slope will present lordosis and vice versa. Cranial incidence is an anatomical parameter characteristic of the cranio-cervical system which makes it possible to analyze the spatial positioning of the head and to predict the desired value of cervical lordosis which is closely correlated to cranial slope.

Conclusion The C7 slope has a predictive value of the shape of the cervical spine in the sagittal plane. One-third of the asymptomatic population had cervical kyphosis. Our results could be used to study sagittal balance before and after arthrodesis, or cervical prosthesis.

Keywords Cervical spine · Sagittal balance · Asymptomatic · Cranial incidence · Spino-cranial angle · C7 slope · T1 slope

Introduction

Man is the only vertebrate that can maintain the upright position on both feet [1]. The relationship between the orientation of the foramen magnum and the cervical spine is of great importance [2] in the evolution of morphological transformation. Akçam and Köklü [3] showed that the natural posture of the head was the same, irrespective of the shape of the skull (hyper or brachycephalic or dolichocephalic). Berthonnaud et al. [4] showed that thoracic kyphosis was associated with anterior inclination of the thoracic and cervical spine. Hellsing et al. [5] deduced that the thoracic spine extended up to the lower cervical spine (C4–C6). Furthermore, Zepa et al. [6] showed a relationship between extension of the atlas and the anterior inclination of the cervical spine. For most authors, the amplitude of cervical lordosis is related to thoracic posture, but for Berthonnaud et al. [4], the two variables evolve in the same direction and for Hellsing et al. [7] there is no relationship. These differing conclusions led us to conduct a princeps study in a series of asymptomatic subjects to define standard values.

The aim of the work was to analyze balance parameters of the cranio-spinal system in asymptomatic volunteers who had agreed to take part in a clinical prospective and radiological study approved by the hospital Bioethics Committee. Roussouly [8–10] showed that economic

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Table 1 Inclusion and exclusion criteria

Inclusion	Exclusion
Adult man or female (with contraception if non menopausal)	Subject treated for back pain or known to have regular back pain
Adult aged more than 18 years and less than 80 years	Subject with lower limb pathology that could interfere on the spine (hip or knee flessum, lower limb discrepancy)
VAS <2 for spine (including radicular)	Female pregnant or breast feeding
Score oswestry ≤20 %	Subject with previous spine or pelvic surgery
Inform consent signed	Subject unable to understand the inform consent
Patients affiliated to the general health security system	

thoraco-lumbar balance requires vertical chain positional parameters that correlate correctly to the subject's pelvic incidence. All studies conducted so far have demonstrated that pelvic incidence is the key to the lumbo-pelvic complex [11]. By analogy, we have defined other morphological sagittal balance parameter knowing the thoraco-lumbar parameters and showing that the cervical spine is the final adaptive factor for maintaining cranial balance.

Materials and methods

Population

This prospective, transversal, single center study was conducted at our University hospital over a 12-month period. Approval was obtained from the Bioethics Committee in a public hospital clinical research program (EOSDATABASE). The study was approved because a low-dose radiation system was used: (EOS Imaging, Paris, France). Informed consent was obtained from 106 healthy subjects.

Asymptomatic volunteer was assessed by analyzing two parameters: the Oswestry score [12], which had to be less than 20, and a visual analog scale (VAS) for spine which had to be less than 2/10. The volunteers came into three age groups: 18–30 years (48.11 %), 30–50 years (25.47 %) and over 50 years (26.42 %). The mean age was 38.03 years (range, 18–76). Males were slightly predominant (55.66 %). Inclusion and exclusion criteria are given in Table 1.

Radiological analysis

All subjects underwent an EOS X-ray in the standard erect position described by Morvan [13]. They stood looking horizontally, using a mirror to stabilize vision, and placed their fingertips on their clavicles. The EOS system enables acquisition of images, including the skull, femoral heads and knees. Radiographs were then modeled in a 3D analysis using sterEOS software (EOS imaging, Paris France, version 1.4.5) avoiding errors related to pelvic rotation. Measurements were made by two independent assessors on 3D images [14]. The inter- and intra-observer reproducibility of measurements made with the EOS system has already been described as excellent [15]. Pelvic parameters: pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS) and spinal parameters of thoracic curvature and lumbar lordosis (L1–S1) and kyphosis (T1–T12) were measured. The position of the C7 plumb line and the spino-sacral angle [16] was calculated. The curvature of the thoraco-lumbar spine was measured using the standard method and the biomechanical approach based on the theory of circle tangent lines described by Roussouly [2, 8, 9]. Measurements of the cervical spine were performed using the parameters defined below.

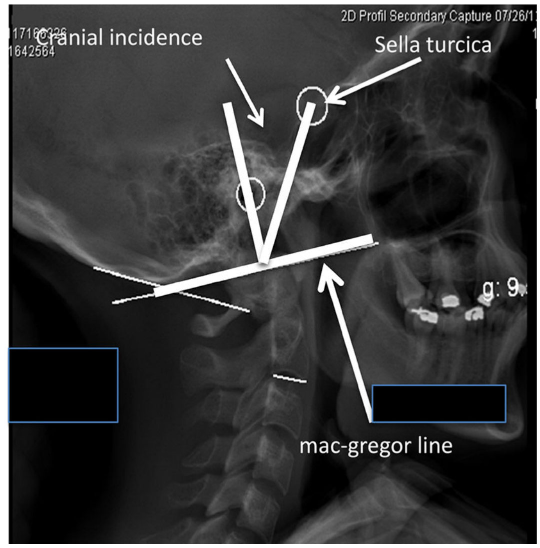

Fig. 1 Cranial incidence angle: angle between the center of the line perpendicular to the McGregor line and the line that joins the middle of the McGregor line to the sella turcica

Cranial parameters

The McGregor line (Fig. 1) was used as a reference point for the skull base. The sella turcica, located a few millimeters from the head's center of gravity, according to vital [17], was chosen as the second reference point. By analogy with the pelvis, we defined a cranial incidence (CI) angle. This angle was defined between the center of the line perpendicular to the McGregor line and the line that joins the middle of the McGregor line to the sella turcica.

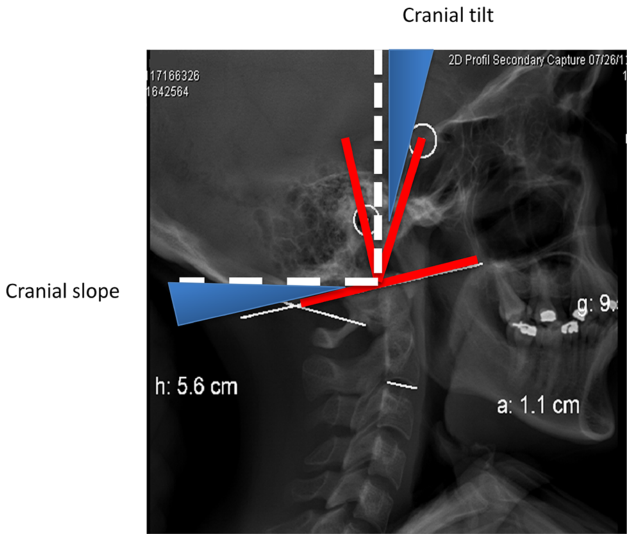

Fig. 2 Cranial slope (angle between the *horizontal line* and the McGregor line), cranial tilt (angle between the *vertical line* and the line joining the center of the McGregor line and the sella turcica), cranial incidence

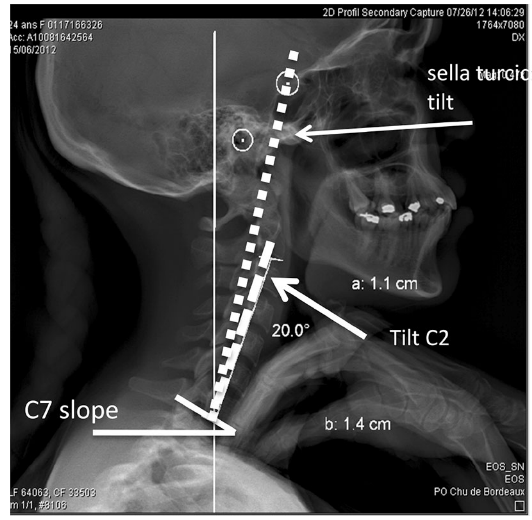

Fig. 3 Tilt C2 (angle between the *vertical line* passing through the center of C7 and a line passing through the center of the lower end plate of C2 and the center of C7), Tilt sella turcica (angle between the *vertical line* passing through the middle of C7 and a line joining the center of the sella turcica and the center of C7), C7 slope (angle between the lower end plate of C7 and the *horizontal line*)

Cranial incidence is a morphological parameter specific to each individual and does not vary as a function of head posture (Fig. 1).

The cranial slope (CS) is the angle between the horizontal line and the McGregor line. It is a postural variable of the position of the skull base in relation to the horizontal line. This angle is positive when the McGregor line is oriented upwards and forwards, zero when this line is horizontal, and negative when it is oriented downwards and forwards (Fig. 2).

Cranial tilt (CT) is the angle between the vertical line and the line joining the center of the McGregor line and the sella turcica. It is also a postural variable, complementary to the cranial slope which provides information about the position of the head (more or less tipped backwards) (Fig. 2).

Cranial tilt and cranial slope are two complementary angles related by the formula: CI = CT + CS.

Cervical spine parameters

The global curvature of the cervical spine (C1–C7) was divided into upper cervical curvature (C1–C2) and lower cervical curvature (C2–C7). Study of the occipito-cervical junction was analyzed by the occiput–C2 angle (O–C2) situated between the McGregor line and the lower end plate of C2 [18, 19]. Measurements were performed using Cobb's technique [20]. Traditional measurements from the external auditory meatus were not reliably reproducible for all subjects and this reference point was not used.

Thoraco-cervico cranial parameters

As proposed by Berthonnaud [4], we took C7 as the base of the cervical spine. The C7 slope (C7S) is the angle between the lower end plate of C7 and the horizontal line (Fig. 3). C2 tilt is the angle between the vertical line passing through the center of C7 and a line passing through the center of the lower end plate of C2 and the center of C7. This angle is positive when the middle of C2 is in front of the C7 line and negative when it is behind (Fig. 3).

The sella turcica tilt (ST tilt) is the angle between the vertical line passing through the middle of C7 and a line joining the center of the sella turcica and the center of C7. The center of the sella turcica was determined using sterEOS software (Biospace Imaging, Paris, France), using the three-point method. In our study, this technique proved highly reproducible between observers ($r = 0.93$). The angle is positive when the sella turcica is in front of the C7 line and negative when it is behind it (Fig. 3).

Intrinsic sagittal cervical balance parameters

To obtain an intrinsic measurement of cervical curvatures similar to the spino-sacral angle of the thoraco-lumbar spine [16], we described the spino-cranial angle (SCA): the angle is defined between the C7 slope and the straight line joining the middle of the C7 end plate and the middle of the sella turcica. It is defined by the formula: SCA = 90°–C7 slope + ST tilt (Fig. 4).

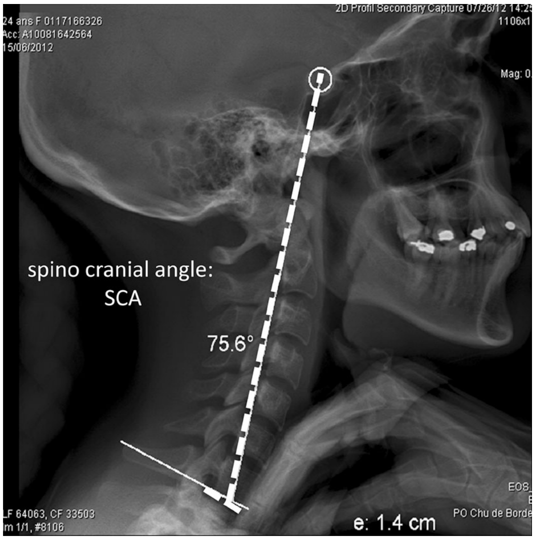

Fig. 4 Spino-cranial angle: angle between the C7 slope and the *straight line* joining the middle of the C7 end plate and the middle of the sella turcica

Statistical analysis

Qualitative variables were analyzed in terms of frequencies and percentages for each modality. Quantitative variables, means, standard deviations (SD) and ranges are presented. As for comparative analyses, correlations were made when symmetric association between two variables was investigated. When a relationship of causality was investigated, linear regression was performed. One of the variables was called variable to be explained and the other explaining variable. A 5 % significance threshold made it possible to determine significant associations whilst regression coefficients gave the direction of the association. The software programs used for this statistical analysis were: SAS version 9.3 and XL-STAT 2012.

Results

The results demonstrated that the study population was truly asymptomatic, with mean VAS score of 0.09 (0–2, SD 0.34). The mean Oswestry score was 1 % (0–16 %, SD 3.06).

Radiological results comprised several parameters.

Descriptive analysis was conducted on all studied parameters

The mean values of pelvic and thoraco-lumbar spine parameters are shown in Table 2. The mean values of cranial parameters are shown in Table 3. The mean values of the sagittal angles of the cervical spine are shown in Table 3. We defined lordosis as a positive value and kyphosis as a negative value. The mean values of C7-related parameters are given in Table 3. The mean value of the spino-cranial angle is shown in Table 3.

Table 2 Pelvic and spine parameters

	Unit	*n*	Mean values	SD	Extreme
Pelvic incidence	Degree	106	51.31	10.42	[32.20; 76.60]
Pelvic tilt	Degree	106	12.59	6.91	[−1.50; 34.50]
Sacral slope	Degree	106	38.71	7.3	[24.00; 58.90]
Lordosis L1/L5	Degree	106	46.37	9.23	[27.50; 70.70]
Lordosis L1/S1	Degree	106	56.84	8.9	[35.00; 88.10]
kyphosis T1/T12	Degree	106	41.83	10.44	[−2.30; 62.20]

Table 3 Cranial, cervical and cranio-cervical parameters

	Unit	*n*	Mean values	SD	Extreme
Cranial incidence	Degree	106	27.32	4.24	[14.00; 36.00]
Cranial slope	Degree	106	1.59	6.81	[−18.00; 16.00]
Cranial tilt	Degree	106	25.04	8.54	[0.00; 47.00]
OC2	Degree	106	15.81	7.15	[0.00; 35.00]
C1–C7	degree	106	34.03	12.18	[6.00; 60.00]
C1–C2	Degree	106	29.16	7.24	[9.00; 45.00]
C2–C7	Degree	106	4.89	12.84	[−25.00; 44.00]
C7 slope	Degree	106	19.64	8.76	[0.00; 42.00]
Tilt C2	Degree	106	10.48	6.93	[−10.00; 31.20]
Tilt sella turcica	Degree	106	12.84	5.66	[−3.00; 31.40]
Spino-cranial angle	Degree	106	83.04	9.05	[61.00; 105.00]

Correlation analysis was conducted to compare the different parameters studied

The statistical study found correlations between the C7 slope and measurements of the cervical spine, the skull, thoracic kyphosis and the sacral slope. Table 4 shows this analysis which is calculated by linear regression which, in this case, is more suitable than the Pearson's test.

The median value of the C7 slope (C7S) was 20°. We divided the cohort into two groups. Group 1 (C7S <20°) with 50 subjects and group 2 (C7S ≥20°) with 56 subjects (Figs. 5, 6). There was a significant difference for cervical lordosis values, for the parameters measured from the center of the C7 end plate (such as sella turcica tilt and the

Table 4 Correlation between C7 slope and other sagittal parameters

Parameters	Coefficient	*p* value	Significance
C7 slope: variable to explore			
OC2 angle	−0.175	0.145	NS
Lordosis C2–C7	0.516	<0.001	S
Lordosis C1–C7	0.537	<0.001	S
Tilt C2	0.710	<0.001	S
Tilt sella turcica	0.403	0.007	S
Thoracic kyphosis	0.638	<0.001	S
Sacral slope	−0.298	0.010	S
Cranial incidence	−0.490	0.015	S
Cranial slope	0.009	0.942	NS
Cranial tilt	−0.060	0.541	NS

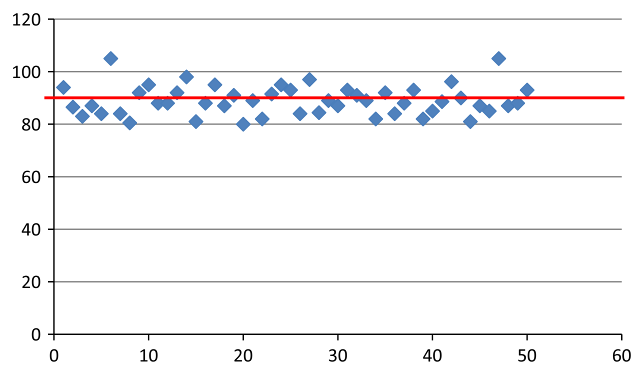

Fig. 5 Distribution of SCA (spino-cranial angle) values in the group C7 slope <20°

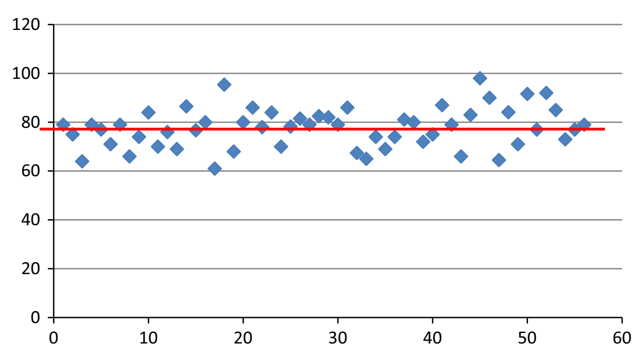

Fig. 6 Distribution of SCA (spino-cranial angle) values in the group C7 slope ≥20°

spino-cranial angle). There was no difference for the angle between the occiput and the C2 axis vertebra (O–C2). Tables 5 and 6 show the distribution of these values in the two groups.

The distribution of the spino-cranial angle is given in Table 7 and Figs. 5 and 6, as a function of the C7 slope.

Table 5 Lordosis C2C7 and occipito–C2 function of C7 slope

C7 slope value	*n*	Mean value	SD	Min	Max	*p*
Lordosis C2C7						
<20°	50	−2.49	8.82	−25	21	<0.0001 (S)
≥20°	56	11.48	12.30	−13	44	
Total	106	4.89	12.84	−25	44	
OC2 lordosis						
<20	50	15.83	6.38	0	30	0.99 (NS)
≥20	56	15.80	7.82	0	35	
Total	106	15.81	7.15	0	35	

Table 6 Spino-cranial angle function of C7 slope

C7 slope	*n*	Mean values	SD	Min	Max	*p*
Spino-cranial angle						
<20°	50	89.01	5.71	80	105	<0.0001 (S)
≥20°	56	77.71	8.12	61	98	
Total	106	83.04	9.05	61	105	

We noted that distribution was homogenous in each subgroup.

We found a very close correlation between the spino-cranial angle and the C7 slope (regression coefficient = −0.818). The difference was significant (p value <0.001). There was also a close correlation between the spino-cranial angle and cervical lordosis (C2–C7) (regression coefficient = −0.607). Table 7 shows all these values and the correlation between the different parameters.

Discussion

Our results provided radiological measurements for an asymptomatic population validated by VAS score less than 2 (mean 0.09) and Oswestry score less than 20 (mean 1 %). A review of the medical literature with regard to sagittal balance of the cervical spine in asymptomatic subjects found marked differences in the methods used to measure angles, in defining the limit vertebrae and in the parameters studied [4, 5, 19, 21].

The occipito-cervical junction is routinely defined by the O–C2 angle [18, 19]. The most reproducible measurement of this angle appears to be that made between the McGregor line and the lower end plate of C2. Its mean value is 14° (±7°) in subjects over 18 years, and 12° (±6°) in those over 60 [19]. We found similar results, with a mean of 15.81° (±7.15°). This angle had a constant value when the C7 slope varied. Moussellard [18] advised restoring this angle during occipito-cervical arthrodesis to maintain a

Table 7 Correlation between Spino-cranial angle and other parameters

Parameters	Coefficient	*p* value	Significance
Correlation between spino-cranial angle and other parameters			
OC2	0.247	0.045	S
Lordosis C2–C7	−0.607	<0.001	S
Lordosis C1–C7	−0.644	<0.001	S
Lordosis C1–C2	0.085	0.487	NS
C7 slope	−0.818	<0.001	S
Tilt C2	−0.064	0.615	NS
Tilt sella turcica	0.590	<0.001	S
SSA (spino-sacral angle)	0.320	0.005	S
Cranial incidence	−0.454	0.029	S
Cranial tilt	0.380	<0.001	S
Cranial slope	−0.501	<0.001	S

horizontal gaze. Results in the literature [19] and in our series were comparable for the C1–C2 angle, with a mean value of 29° (Table 3). The results for cervical lordosis, defined between C2 and C7, varied greatly in the literature. In our series, mean lower cervical lordosis (C2–C7) was 4.89° (±12) (Table 3). These results were comparable to those of Lee [21] who used the posterior tangent method. Conversely, Kuntz [19], in his literature review, found a mean angle of 17°, but he included highly heterogenic groups with both children and adults without control of the gaze during the X-ray shot. Berthonnaud [4] proposed an analysis of global cervical lordosis by measuring the apex and the inflexion point, and found a mean value of global cervical lordosis of 23.9°. In our series, we found a mean value of 34° between C1 and C7. The fact that 33.96 % of patients presented with C2–C7 kyphosis was most likely the cause of this variation, which is not accounted for when using the apex to measure lordosis. The C1–C2 angle (mean 29.16°, range 9–45, SD 7.24) is the final adaptive factor of cranial orientation and is of major importance when calculating potential variations in the clinic. Our series is the first to report a C2–C7 kyphosis angle in more than a third of an asymptomatic population. This could become an essential factor when analyzing cervical disease, since until now the loss of cervical lordosis was considered to be pathological. Only an article by Fineman [23] suggested that post-traumatic muscle spasm may be absent on the radiographs of healthy spines with kyphosis.

Our results indicated that there is linear chain of correlation linking the base of the cervical spine represented

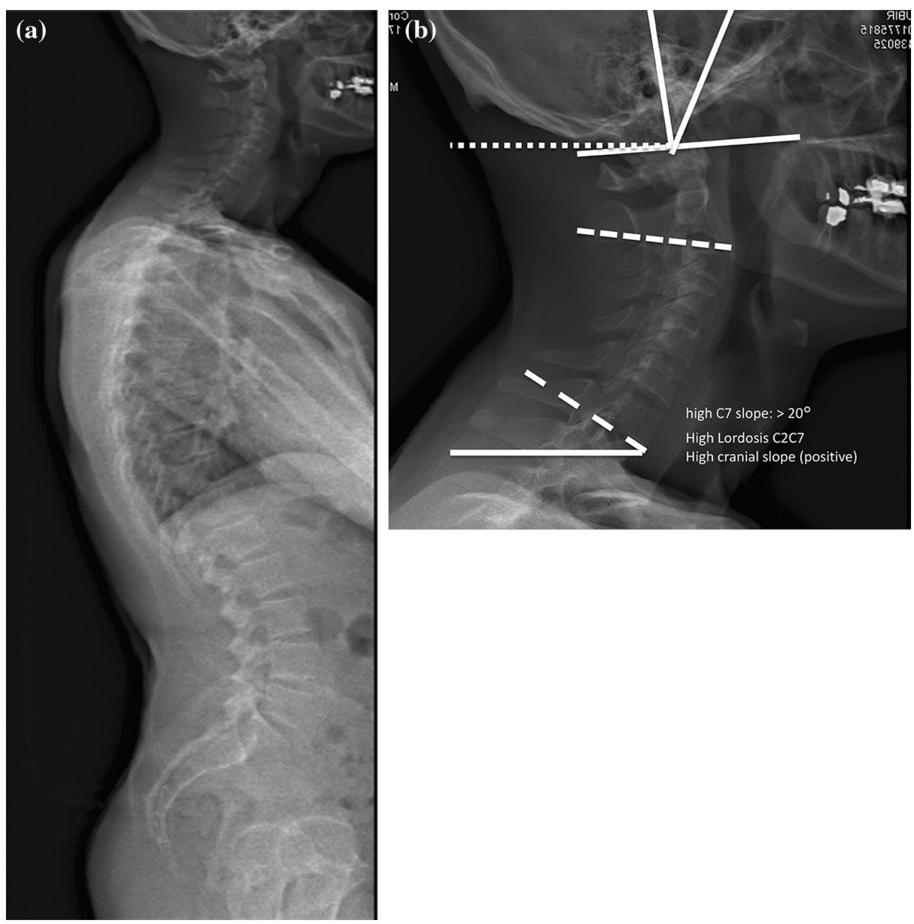

Fig. 7 Hyperlordotic cervical and lumbar spine: C7 slope is high, cranial slope is positive: **a** full spine and pelvis sagittal view **b** cervical and cranial parameter

by C7 with the skull. There is also a statistical correlation between this parameter and thoracic kyphosis and the sacral slope (Table 4). Roussouly [2] showed that the C7 plumb line is one of the key parameters used to analyse sagittal balance in the thoraco-lumbar region. Indeed, there is a constant geometric correlation between the C7 vertebra and the sacral end plate [16].

Like the spino-sacral angle described by Roussouly [16], we defined the spino-cranial angle, which had a constant value of 83° ± 9°. We can consider that, from the energetic point of view, there is an economic balance in asymptomatic subjects which enables them to maintain head posture with horizontal gaze. This angle allows for analysis of the position of the sella turcica and of the base of the cervical spine, as defined by C7 slope. A marked C7 slope was compensated by marked lordosis and positive cranial slope, and vice versa (Figs. 7, 8), whereas the O–C2 or C1–C2 angle remained constant irrespective of the value of the C7 slope. The C7 slope may vary depending on the thoraco-lumbar degenerative disease. Depending on the C2–C7 cervical lordosis, patients may have different compensation capacities. Thoracic hypo-kyphosis resulting from a loss of lumbar lordosis would be easily compensated by a decrease in cervical lordosis in patients with a marked C7 slope. Degenerative thoracic hyper-kyphosis would be difficult to compensate for patients whose initial C7 slope was marked, whereas it would be easier to compensate for in those whose initial slope was slight. Our study also showed that the sacral slope and the C7 slope were statistically correlated. When the sacral slope decreases, the C7 slope increases (regression coefficient = 0.3). Hence a lumbar degeneration that modifies the sacral slope (usually reducing it due to pelvic retroversion), would affect the C7 slope, and depending on the initial value of the C7 slope, would trigger cervical disorders, especially if C2-C7 lordosis cannot be increased.

Berthonnaud et al. [4] showed that there was a correlation between thoracic kyphosis and cervical lordosis. In a recent paper, Lee [22] defined a cranio-cervical system based on the T1 vertebra. He described T1 incidence as the angle between the line perpendicular to T1 and the line joining the middle of the upper T1 end plate to the manubrium sterni. He defined T1 slope and tilt. In our opinion, the parameters used are not as reproducible as

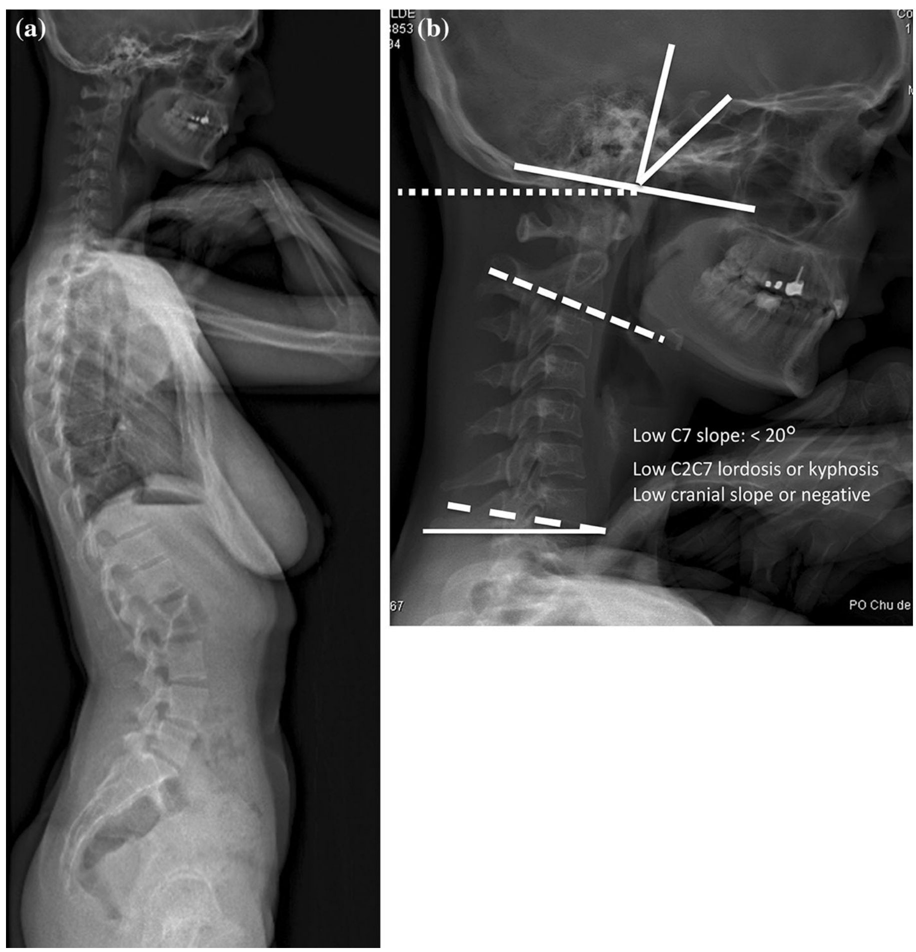

Fig. 8 Cyphotic cervical spine and low lordosis lumbar spine: C7 slope is low, cranial slope is negative **a** full spine and pelvis sagittal view **b** cervical and cranial parameter

those of the sella turcica and the McGregor line, since reference points depend on the rib cage and may be perturbed by pulmonary parameters. Furthermore, the reference point at the top of the manubrium sterni is often missing due to the patient's morphology. Cranial incidence seems more reliable for analyzing cervical sagittal balance by analogy to the lumbo-pelvic complex. Hence, when cranial incidence increases, the amplitude of C1–C7 cervical lordosis is lower, and vice versa. This inverse variation is similar to that seen in lumbar lordosis with regard to its effects on pelvic incidence and the sacral slope.

Given the multidirectional mobility of the cervical spine it may be possible that there are more than one economical positions of the cranio-spinal axis. This is a limitation of this study and is important to analyze knowing that today a lot of workers are in sitting position and that in this position the lumbar lordosis decreased with pelvic retroversion. This is responsible for the adaptation of the thoracic and cervical orientation. Other studies are requested to analyze this specific point.

In our study, the age groups were not completely homogenous; half the sample was under 30 years of age. Reproducibility, by inter and intra-observer studies, was good [15] when using stereos software and no difference was found in between the 3 groups for all measurements. EOS produces very high-quality images which can be enlarged for accurate measurements.

Recent studies [24] have mentioned that cervical spine sagittal balance may have an impact on the clinical results of cervical spine surgery. Our results showed a direct correlation between the C7 slope and sagittal balance parameters of the cervical and thoraco-lumbar spine. They could be used to study these parameters in degenerative diseases of the cervical spine, deformative diseases and spondylolisthesis. Pre- and post-operative radiographs of patients undergoing arthrodesis or cervical prostheses could help to understand certain failures caused by balance disorders.

Conclusion

This study demonstrated a close correlation between the C7 slope and the cranio-cervical system. Economic sagittal balance of asymptomatic subjects was defined as a constant SCA of 83° ± 9°. To maintain this balance, a spine with a marked C7 slope will present high lordosis, and vice versa. The concept of physiological cervical lordosis has been completely modified by this work, since a third of our asymptomatic population presented a kyphotic cervical spine. Cranial incidence is an anatomical parameter characteristic of the cranio-cervical system enabling analysis of the spatial positioning of the head by measuring the cranial slope. The C7 slope value is closely correlated to C2–C7 lordosis. The results of our study could be used as a basis to study sagittal balance before and after arthrodesis or cervical prosthesis placement.

Conflict of interest None.

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