SAGITTAL BALANCE OF THE CERVICAL SPINE IN CHILDREN OLDER THAN 4 YEARS: WHAT IS THE NORM?

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Objective. To search for normal parameters of the sagittal balance of the cervical spine in children, to analyze their dynamics in different periods of childhood, and to compare them with the norm given for the adult population.

Material and Methods. To assess the parameters of the sagittal balance of the cervical spine, radiographs were selected that were initially evaluated by radiologists as a variant of the norm. The final sample consisted of 73 radiographs of 44 girls and 29 boys aged 4 to 17 years. Digital radiographs were used to evaluate the 10 most common parameters presented in publications: the angular values of Oc–C2, C2–C7, C7S, Th1S, TIA, NT, CeT, CrT, SCA, as well as the cSVA distance measured in mm. The measurements were carried out independently by 3 specialists working with pediatric patients: an orthopedic surgeon (experience up to 5 years), an orthopedic surgeon (experience more than 15 years), and a radiologist specializing in skeletal pathology (experience more than 5 years). The obtained results were subjected to statistical processing.

Results. Using multivariate analysis of variance, the presence of a statistically significant difference in age was revealed only for cSVA, gender differences were revealed for 6 out of 10 parameters. Most of the parameters showed good and satisfactory agreement between specialists. A very strong correlation was established between the parameters C7S and Th1S, which correlates with the adjacent position of the vertebrae. The C2–C7 and SCA parameters have a strong positive correlation with each other, the CeT parameter is strongly negatively correlated with both of them. The TIA has a strong negative correlation with SCA and a moderate positive correlation with NT, CeT, C7S, and Th1S. The cSVA and CrT values strongly correlate only with each other. Comparison of the obtained parameters of the sagittal balance in children with the data in scientific publications on the adult population revealed statistically significant differences in the values of 6 out of 10 of them.

Conclusion. The age norms of the main parameters of the sagittal balance for children, and their gender differences were determined. Their difference from the normal parameters of the adult population was established, which requires that these features be taken into account in clinical practice.

Key Words: cervical spine, sagittal balance, children, vertebrology.

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During evolution, humans gained upright posture, which was the reason for the onset of physiological curves of the mobile regions of the spine: cervical lordosis, thoracic kyphosis, and lumbar lordosis. Due to the progressive study of the biomechanics of the spine, these curves are no longer considered isolated with anatomically determined mean values. This has resulted in the introduction of the concept of "spine balance", which was first defined in Dubousset's theory about the "cone of economy" [1]: the space around the vertical axis, the top of which is located in the area of the feet and the bottom is in the area of the head. According to this theory, being in the cone of economy, the human body maintains a stable vertical posture without involving additional muscles or the threat of falling, meaning no additional waste of energy. Simultaneously, the author conditionally treated the pelvis as a single "pelvic vertebra", which assignes the profile of the entire vertebral column.

The sagittal balance theory has been developed due to a huge number of studies in which the relationship of anatomical characteristics of the pelvis and spinal curvature with clinical complaints, primarily in deformities and degenerative disorders of the lumbar and thoracic spine, has been considered. Meanwhile, the most crucial thing is the fact that special attention was paid not so much to the absolute values of each parameter (pelvic incidence, pelvic and sacral tilt, general and segmental lumbar lordosis, thoracic kyphosis), as to the search for the relationship between them [2–4].

The last link in this biomechanical chain is the cervical spine. Given its distance from the supporting elements of the system (pelvic vertebra), high multiplanar mobility and anatomical features of different regions (suboccipital, subaxial, and cervicothoracic), it is quite difficult to determine a direct connection of the biomechanical parameters of the neck with those listed above, that confirms the absence of such studies at the moment.

However, a number of local indicators characterizing the sagittal balance of the cervical spine are suggested (Table 1), as well as two ways of evaluation of the global sagittal balance of the spine, including the cervical spine:

1) global sagittal shift of a vertical (C7 sagittal vertical alignment, C7 SVA), which describes the horizontal distance between the plumb line from the C7 vertebra and the posterior edge of the S1 cranial plate [2, 5, 6]; this shift increases in the elderly [2, 6];

2) the angle between the vertical line drawn through the center of rotation of the hip joints and the line connecting the same point and the vertex of the C2 odontoid process (denoted in the literature as OD-HA, odontoid-hip axis angle). It is believed that the angle does not depend on age and is invariable in the absence of pathology [2, 6].

Nevertheless, despite the abundance of indicators, there are currently well-established opinions to the effect that the sagittal cervical alignment (SCA) defining general cervical lordosis can be regarded as permanent in the population [7]. Meanwhile, only with respect to cSVA > 40 mm and Th1/C7 slope > 40°, a correlation with the unsatisfactory quality of life of patients calculated by standard scale has been statistically proven [7, 8].

It is critical that the authors state that the indicated values were determined on asymptomatic volunteers over the age of 19. This calls into question their suitability as a standard in relation to pediatric patients.

A search for papers devoted to the issues of normal spine balance in the pediatric age group reveals single articles with small samples and completely different techniques.

The objective is to search for normal parameters of the sagittal balance of the cervical spine in children, to analyze their dynamics in different periods of childhood and to compare them with the norm given for the adult population.

Material and Methods

The material for the study was two-plane radiographs of the spine, retrospectively selected from the radiation archive (PACS server) of one of the children's outpatient facilities in St. Petersburg. The criteria for the sampling of radiographs were the following:

1) children from 4 to 17 years old, inclusive;

2) X-ray examination in relation to any condition not associated with orthopedic pathology or spinal disease: chest examination, examination by a neurologist;

3) X-ray capture of the entire cervical spine and the base of the skull;

4) examination in a vertical position.

To evaluate the parameters of the sagittal balance of the cervical spine, radiographs initially evaluated by radiologists as a normal variant were chosen. The final sample consisted of 73 radiographs of 44 girls and 29 boys. Before further processing, depersonalization of information concerning patients besides that of gender and age was performed; the distribution is given in Fig. 1.

The technique for measuring the most commonly used parameters of the sagittal balance of the neck is shown in Table 1.

The ten most common indicators shown in the papers were evaluated using X-ray images: angular values such as Oc–C2, C2–C7, C7S, Th1S, TIA, NT, CeT, CrT, and SCA, as well as the cSVA distance measured in millimeters (Fig. 2). To exclude potentially possible measurement errors presented by various software programs for working with DICOM files, all calculations were performed in the licensed version of the RadiAnt DICOM Viewer (version 2021.2, Copyright © 2009–2022, Medixant).

Statistical analysis and visualization of the obtained results were done using the free R computing environment (version 3.5.1, GNU GPL v. 2).

The measurements were carried out independently by 3 specialists working with pediatric patients: an orthopedic surgeon (experience up to 5 years), an orthopedic surgeon (experience more than 15 years) and a radiologist specializing in skeletal pathology (experience more than 5 years). The evaluation of the consistency between specialists in measuring parameters, considering their quantitative type, was performed by calculating the mean coefficient of variation V for each of the parameters for 15 radiographs randomly selected from the total sample (Table 2).

Most of the parameters showed good and satisfactory consistency between specialists. The unsatisfactory consistency of the three parameters (>0.3) is probably due to the lack of ossification of growth zones in young children (endplates and the apex of the odontoid process), which causes difficulties in determining landmarks for measuring angles.

Prior to the statistical processing of the data, the nature of the distribution of the measured values was assessed using a graphical method: constructing histograms and distribution density curves and Q-Q plot for a visual comparison of the actual distribution with the normal one. Additionally, we calculated the criteria for checking the normality (the Shapiro – Wilk test and the Lilliefors test). In the presence of minor deviations in the graphical characteristics of the distribution, the estimated verification criteria for almost all parameters, with the exception of TIA, do not allow rejecting the null hypothesis that the distributions are normal ($p > 0.05$). There were more pronounced graphical deviations only in relation to TIA, and, according to the Lilliefors test, there are indications for rejecting the null hypothesis ($p = 0.03$). Nevertheless, according to the Shapiro – Wilk test, there are no such grounds (p = 0.17). As an illustration, Fig. 3 shows the indicators of the distribution of the angle of subaxial lordosis and TIA.

The entire sample was divided into three age groups (4–6, 7–12, and 13–17 years old) and, respectively, two gender groups. The distribution was additionally checked for normality in each group for each parameter using the Shapiro – Wilk

Table 1

Parameters of the sagittal balance of the cervical spine with the method of calculation and description

Parameter	Method of calculation	Notes
Oc–C2 angle (high cervical angle) [5, 10–12]	Intersection of McRae lines and tangent to the C2 lower endplate	Normally, it is always lordotic [12]. Oc–C2 accounts for 77 % of the total amount of the cervical lordosis [13, 14]
C2–C7 angle (low cervical curvature) [5, 8–12]	Intersection of tangents to C2 and C7 lower endplates	Normally corresponds to lordosis, but may be neutral, sigmoid or kyphotic [15]. It has an inverse relation with the Oc–C2 angle [12, 16]. C2–C7 accounts for 23 % in the total amount of the cervical lordosis [13, 14]. There are 5 ways to measure the C2–C7 angle [5, 8–10, 14], and the Cobb method is reliable only for lordosis [8, 15, 17]
C7 slope (C7S)	Angle between horizontal and the C7 upper endplate	With a slope of more than 20°, the cervical spine has a lordosis, and with a slope of 20° or less, it has a neutral or kyphotic profile [5, 11, 12]
Th1 slope (Th1S, T1S) [8–10, 13]	Angle between horizontal and upper endplate Th1	Often Th1 is difficult to visualize on radiographs due to overlapping shoulder joints. Formula that allows to focus on C7: $T1S = 0.87C7S + 7°$ [18]
Spino-cranial angle (SCA)	Angle between the C7 upper endplate and the line drawn through its middle and the center of the sella turcica	This angle is constant in the absence of pathology and reflects the displacement of the head relative to the cervicothoracic junction [12, 19]
Thoracic inlet angle (TIA) [5, 8–10, 13]	The angle between the perpendicular to the middle of the upper endplate of Th1 and the line connecting this point and the upper point of the sternum	There is an opinion that it is a constant anatomical value, like PI [13], however, the possibility of changing its value during flexion-extension of the neck has been shown [20]
Neck tilt (NT) [8–10, 13]	Angle between the vertical and the line between the apex of the sternum and the middle of the Th1 cranial endplate	Lee et al. [21] drew attention to the comparability of the NT value among different researchers. Assuming the stability of the index, they presented the results of corrective vertebrotomies in the cervical spine for deformities and noted a statistically significant change in TIA and T1S before and after surgery, while maintaining the NT value at the preoperative level. The three parameters are related by the formula $TIA = T1S + NT$. They have a strong correlation: an increase in TIA leads to an increase in T1S and an increase in cervical lordosis [13, 20]
Cervical tilt (cervical tilt, CeT) [10, 13]	The angle between the vertical drawn from the middle of the Th1 cranial endplate and the line connecting the same point with the C2 odontoid	–
Cranial tilt (cranial tilt, CrT) [10, 13]	The angle between the vertical drawn from the middle of the Th1 cranial endplate and the line connecting the same point with the C2 odontoid	The formula that combines two parameters and the Th1 slope: $T1S = CeT + CrT$, and the ratio between the summands is 70 % and 30 %, respectively [13]
Vertical cervical shift (cervical sagittal vertical alignment, cSVA) [8–10, 12]	Distance (in mm) between lead lines drawn from the center of the C2 body and the posterior cranial angle of the C7 body	Characterizes the displacement of the head. It has been established on biological models that with an increase in cSVA due to hyperkyphosis of C2–C7 and hyperlordosis of C0–C2, an increase in the size of the radicular foramen occurs, which may be a compensatory mechanism for radiculopathies [16]

test. In all cases, no sufficient reasons for rejecting the null hypothesis were found ($p > 0.05$).

Results

According to distributions close to normal, the values of the parameters of sagittal balance in children obtained by us are shown as mean values with 95 % and 99 % confidence intervals (Table 3).

The linear dependence of the sagittal balance parameters on the age of children was evaluated by calculating the Kendall tau rank correlation coefficient. It was done because the age of children in the cohort does not conform to the normal distribution (the Shapiro – Wilk test: W = 0.9336; p = 0.0008) and has repeating ranks when ordering. A statistically significant correlation with age was found only for the angle Oc–C2 (a very weak negative) and the distance cSVA (weak positive), respectively. The distributions of these parameters are given in Fig. 4.

Due to multivariate analysis of variance, the presence of a statistically significant difference between the age groups was detected only for the cSVA parameter, whereas gender contrasts were recorded in 6 out of 10 parameters (Table 4).

To evaluate the differences between specific age groups, a pair-wise comparison was performed using the Tukey's range test (Table 5). A statistically significant difference in the value of the cSVA parameter was recorded in children of senior school age (13–17 years old) in comparison with younger age groups ($p < 0.05$).

Table 6 shows the mean values of the parameters for boys and girls, along with an evaluation of the gender difference using the Student's t-test. Gender differences are insignificant for 4 out of 10 parameters: Oc–C2, NT, CrT, cSVA.

The analysis of the linear relationship between the parameters of the sagittal balance of the cervical spine was performed by constructing a correlation matrix consisting of Pearson correlation coefficients and presenting it in the form of a diagram (Fig. 5).

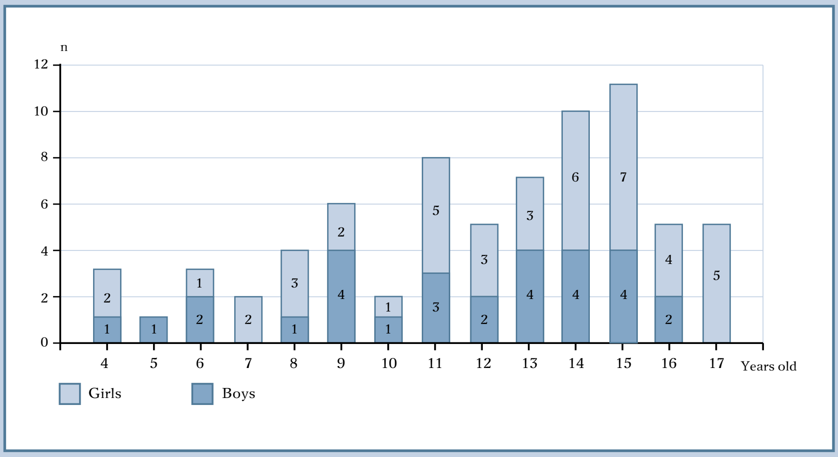

Fig. 1
Distribution of children by gender and age

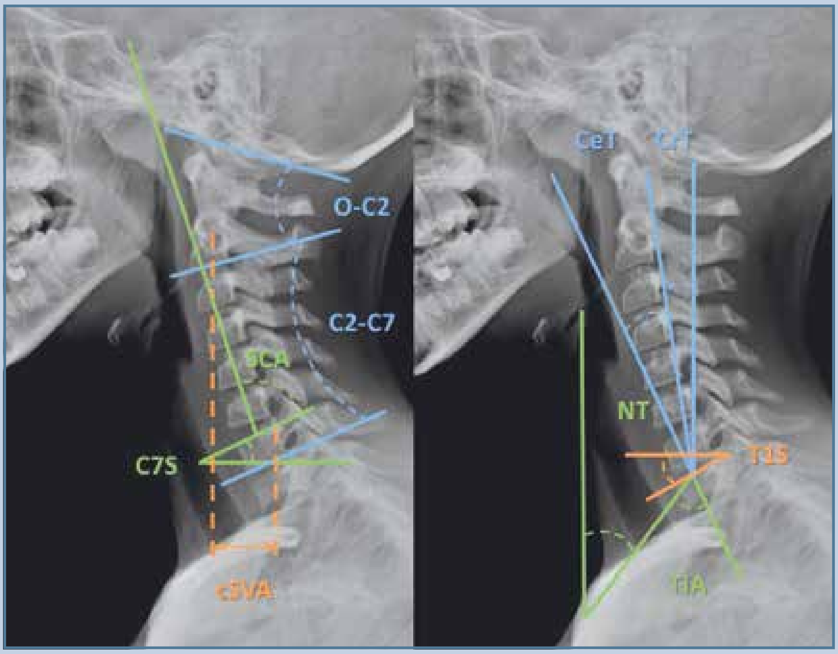

Fig. 2
Parameters of the sagittal balance of the cervical spine (detailed description in the text and in Table 1)

A very strong correlation has been determined between the parameters C7S and Th1S, which corresponds to the adjacent position of the vertebrae. Both parameters characterizing the slope of the base of the cervical spine have a strong correlation with the CeT parameter reflecting the general slope of the neck, a strong negative correlation with the C2–C7 parameter characterizing the sagittal profile of the subaxial spine, and with the SCA indicator corresponding to the general position of the head relative to the C7 vertebra. The correlation with another head position indicator (CrT) is weak.

Table 2

Coefficients of variation of values when measuring the parameters of the sagittal balance by three specialists

Parameter	Oc–C2	C2–C7	cSVA	C7S	Th1S	TIA	NT	CeT	CrT	SCA
V	0.237	0.349	0.166	0.103	0.123	0.117	0.127	0.311	0.334	0.053

Criteria for assessing the level of consistency V: less than 0.2 — good consistency, from 0.2 to 0.3 — satisfactory, more than 0.3 — unsatisfactory.

Indicators C2–C7 and SCA have a strong positive correlation with each other; the CeT parameter strongly negatively correlates with both of them. TIA has a strong negative correlation with SCA and an average positive correlation with NT, CeT, C7S, and Th1S. The cSVA and CrT indicators have a strong relationship only with each other.

The rest of the parameters have a weak or very weak statistically significant correlation.

Discussion

A number of studies support a gradual increase in the parameters of PI, PT, LL, and TK in children as they grow and attain values typical for adults [11, 22–24]. Meanwhile, some studies show that SS does not change significantly with children's growth [22], whereas others show its statistically significant increase during this period [24]. It is shown that the global sagittal balance, estimated by the SVA indicators, as well as the CEA (considering the vertical lowered from the center of the external auditory meatus), changes from positive to negative values in childhood: from 25.4 mm to -8.6 mm for the SVA and from 8.1 mm to -6.5 mm for the CEA [11, 23], where "-" indicates the projection of the indicator posterior to the vertical line.

It is stated that cervical lordosis begins to form within the embryo (which queries the association of spinal bends with verticalization) and after birth, when attempting to hold the head and sit, just enhances [11, 25, 26]. Nonetheless, its presence does not characterize all children. For example, when there are no complaints in children, cervical lordosis occurs in 40–71 % of cases, direct profile in 16–23 % of cases, and kyphosis in 5.8–44.0 % of cases [24, 26].

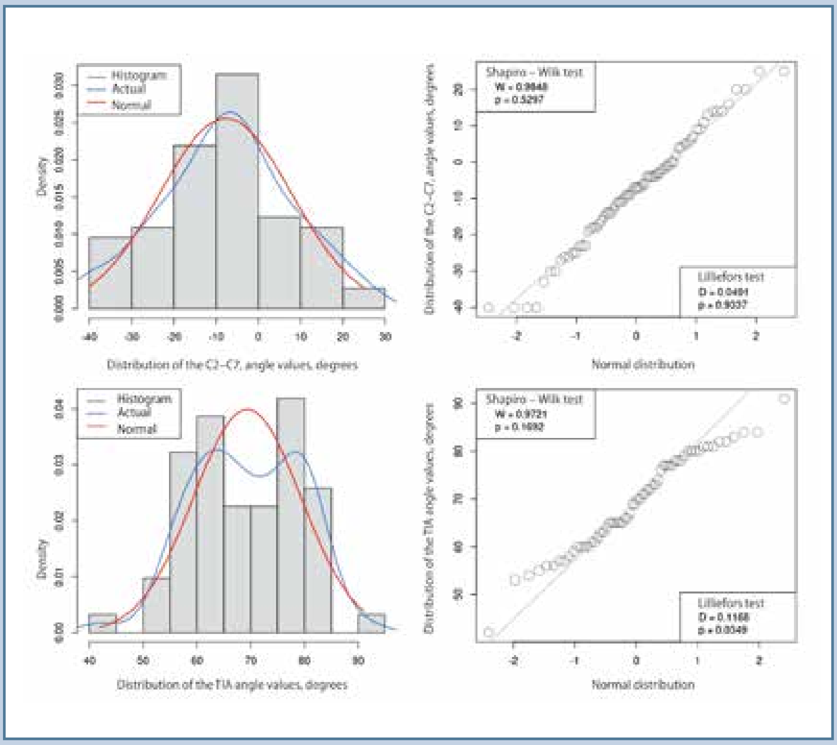

Fig. 3
Variants of the distributions of the parameters values of the sagittal balance of the cervical spine in children: on the left - histograms and density curves of the actual and normal distributions of the values; on the right – a Q-Q plot of values with normality test criteria

Without finding any significant differences in general cervical lordosis in patients of different ages and gender, the researchers nevertheless attribute to the age characteristics of children a greater kyphosis of the vertebral bodies with discs more subject to lordosis [26] and to gender characteristics a more pronounced lordosis at the suboccipital level in girls and at the subaxial level in boys [11, 26]. It is assumed that the features of subaxial lordosis correlate with global cervical lordosis at the level of C1–C7 and remain as children grow [11]. These findings are consistent with the reported gender differences in suboccipital and subaxial lordosis. There is also a significant reduction in subaxial lordosis and the slope of the C7 vertebra after 10 years, as well as a strong correlation between the slope of the C7 vertebra and the values of global cervical lordosis (C1–C7) and thoracic kyphosis TK [11].

Kasai et al. [25] identified the features of the spatial orientation of the facet joints of the cervical vertebrae in the

Table 3

The values of the parameters of the sagittal balance of the cervical spine in children

Parameter	Mean value	95 % CI	99 % CI
Oc–C2, degree	-23.8 ± 8.7	(-25.8; -21.8)	(-26.5; -21.1)
C2–C7, degree	-7.8 ± 15.6	(-11.4; -4.1)	(-12.6; -2.9)
C7S, degree	24.0 ± 8.8	(22.0; 26.1)	(21.3; 26.8)
Th1S, degree	28.0 ± 8.0	(26.1; 29.9)	(25.5; 30.5)
TIA, degree	69.4 ± 10.0	(66.8; 71.9)	(66.0; 72.7)
NT, degree	41.1 ± 7.6	(39.2; 43.0)	(38.5; 43.6)
CeT, degree	19.8 ± 8.4	(17.8; 21.8)	(17.2; 22.4)
CrT, degree	8.5 ± 8.4	(7.2; 9.7)	(6.8; 10.1)
SCA, degree	80.4 ± 10.3	(77.9; 82.9)	(77.1; 83.7)
cSVA, mm	24.1 ± 9.2	(22.0; 26.3)	(21.3; 27.0)

The «-» sign in front of the digital value corresponds to lordosis.

sagittal plane in growing children: the joint space gradually changes its plane from almost horizontal to more vertical, remaining unchanged after 10 years. The authors connect the phenomenon of pseudosubluxation in young children exactly with this horizontal orientation of the joints. The researchers also noted a gradual decrease in cervical lordosis C3–C7 under the age of 9 years, followed by an increase [25]. Other authors point out that cervical lordosis rises until age of 17 years and then begins to decrease [24].

All researchers are faced with a common ethical problem: the impossibility of X-ray examination of healthy children without clinical symptoms and complaints. And the presence of reasons calls into question the possibility of recognizing the parameters obtained on such radiographs as the norm. Since it is impossible to carry out a complete examination of this type of childhood, the above data were collected from children who were often examined for injury or suspected scoliosis, while the authors excluded radiographs with revealed pathology. Evidently, ethical limitations and sampling features are the reasons for the ambiguous data collected by different authors.

In our paper, a reasonably strong direct relationship has been established between a number of factors, clarified by compensatory instruments for maintaining the vertical position of the head. Critical sex contrasts between boys and girls were found in more than half of the assessed parameters, and significant changes between different periods of childhood were found within the cSVA parameter only.

Comparison of the sagittal balance parameters of the cervical spine obtained from a sample of children with the parameters of the adult population in the articles revealed statistically significant differences in 6 out of 10 parameters in the presence of a very small absolute difference at first glance (Table 7).

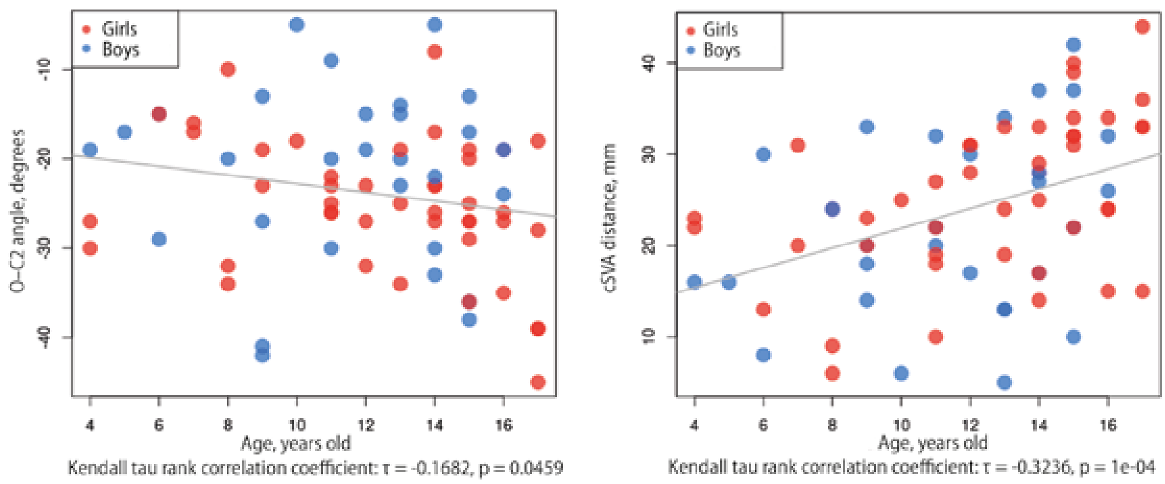

Fig. 4

Scattering diagrams of sagittal balance parameter values for Oc–C2 angle and cSVA parameters depending on age with Kendall tau rank correlation coefficients

Table 4

Results of multivariate analysis of variance of the influence of age and gender on balance parameters

Parameter	Levene's Test		Influencing factors			
			Age		Gender	
	F	p	F	p	F	p
Oc–C2	0.1872	0.8297	0.633	0.5340	2.398	0.1260
C2–C7	0.2357	0.7909	2.144	0.1249	9.922	0.0024
C7S	0.4802	0.6207	0.907	0.4084	8.224	0.0055
Th1S	1.4328	0.2456	0.131	0.8778	8.490	0.0048
TIA	0.7158	0.4930	1.295	0.2816	12.171	0.0009
NT	0.0243	0.9760	1.059	0.3530	1.053	0.3090
CeT	0.0529	0.9485	0.553	0.5780	17.300	9.04e-05
CrT	0.0924	0.9118	0.772	0.4660	2.190	0.1430
SCA	0.2759	0.7598	1.568	0.2160	21.041	2.11e-05
cSVA	1.2597	0.2902	6.581	0.0024	1.151	0.2870

Table 5

Difference in cSVA distance by age group and statistical significance of differences calculated by Tukey's test

Parameter	Mean value, mm			p	7–12 y. o.	13–18 y.o.
	4–6 y.o.	7–12 y.o.	13–18 y.o.	4–6 y.o.	0.8726	0.0376
cSVA	18.3	20.1	27.0	7–12 лет	–	0.0080

Table 6

Difference in parameters by gender

Parameter	Mean value		Student's t-test	Statistical significance, p
	Boys	Girls		
Oc–C2, degree	-21.7	-25.1	1.5758	0.1215
C2–C7, degree	-14.8	-3.1	-3.3258	0.0015
C7S, degree	27.7	21.6	3.0578	0.0033
Th1S, degree	31.4	25.9	3.0943	0.0029
TIA, degree	74.3	65.8	3.8168	0.0003
NT, degree	42.4	40.1	1.1552	0.2531
CeT, degree	24.4	16.8	4.4490	3.24e-05
CrT, degree	7.3	9.2	-1.5004	0.1387
SCA, degree	73.9	84.5	-4.9171	7.219e-06
cSVA, mm	22.4	25.3	-1.2812	0.2056

Conclusion

The angulometric values found in this study reflect the sagittal balance characteristics of the cervical spine in children, and further studies are needed to understand better the biomechanics of this complex and highly mobile anatomical region. However, the obtained results can be used as a starting point to evaluate the pathology of the cervical spine and the effectiveness of its treatment in pediatric patients.

During the study, age references for the main indicators of sagittal balance of the cervical spine of children and their differences by gender were determined. Furthermore, their differences from the normal parameters of the adult population have been identified, which makes it necessary to consider these features in clinical practice.

The significance of the results is limited by the retrospective design and the inability to test volunteers in a pediatric group.

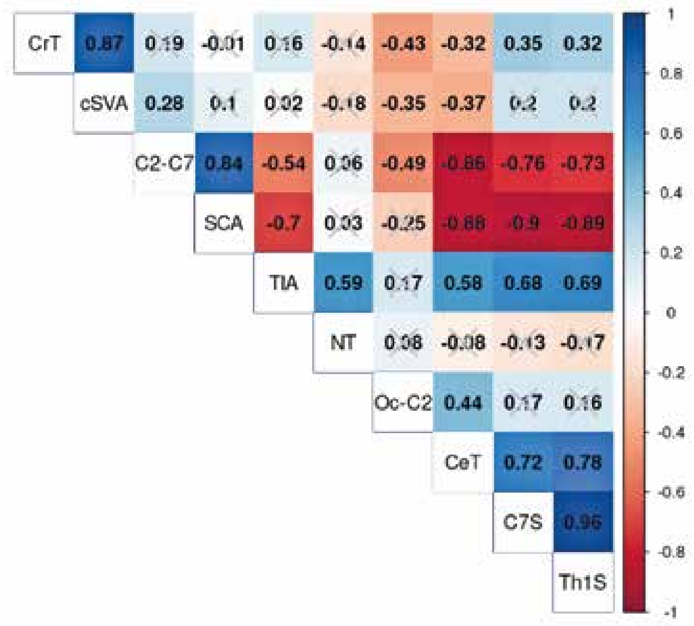

Fig. 5
Diagram of correlations between the parameters of the sagittal balance of the cervical spine, calculated using Pearson's test (statistically insignificant correlation coefficients are crossed out, $p > 0.05$)

Information on inter-professional consistency in parameter estimation may, on the one hand, require a broad response and, on the other hand, raise the issue of finding solutions for the elimination of the subjective factor.

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The authors declare that they have no conflict of interest or financial motivation to conduct the research.
The study was conducted within the framework of a planned study approved by the Ethics Committee of the Federal State Budgetary Institution St. Petersburg Research Institute of Phthisiopulmonology of the Ministry of Health of the Russian Federation, Protocol No. 65.4 dated January 22, 2020.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

Table 7

Comparison of the parameters values of the sagittal balance of the cervical spine in children and adults

Parameter	Mean value in children	Mean value in adults (according to literature data)	Student's t-test	Statistical significance, p
Oc—C2, degree	-23.78 ± 8.68	-15.81 ± 7.15	-7.8588	2.8e-11
C2—C7, degree	-7.75 ± 15.58	-9.90 ± 12.50	1.1769	0.2431
C7S, degree	24.04 ± 8.80	19.60 ± 8.80	4.3099	5.1e-05
Th1S, degree	28.01 ± 8.04	25.70 ± 6.40	2.4406	0.0172
TIA, degree	69.35 ± 9.98	69.50 ± 8.60	-0.1145	0.9092
NT, degree	41.08 ± 7.59	43.70 ± 6.10	-2.7187	0.0085
CeT, degree	19.79 ± 8.41	18.00 ± 6.60	1.8228	0.0725
CrT, degree	8.47 ± 8.41	7.70 ± 5.00	1.2080	0.2310
SCA, degree	80.38 ± 10.29	83.00 ± 9.00	-2.1179	0.0379
cSVA, mm	24.12 ± 9.21	4.70—21.30	2.6203	0.0107

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