ANALYSIS OF THE MUTUAL INFLUENCE OF CERVICAL SAGITTAL BALANCE PARAMETERS IN CHILDREN IN NORM AND WITH DOWN SYNDROME

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Objective. To analyze the correlations and dependencies of parameters of the cervical sagittal balance, as well as the corresponding compensatory mechanisms on the example of children without orthopedic pathology and children with Down syndrome.

Material and Methods. Digital radiographs of 110 children were used to evaluate the mutual influence of cervical sagittal balance parameters. The age range was 4-17 years. Group 1 included 60 children without identified orthopedic pathology: 26 boys and 34 girls, with an average age 11 years (7.0–14.0 years). Group 2 included 50 children with Down syndrome: 24 boys and 26 girls, with an average age 9 years (7.0–12.0 years). Based on the digital radiographs, eight key angular parameters of cervical sagittal balance were assessed: O–C2, O–C7, C1–C2, C2–C7, C7S, T1S, TIA, NT. Statistical analysis of the data was performed using rank correlation analysis and multivariate regression.

Results. In the assessment of rank correlations, the leading positive correlation between the cervical lordosis and thoracic inlet angle (TIA) values was determined. Based on the results of multivariate regression, the main trends in the change in key angles of the cervical sagittal balance in children were determined. An increase in TIA by 1° leads to increase in the C2–C7 angle by an average of 0.6° ($p = 0.004$) and the C1–C2 angle by 0.4° ($p = 0.028$) for both girls and boys without identified orthopedic pathology. This rule is also equivalent when the TIA angle decreases with age. At the same time, girls have C2–C7 angle on average 2.9° ($p = 0.021$) larger and C1–C2 angle 1.2° ($p = 0.112$) larger than boys. Similar trends are true for children with Down syndrome, but with a less pronounced regression effect of factors. Thus, in children with Down syndrome, an increase in TIA by 1° is associated with a mean increase in the C2–C7 angle by 0.5° ($p = 0.004$) and the C1–C2 angle by 0.2° ($p = 0.035$). Girls have C2–C7 angle on average by 3.1° ($p = 0.018$) larger than boys. A similar dependence could not be determined for the C1–C2 angle.

Conclusion. The cervical spine, despite its high mobility, has a clear connection with the underlying spine departments. In our work, we succeeded in proving that the thoracic input angle (TIA) having small variability for each specific child, is the basis for the formation of cervical lordosis C2–C7 and local lordosis at the level of C1–C2. The formulas obtained as a result of building the regression models allow, knowing the TIA value, the age and gender of the child, to calculate the theoretical value of C2–C7 and C1–C2 values. This may help to identify signs of both sagittal imbalance and atlantoaxial instability in different groups of children, including those with Down syndrome. At the moment, the obtained formulas are theoretical and need further validation.

Key Words: cervical sagittal balance; cervical spine; children; Down syndrome; vertebrology.

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A thorough study of the natural spine curves, such as lumbar lordosis, thoracic kyphosis and cervical lordosis, resulted in the concept of spinal balance formulated by Dubousset [1] that is currently very popular among researchers around the world. This trend is represented in the constantly increasing number of articles related to this issue and the active search for an optimal methodology to analyze the parameters, normal values for different patient populations, and the interrelation between these parameters.

For a long time, the cervical spine has remained without a closer look within the sagittal balance concept because of its high mobility and remoteness from the spinopelvic region; the latter, in turn, was analyzed in sufficient detail [1–3]. However, the number of articles that in some way deal with the issue of cervical sagittal balance is increasing from year to year [4].

Most authors focus on the analysis of cervical sagittal balance parameters in both asymptomatic patients [5–8] and groups of patients with various nosologies, mainly degenerative diseases of the spine [9–15]. There are also works on changes in cervical sagittal balance in patients with Scheuermann's disease [16] and idiopathic scoliosis of different types [17–20]. The latest trend in publications on cervical sagittal balance is the search for interrelations between param-

eters and relation with the lower parts of the spine [3, 16, 21]. At the same time, the key feature of the overall majority of such articles is the analysis of these parameters in adult patients. There are occasional publications on cervical sagittal balance in pediatric patients and, as a rule, they do not provide a clear and integrated methodology for analyzing certain parameters and interrelations between them [3, 22–25].

When analyzing the correlations between the cervical sagittal balance parameters, there are indications of a close biomechanical connection between the upper thoracic spine and the magnitude of cervical lordosis, as well as with the magnitude of C1–C2 lordosis [3, 16, 23]. Age-related changes in the cervical sagittal balance in pediatric patients were also characterized [3, 25]. The heterogeneity of the samples and the lack of an integrated methodology for data analysis lead to some inconsistencies between the results obtained by different authors.

This publication is a consecutive continuation of our recent work on the analysis of the cervical sagittal balance parameters in healthy children and in children with Down syndrome [23]. It is based on the theory of the presence of definite biomechanically substantiated correlations between the key parameters of the cervical sagittal balance and the corresponding compensation mechanisms in the development of natural curves of the neck.

The objective is to analyze the correlations and dependencies of the cervical sagittal balance parameters, as well as the corresponding compensatory mechanisms through the example of pediatric patients with no identified orthopedic pathology and pediatric patients with Down syndrome as initially predisposed to the development of atlantoaxial instability, one of the signs of cervical sagittal imbalance.

Material and Methods

The study material is represented by radiological images of the cervical spine of 110 pediatric patients performed in the lateral plane and in the neutral position. Images were selected from the radiological archive of two institutions: the Federal Center for Traumatology, Orthopedics and Endoprosthetics (Smolensk) and the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics (Moscow). Patients were retrospectively divided into 2 groups.

Group 1 included patients who applied for an outpatient appointment in the Federal Center for Traumatology, Orthopedics and Endoprosthetics (Smolensk) with complaints of back pain, cervical spine pain, or poor posture. To exclude abnormality of the musculoskeletal system, these patients underwent postural radiography of the spine and radiography of the cervical spine. Based on the results of the clinical and radiological examinations, their condition was described as the absence of orthopedic abnormalities. Therefore, the selection criteria were the following:

- age 4 to 17 years inclusive;
- the patient's ability to independently maintain an upright body position;
- successful completion of postural radiography of the spine;
- results of postural radiography of the spine in two planes revealed no abnormalities of the musculoskeletal system;
- no indications of the presence of any genetic syndrome.

Additionally, patients were divided into subgroups according to their sex and age.

Group 2 included pediatric patients who underwent a routine examination for cervical spine abnormalities associated with Down syndrome at the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics (Moscow). All patients underwent radiography of the cervical spine in the lateral plane. For the final sample, patients with Down syndrome diagnosed with certain abnormalities of the cervical spine were excluded from the total number of pediatric patients who underwent the examination. The selection criteria for Group 2 were the following:

- Down syndrome (of any type) confirmed by genetic testing;
- age 4 to 17 years inclusive;
- the patient's ability to independently maintain an upright body position;
- successful completion of cervical spine radiography in the lateral plane;
- results of cervical spine radiography in the lateral plane revealed no cervical spine abnormalities.

Additionally, patients were also divided into subgroups according to their sex and age.

Features of patients in groups 1 and 2 are provided in Table 1.

For all patients, the key angular parameters of cervical sagittal balance associated with a particular anatomical area were calculated. To characterize the upper local cervical lordosis at the level of the craniovertebral junction, O–C2 and C1–C2 parameters were used; as well as O–C7 and C2–C7 parameters were used for the cervical lordosis, and C7S, T1S, TIA, and NT parameters – for the ratios of the cervical spine and the thorax. The technique for measuring the parameters is provided in Fig. 1.

To eliminate the error associated with the various software tools used to analyze the radiological images, all measurements were performed in the RadiAnt DICOM Viewer software, licensed version 2022.1 (64 bit) (Copyright© 2009–2023, Medixant).

Statistical data analysis and visualization were performed using the R language (version 4.3.1) in RStudio IDE (version 2023.09.0). The sample compliance with the normal distribution was determined using the Shapiro–Wilk test. The rank-based correlation was estimated with the Spearman's correlation coefficient for quantitative values beyond the normal distribution and with the Pearson coefficient for normally distributed values. To find the correlation between a categorical value (sex) and quantitative values, the point-biserial correlation coefficient was used. To assess multiple interactions of values and to determine latent patterns, multivariate regression analysis was performed. The null hypothesis in statistical tests was rejected at significance level $p < 0.05$.

Results

Evaluation of the normality of the criteria distribution in the sample using the Shapiro-Wilk test revealed a normal distribution ($p > 0.05$) for the following parameters in Group 1: O–C7 angle, C7 slope (C7S), T1 slope (T1S), TIA, and NT. The distribution was beyond normal ($p < 0.05$) for the following parameters: age, O–C2 angle, C1–C2 angle, and C2–C7 angle. In Group 2, there was a normal distribution ($p > 0.05$) for the following parameters: O–C2 angle and T1 slope (T1S). Other parameters (O–C7, C1–C2, C2–C7, C7S, TIA, and NT) have a non-normal distribution ($p < 0.05$).

For each of the groups and age-related subgroups, the mean values of cervical sagittal balance parameters were calculated using the median and quartiles. The mean values of each parameter are provided in our previous work [23].

For each group of patients, rank-based correlations between all parameters were analyzed using the Spearman's, Pearson, and point-biserial correlation coefficients. As a result, data on the most significant correlations were obtained for Group 1 (pediatric patients with no identified orthopedic abnormalities). The most significant correlation was found between the C7 and T1 slope angles and the thoracic inlet angle (TIA), which is associated with the close anatomical link of these parameters. Being the main component of cervical lordosis, the C2–C7 angle also has significant positive correlation with the C7 and T1 slope angles and TIA; it confirms the core role of the thoracic inlet angle in the development of cervical lordosis. The C1–C2 angle has a moderate positive correlation with the angle of the O–C7 total cervical lordosis, since it is the part thereof. There is a relation between the O–C7 and C2–C7 angles that are related to the magnitude of cervical lordosis and the sex and the age. This relation can be described as a trend for the total cervical lordosis to decrease with age, which is more significant in boys. The most significant rank-based correlations in Group 1 ($p < 0.05$) are provided in Table 2.

Table 1
Age and sex features of patients in groups 1 and 2

Parameters	Group 1	Group 2
Total number of patients, n	60	50
Age range, years	4–17	4–17
Mean age, years	11	9
Distribution by sex (boys : girls)	26 : 34	24 : 26
Age subgroups, n		
4–7 years	17	16
8–11 years	19	18
12–17 years	24	16

In Group 2 that included pediatric patients with Down syndrome, there were no significant sex-related differences in parameter alteration; however, age-related differences were more significant, with maintaining general trends toward a decrease in cervical lordosis and TIA with age. The most significant rank-based correlations in Group 2 ($p < 0.05$) are provided in Table 3.

For children with Down syndrome, the thoracic inlet angle (TIA) is also the basis for the development of the total cervical lordosis; however, its impact on the final magnitude of cervical lordosis is less significant: TIA – C2–C7 – $r = 0.53$ (Group 1) and $r = 0.49$ (Group 2); TIA – O–C7 – $r = 0.57$ (Group 1) and $r = 0.34$ (Group 2). Since the O–C7 angle is comprised of the O–C2 and C2–C7 angles, the effect of TIA on the O–C7 total cervical lordosis is statistically significantly reduced exactly because of the indirect effect on the craniovertebral junction (O–C2). The above correlations indicate a greater variability of angles in the craniovertebral zone (O–C2, C1–C2) in pediatric patients with Down syndrome; this is confirmed by numerous empirical evidence describing the predisposition of this group of patients to atlantoaxial instability. Schematic visualization of the interrelation of the cervical sagittal balance parameters in both groups is provided in Fig. 2 and 3.

To search for multivariate interactions of the parameters, as well as latent patterns of interrelation for the groups of parameters, a multivariate regression analysis was performed for each of the analyzed groups, with the development of corresponding models. During the analysis, the core groups of variables with the effect on the development of the lower cervical lordosis (C2–C7) and local cervical lordosis at the level of the craniovertebral junction (C1–C2) were age, sex, and thoracic inlet angle (TIA). At the early stage of the analysis, a regression model of sex- and age-dependent TIA change was developed for both groups (Fig. 4, 5).

As a result of the regression analysis, a general trend towards a decrease in TIA with age was determined, with significant sex dimorphism in healthy pediatric patients.

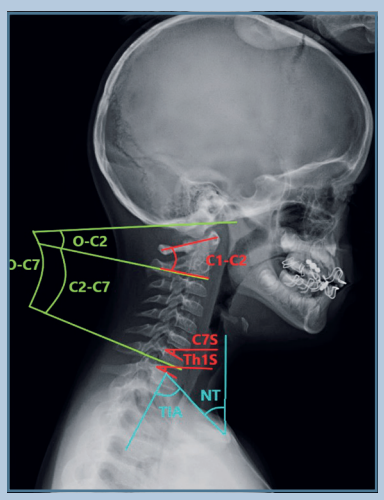

Fig. 1
Methodology for measuring cervical sagittal balance parameters

Then, regression models of the dependence of the angle C2–C7 on age and sex were built for both groups (Fig. 6, 7).

As for the age-related change in TIA, there is a trend for the C2–C7 angle to decrease. There is also no significant sex dimorphism in pediatric patients with Down syndrome, which is confirmed by the earlier study of rank-based correlations.

For the most variable parameter (C1–C2 angle), a regression model was also built to determine the trends in its age-related changes (Fig. 8, 9).

This regression revealed a small variability of the C1–C2 angle in both healthy boys and girls. At that, the variability was more significant, including due to sex dimorphism, in the group of pediatric patients with Down syndrome. Based on the regression results, it can be concluded that there is greater C1–C2 stability in pediatric patients without Down syndrome, which can firstly be associated with the absence of a predisposition to hypermobile ligaments in this group.

Based on the results of multivariate regression, the main trends in the change of key angles of the cervical sagittal balance in pediatric patients may be defined. An increase of 1° in TIA leads to an increase by a mean of 0.6° ($p = 0.004$) in the C2–C7 angle and by 0.4° ($p = 0.028$) in the C1–C2 angle in both girls and boys with no identified orthopedic abnormalities. This principle is also true for a decrease in the TIA angle with age. Along with that, the C2–C7 and the C1–C2 angles in girls are greater than in boys: by 2.9° ($p = 0.021$) and by 1.2° ($p = 0.112$), respectively.

Similar trends are true for pediatric patients with Down syndrome, however, with a less significant regression effect of variables. Thus, in patients with Down syndrome, a 1° increase in TIA is associated with a mean increase by 0.5° ($p = 0.004$) in the C2–C7 angle and by 0.2° ($p = 0.035$) in the C1–C2 angle. In girls, the C2–C7 angle is greater on mean by 3.1° ($p = 0.018$) than in boys. No similar dependence was found for the C1–C2 angle.

Table 2

Distribution of the most significant rank correlations in Group 1

Parameter 1	Parameter 2	Coefficient	Technique	*p* value
Age	O–C7 angle7	–0.37	Spearman	0.003
Sex	C2–C7 angle	–0.30	Point-biserial correlation	0.021
Sex	C7 slope	–0.29	Point-biserial correlation	0.024
Sex	T1 slope	–0.28	Point-biserial correlation	0.028
O–C2 angle	O–C7 angle	0.51	Spearman	<0.001
O–C2 angle	C1–C2 angle	0.64	Spearman	<0.001
O–C7 angle	C1–C2 angle	0.34	Spearman	0.008
O–C7 angle	C2–C7 angle	0.72	Spearman	<0.001
O–C7 angle	C7 slope	0.68	Pearson	<0.001
O–C7 angle	T1 slope	0.66	Pearson	<0.001
O–C7 angle	TIA	0.57	Pearson	<0.001
C2–C7 angle	C7 slope	0.65	Spearman	<0.001
C2–C7 angle	T1 slope	0.64	Spearman	<0.001
C2–C7 angle	TIA	0.53	Spearman	<0.001
C7 slope	T1 slope	0.92	Pearson	<0.001
C7 slope	TIA	0.75	Pearson	<0.001
T1 slope	TIA	0.74	Pearson	<0.001
TIA	NT	0.57	Pearson	<0.001

Table 3

Distribution of the most significant rank correlations in Group 2

Parameter 1	Parameter 2	Coefficient	Technique	*p*-value
Age	O–C7 angle	–0.45	Spearman	0.001
Age	C7 slope	–0.49	Spearman	<0.001
Age	T1 slope	–0.49	Spearman	<0.001
Age	TIA	–0.59	Spearman	<0.001
Age	NT	–0.39	Spearman	0.005
Age	C2–C7 angle	–0.54	Spearman	<0.001
O–C2 angle	O–C7 angle	0.44	Pearson	0.001
O–C2 angle	C1–C2 angle	0.65	Pearson	<0.001
O–C7 angle	C1–C2 angle	0.36	Pearson	0.011
O–C7 angle	C7 slope	0.70	Pearson	<0.001
O–C7 angle	T1 slope	0.63	Pearson	<0.001
O–C7 angle	TIA	0.34	Spearman	0.016
O–C7 angle	C2–C7 angle	0.85	Pearson	<0.001
C1–C2 angle	C7 slope	0.30	Pearson	0.032
C7 slope	T1 slope	0.90	Pearson	<0.001
C7 slope	TIA	0.63	Spearman	<0.001
C7 slope	C2–C7 angle	0.68	Pearson	<0.001
T1 slope	TIA	0.71	Spearman	<0.001
T1 slope	C2–C7 angle	0.68	Pearson	<0.001
TIA	NT	0.70	Spearman	<0.001
TIA	C2–C7 angle	0.49	Spearman	<0.001

Considering the regression coefficients obtained, theoretical formulas were generated for calculating the C2–C7 and C1–C2 angles based on the TIA values, sex, and age.

For boys with no identified orthopedic abnormalities, the formula for calculating the C1–C2 angle is the following: (18.2 + 0.5 × Age + 0.4 × TIA) ± 8.7; confidence interval (95%): ±8.7° (standard error: σ = 4.43°; *t* = 1.96). For the C2–C7 angle: (–10.8 + 1.7 × Age + 0.6 × TIA) ± 11.3; confidence interval (95%): ±11.3° (standard error: σ = 5.77°; *t* = 1.96).

For girls with no identified orthopedic abnormalities, the formula for calculating the C1–C2 angle is the following: (16.8 + 0.6 × Age + 0.3 × TIA) ± 9.5; confidence interval (95%): ±9.5° (standard error: σ = 4.85°; *t* = 1.96). For the C2–C7 angle: (–12.4 + 1.9 × Age + 0.7 × TIA) ± 12.8; 95% confidence interval: ±12.8° (standard error: σ = 6.53°; *t* = 1.96).

For boys with Down syndrome, the formula for calculating the C1–C2 angle is the following: (20.4 + 0.8 × Age + 0.45 × TIA) ± 9.8; confidence interval (95%): ±9.8° (standard error: σ = 5.0°; *t* = 1.96). For the C2–C7 angle: (–7.2 + 2.3 × Age + 0.65 × TIA) ± 12.7; confidence interval (95%): ±12.7° (standard error: σ = 6.5°; *t* = 1.96).

For girls with Down syndrome, the formula for calculating the C1–C2 angle is the following: (18.6 + 0.65 × Age + 0.35 × TIA) ± 8.5; confidence interval (95%): ±8.5° (standard error: σ = 4.35°; *t* = 1.96). For the C2-C7 angle: (–5.0 + 1.9 × Age + 0.55 × TIA) ± 11.2; confidence interval (95%): ±11.2° (standard error: σ = 5.7°; *t* = 1.96).

The formulas obtained may help in calculating the theoretical parameters of the cervical sagittal balance, and consequently, in the early detection of predictors of cervical functional and anatomical abnormalities in pediatric patients. Emphasis should be put on the kyphosis development in the C1–C2 angle as one of the predictors of atlantoaxial instability, especially in pediatric patients with Down syndrome. However, it is important to notice that the formulas obtained at this stage of data accumulation and processing are theoretical and require additional validation.

Discussion

The correlations between the spinopelvic parameters (PI, PT, LL, SS, etc.) and their impact on thoracic kyphosis (TK) have been analyzed in detail in many earlier studies. Different formulas were generated to calculate certain parameters of spinopelvic correlations. The fundamental formula describing the relations between the pelvic and lumbar parameters is the geometric dependence of the pelvic tilt (PT) and the sacral slope (SS) expressed as the pelvic index (PI): PI = PT + SS; it was confirmed by Schwab et al. [26], as well as with many other studies on the spinopelvic balance in children and adults [27].

Berthonnaud et al. [28] and Roussouly et al. [29] in their studies on global sagittal balance concluded that there is a relation between the sagittal parameters of adjacent spinal regions, as well as of separate ones, which allows considering the pelvis and spine as a single system for the development of physiological spinal curves. They also described the correlations between the magnitude of cervical lordosis and thoracic kyphosis [28, 29].

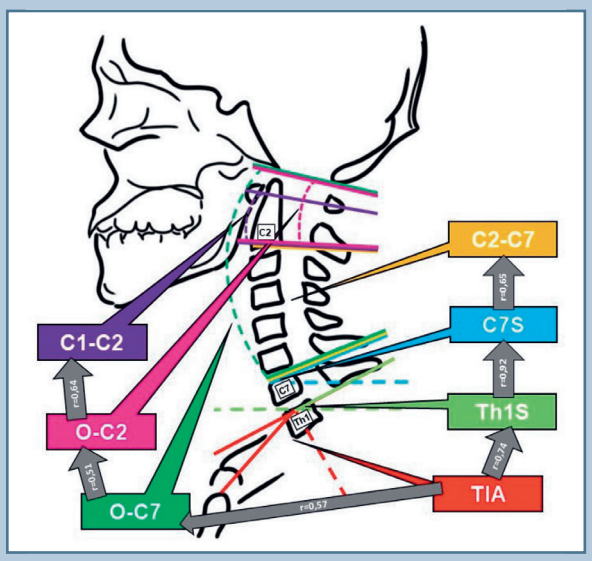

Fig. 2
Scheme of interrelation of cervical sagittal balance parameters in Group 1

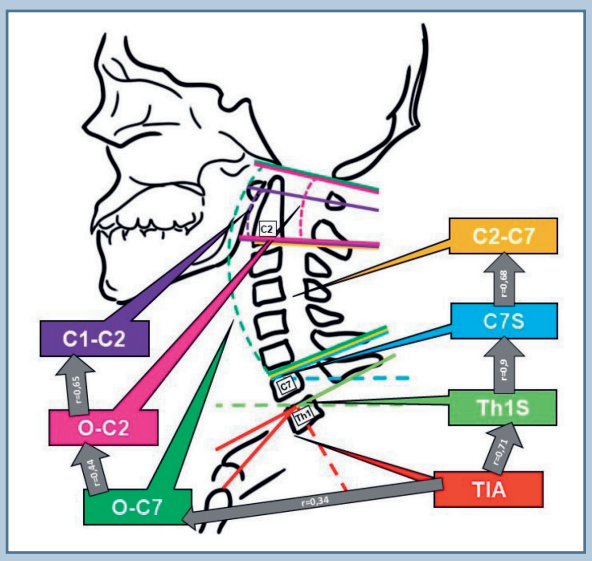

Fig. 3
Scheme of interrelation of cervical sagittal balance parameters in Group 2

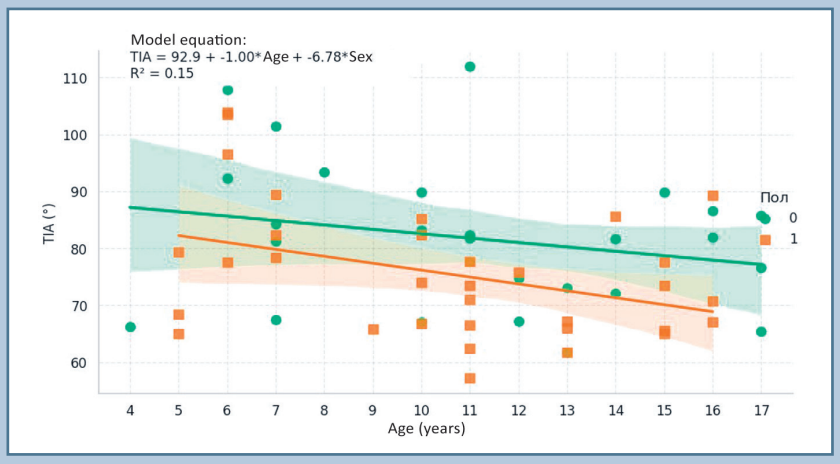

Fig. 4
Regression plot of TIA depending on age and sex in Group 1: green – boys, orange – girls

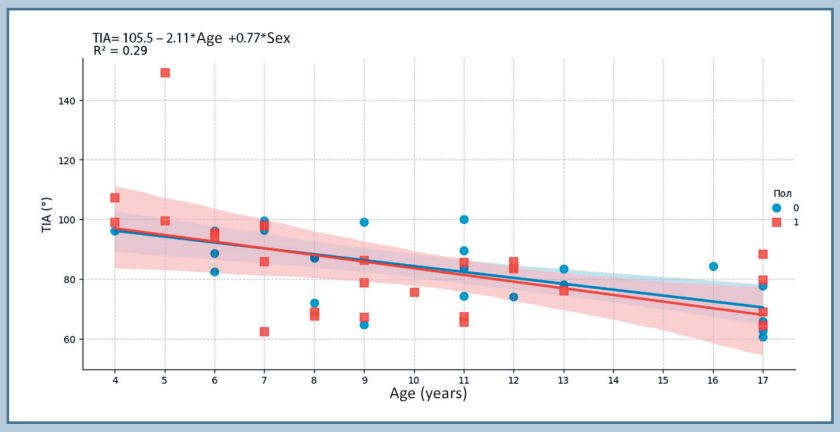

Fig. 5
Regression plot of TIA depending on age and sex in Group 2: blue – boys, red – girls

Lee et al. [30] analyzed the correlations and dependencies in the generation of essential parameters of cervical sagittal balance using the radiological images of 77 adult volunteers with no spinal abnormalities. As a result of the study, the thoracic inlet angle (TIA) parameter was proved to be relatively stable for each individual and to play an essential role in the development of the magnitude of cervical lordosis. However, its relation with local lordosis at the level of the craniovertebral junction (C1–C2) was not statistically confirmed; it may indicate a significant mobility and variability of this angle in the population. The authors defined an essential geometric correlation between the thoracic inlet angle (TIA), neck tilt (NT), and T1 slope (T1S) as the following formula: TIA = T1S + NT [30]. Later, Le Huec et al. [4] described a close correlation between the C7 slope (C7S) and the magnitude of cervical lordosis (C2–C7), thereby once again confirming the key function of the cervicothoracic junction in the development of cervical lordosis. Shao et al. [31] analyzed the radiological images of 246 asymptomatic patients in order to study the essential parameters that have an effect on the progression of cervical sagittal imbalance; they interpreted these values as C2C7SVA changes. Using a regression model, the authors found that the most significant parameters for the progression of sagittal imbalance include body mass index, orbital slope (OS), the O–C2 angle, cervical lordosis magnitude, and the T1 slope (T1S). As a result of the study, a corresponding formula was obtained that included the most significant parameters for the progression of sagittal imbalance: C2C7SVA = 0.38 × BMI – 0.73 × OS + 0.73 × C0C2 + 0.15 × CL + 0.18 × TS – 6.53. The authors point out that this research may help surgeons in more accurate determination of the treatment prognosis when planning reconstructive surgical interventions.

In 2020, Alijani and Rasoulian [21] published a large-scale comparative study of radiological images of 420 adult patients divided into 4 groups based on the presence of symptoms of spinal diseases. The results revealed no statistically significant differences between asymptomatic, symptomatic, and surgically treated patients. The sagittal vertical axis C7SVA correlated with the magnitude of cervical lordosis (C2–C7; $r = 0.7$) in all groups. Regardless of the group, when analyzing the complete sample, a correlation between the C1–C2 angle and the magnitude of lumbar lordosis was found (LL; $r = 0.1$) [21]. This conclusion can be interpreted as further evidence that, despite the remoteness of particular anatomical structures, the spine functions as a single system, with the development of natural curves according to the common biomechanical laws.

Alongside with the study of the cervical sagittal balance parameters in asymptomatic patients or patients with degenerative diseases, data were accumulated on the sagittal profile of patients with various dysplastic disorders. Patients with Scheuermann's disease and idiopathic scoliosis were the most studied groups from this point of view. Janusz et al. [16] in their study of global sagittal balance in adolescents and adults with Scheuermann's disease concluded that the apex

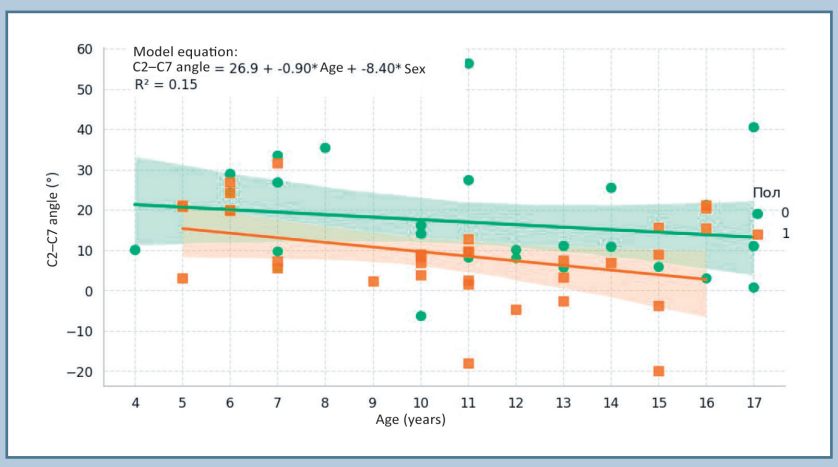

Fig. 6
Regression plot of the C2–C7 angle depending on age and sex in Group 1: green – boys, orange – girls

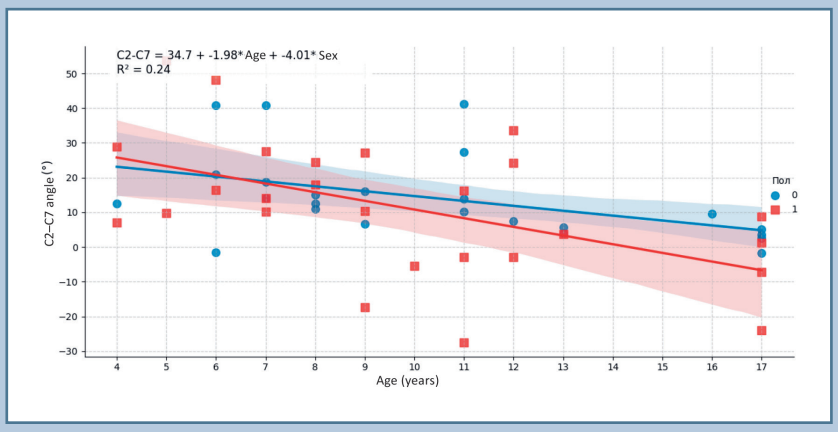

Fig. 7
Regression plot of the C2–C7 angle depending on age and sex in Group 2: blue – boys, red – girls

of structural kyphosis has a significant impact on the T1S angle, TIA, and NT and leads to changes in the curvature of the C2–C7 cervical lordosis. In studies describing cervical sagittal balance in patients with scoliosis, compensatory changes in parameters were registered after reconstructive surgical interventions in a significant number of patients [17–20].

Just few studies include group of pediatric patients with no identified orthopedic abnormalities. In most cases, this is associated with the complexity of the ethical justification of the indications for radiological examination of healthy children.

In 2012, Lee et al. [22] published a cross-sectional study based on radiological images of 181 pediatric patients with excluded spinal or musculoskeletal abnormalities during the examination. They determined a key age-related trend associated with an increase in thoracic kyphosis and cervical lordosis up to and including 17 years of age. At that, 40% of the examined pediatric patients had hypolordosis or kyphosis of the cervical spine. It is important to emphasize that this article for the first time described the close correlation between the thoracic and cervical spine as a single biomechanical compensatory and regulating component for maintaining the vertical body position on such a large cohort of pediatric subjects [22].

D.A. Glukhov et al. [2] also made a significant contribution to the study of cervical sagittal balance in pediatric patients. They analyzed 73 radiological images of the cervical spine of pediatric patients with no identified orthopedic abnormalities. During the research, normal values of cervical sagittal balance parameters and key sex-related differences were determined, and the corresponding correlations were assessed. When comparing the parameters with normal adult values, statistically significant differences were obtained for 6 of the 10 parameters.

As a rule, such studies have several limitations, and our work was no exception. The main limitation of this study is the impossibility to pre-estimate the power and size of a sample. Being a continuation of our previous study [23], this work is related to the analyses of the interrelation mechanisms for cervical sagittal balance parameters in pediatric patients. A cohort of patients with Down syndrome was selected as a comparison group, since this population is predisposed to different musculoskeletal disorders. During the study, we managed to prove that the natural spine curvatures described by the sagittal balance parameters develop in pediatric patients with Down syndrome according to the same algorithm that was similar to children with no identified orthopedic abnormalities. At that, the effect of each key segment on the development of cervical and local lordosis at the C1–C2 level was reduced for pediatric patients with Down syndrome. This can be explained by the greater mobility of the ligamentous apparatus and hypotonia of the neck muscles, typical signs of Down syndrome.

As a result, we came to the conclusion that the thoracic inlet angle (TIA) is essential for the further development of all components of cervical lordosis. There are also age- and sex-related dif-

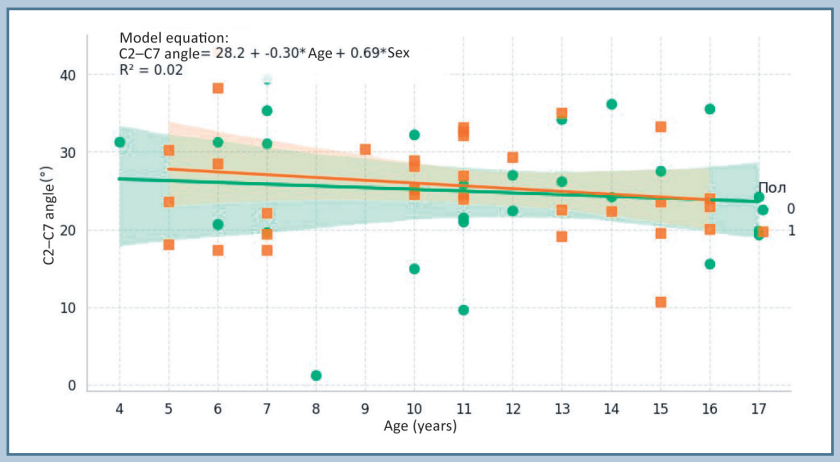

Fig. 8
Regression plot of the C1–C2 angle depending on age and sex in Group 1: green – boys, orange – girls

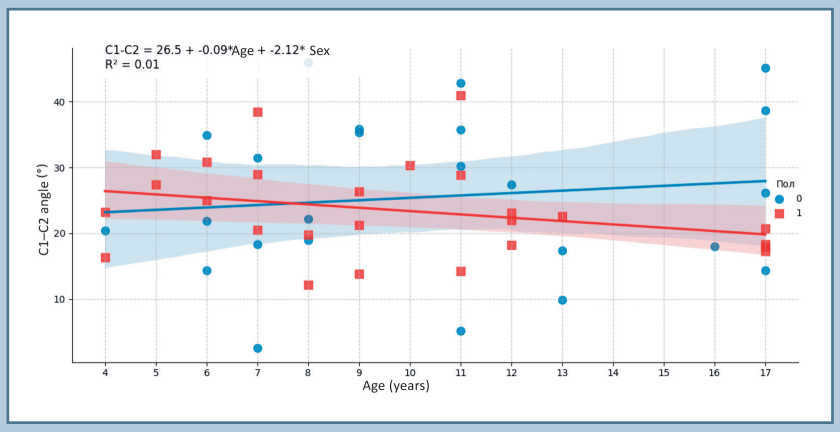

Fig. 9
Regression plot of the C1–C2 angle depending on age and sex in Group 2: blue – boys, red – girls

ferences in the values of the essential parameters of the cervical sagittal balance (C1–C2, C2–C7). The dependencies revealed allowed us to derive the corresponding formulas for calculating the C1–C2 and C2–C7 angles based on the TIA and age values for boys and girls with Down syndrome and for children with no identified orthopedic abnormalities. These formulas may help in identifying gross deviations in the cervical sagittal balance in children, as well as in searching for predictors of atlantoaxial instability that is characterized by the C1–C2 local kyphosis development.

Conclusion

Working on a more detailed analysis of the cervical sagittal balance, on its correlation with the global balance, as well as the search for a methodology and the practical application of the results obtained should be continued. There remains a need to accumulate data on the analysis of the cervical sagittal balance of both pediatric patients with no orthopedic abnormalities and syndromic patients to perform further research and to search for the ways to apply the data obtained during clinical practice.

Despite its high mobility, the cervical spine has a definite relation with the lower spine departments. In our study, we managed to prove that the thoracic inlet angle (TIA), with little variability for each individual child, is the basis for the development of the C2–C7 cervical lordosis and the C1–C2 local lordosis. Giving the TIA value, as well as the age and sex of a child, it is possible to calculate the theoretical value of the C2–C7 and C1–C2 angles that are components of cervical lordosis. The formulas we derived for calculating these angles allow identifying signs of both sagittal imbalance and atlantoaxial instability in heterogeneous groups of children, including those with Down syndrome. However, the described formulas are currently theoretical and require additional validation. Further study of the cervical sagittal balance in pediatric patients will make the formulas more accurate and practically applicable for various groups of patients.

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The study was approved by the local ethics committees of the institutions.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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