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Original Study Article

Footprint analysis in flatfoot assessment

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BACKGROUND: A flatfoot is the most common condition in the practice of a pediatric orthopedist. A flatfoot is primarily diagnosed based on the assessment of the degree of the foot flattening. Along with clinical examination, footprint analysis is often used in practice due to the safety of this study and convenience and ease of implementation.

AIM: This study aimed to determine how much footprints can correlate with the clinical assessment of flatfoot in children and which footprint indices are the most valuable in flatfoot assessment.

MATERIALS AND METHODS: The study included the survey results of 76 children aged 7–15 years of the St. Petersburg 49th school "School of Health" for 2021–2022. In this study, anthropometric data, clinical parameters (value of the heel valgus, arch angle, and Friedland index) and footprint indices and angles (Schwartz and Clarke angle, Chippaux–Smirak index, Staheli index, Cavanagh and Rodgers index, and Irwin index) were analyzed. In the study, the average values were calculated, and correlation and regression analyses were performed.

RESULTS: The footprint parameters did not have moderate and strong correlations with clinical parameters. Footprint parameters that assessed the area of the barefoot zone on the footprints (Irwin index and Cavanagh and Rodgers index) showed statistically significant moderate and strong correlations among plantographic parameters. Among linear and angular footprint parameters, the Chippaux–Smirak index showed statistically significant moderate and strong correlations.

CONCLUSIONS: The footprint criteria weakly correlated with the foot shape criteria in a clinical assessment, which does not allow us to interpolate the footprint's data to the clinical evaluation data of the foot. The Cavanagh and Rodgers index, Irwin index, and Chippaux–Smirak index had statistically significant moderate and strong correlations with other indices, which makes them more valuable in the assessment of feet according to the footprint analysis.

Keywords: flatfoot; flatfeet; footprints; footprint analysis; clinical and radiological parameters of the feet; flatfoot assessment.

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Оригинальное исследование

Плантография в диагностике плоскостопия у детей

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Обоснование. Плоскостопие — наиболее часто встречающееся состояние в практике детского ортопеда. При диагностике плоскостопия оценивают степень уплощения стопы. Наряду с клиническим осмотром в практике часто используют плантографию ввиду безвредности этого исследования, а также удобства и простоты выполнения.

Цель — определить, насколько данные плантографии могут соотноситься с клиническими данными при диагностике плоскостопия у детей и какие плантографические индексы наиболее ценны для установления плоскостопия.

Материалы и методы. В исследование вошли результаты обследования 76 детей в возрасте от 7 до 15 лет ГБОУ школа-интернат № 49 Петродворцового района Санкт-Петербурга «Школа здоровья» за 2021–2022 гг. В настоящей работе анализировали антропометрические данные, клинические параметры (величина вальгуса заднего отдела, угол продольного свода, индекс Фридланда) и плантографические индексы и углы (угол Schwartz и Clarke, индексы Chippaux–Smirak, Staheli, Cavanagh и Rodgers, Irwin). Рассчитывали средние величины, определяли корреляционные связи между изучаемыми параметрами, а также выполняли регрессионный анализ.

Результаты. Для исследуемых плантографических параметров не установлено умеренных и сильных корреляционных связей с клиническими параметрами. Наибольшее количество статистически значимых умеренных и сильных корреляционных связей между другими плантографическими параметрами выявлено для индексов, учитывающих площадь зоны анемии на плантограмме к площади отпечатка стопы (индекс Irwin и индекс Cavanagh и Rodgers). Из плантографических показателей, характеризующих линейные и угловые величины, наибольшее количество статистически значимых умеренных и сильных корреляционных связей имел индекс Chippaux–Smirak.

Заключение. Для основных плантографических критериев формы стопы обнаружены лишь слабые корреляционные связи с критериями, характеризующими форму стопы при клиническом исследовании, что не позволяет интерполировать данные плантографии на данные клинической оценки формы стопы. Из исследуемых плантографических углов и индексов наибольшее количество статистически значимых умеренных и сильных корреляционных связей с другими индексами имели индексы Cavanagh и Rodgers, Irwin, а также индекс Chippaux–Smirak, что делает их более полезными при оценке формы стопы по плантограмме.

Ключевые слова: плоскостопие; плантография; клинико-рентгенологические параметры стоп; диагностика плоскостопия.

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BACKGROUND

Platypodia is one of the most common conditions that orthopedists often face in everyday practice. Despite the wide coverage of this condition in the literature, many questions remain in the diagnosis of platypodia [1]. Most assessment systems for platypodia, such as clinical pedometry, determination of the foot shape/position index (FPI), assessment of tarsal joint mobility, biomechanical analysis of gait, consider both the foot shape and functional state [1, 2]. Traditionally, the initial stage of diagnostics is the identification of a flattened foot arch based on clinical examination and radiography. In addition to clinical and radiological examinations, plantography is significant in the diagnosis of platypodia in children [2]. The plantographic study allows for the indirect assessment only of the degree of flattening of the foot arch based on the analysis of the plantar imprint, without providing information on the degree of foot mobility and deformity genesis [3, 4]. Moreover, this method is in demand because of the simplicity of obtaining a plantographic imprint and its safety [5]. The possibility of a non-invasive objective assessment of the severity of foot flattening using plantography indicates its widespread use in cohort and population studies.

This study aimed to determine how plantography data can correlate with clinical data in diagnosing platypodia in pediatric patients and which plantographic indices are most valuable for establishing platypodia.

MATERIALS AND METHODS

The study analyzed examination results of pediatric patients from the Boarding School No. 49 of the Petrodvorets district of St. Petersburg “School of Health” for 2021–2022. The study population included a probabilistic sample obtained through simple random selection. Plantographic and physical studies were performed. The examination results of 76 children aged 7–15 years, including 46 boys, and 30 girls, were analyzed. Pediatric patients with neurological diseases and severe orthopedic pathologies after surgical interventions on the lower extremities were excluded from the study. Based on the methodology, no preliminary calculation of the sample size was performed.

During the physical examination, the following anthropometric data and measurements were collected:

- Rearfoot valgus
- Friedland index
- Clinical angle of the arch of the foot (Dahle angle)
- Body height and weight

The clinical assessment method of the foot shape is presented in Fig. 1.

Rearfoot valgus was measured by plotting the angle between the lines of the axes of the rearfoot and lower leg, which intersected in the center of the Achilles tendon on the line connecting the tops of the medial and lateral malleoli (Fig. 1*a*).

The Dahle angle was plotted using three points, and the location was determined by palpation of the foot, namely, the center of the medial malleolus, tuberosity of the navicular bone, and center of the head of the metatarsal bone I (Fig. 1*b*) [5, 6].

The Friedland index was calculated as the ratio of the foot height (vertical line connecting the top point of the foot in the instep area and the point of the support surface) to the foot length (horizontal line connecting the points of the front and rear edges of the foot), $H/L \times 100\%$ (Fig. 1*c*).

Plantography was performed on the DiaSled-M hardware and software complex. Plantograms were analyzed using five methods that most often used in clinical practice [7, 8]. Moreover, both the angular values and ratios of the lines plotted according to plantograms and the area of the loaded part of the plantar surface (anemia zones) were considered. The schemes for calculating plantograms are presented in Fig. 2.

The Schwartz and Clarke angles were plotted. Along the medial edge of the footprint, two points were set in the most medial parts of the forefoot and rearfoot, and a tangent line was drawn along these points. Point 3 was placed at the top of the concave part of the footprint in the anterior section; as a result, angle α was plotted (Fig. 2*a*) [8].

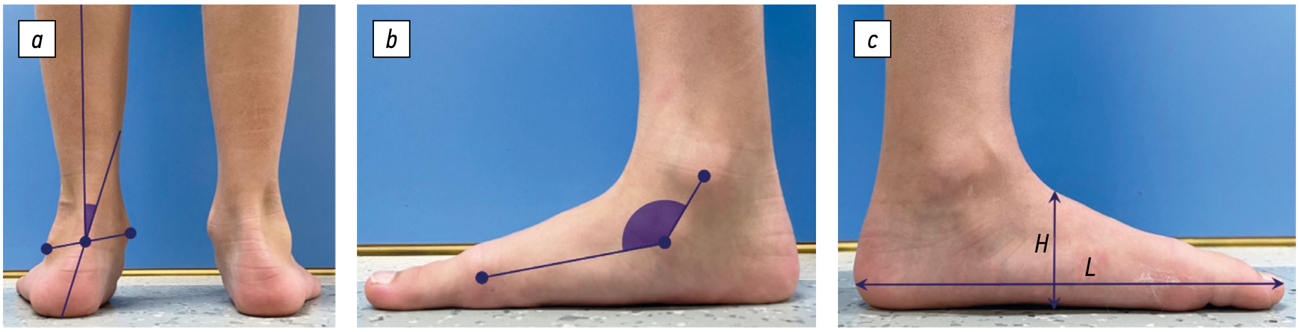

Fig. 1. Method for assessing the foot shape, including measuring the rearfoot valgus (*a*), angle of the longitudinal arch of the foot (Dahle angle) (*b*), and Friedland index (*c*)

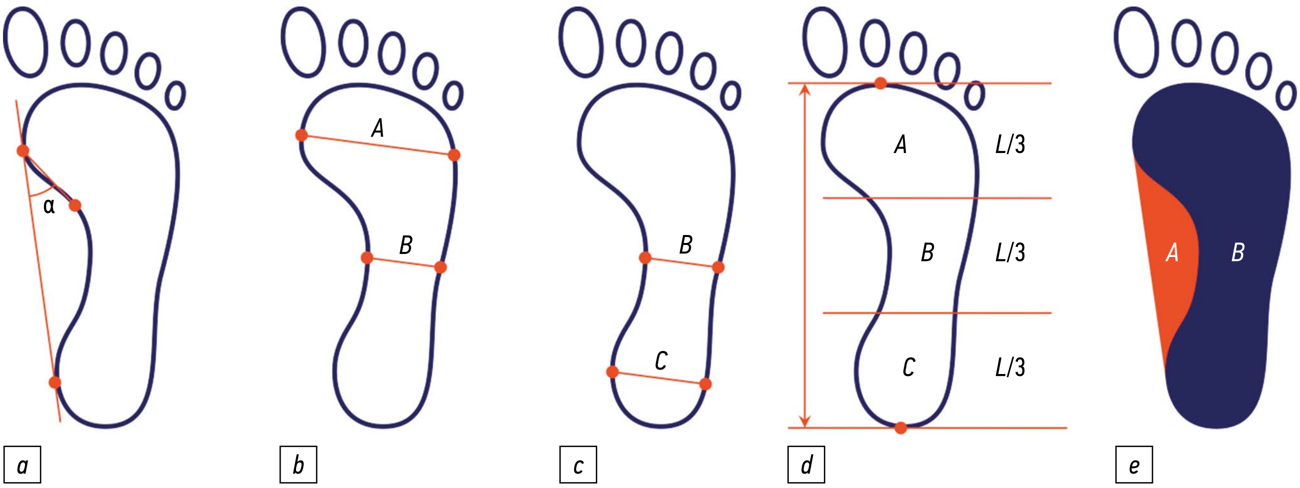

Fig. 2. Plantogram analysis techniques: *a,* Schwartz, and Clarke angle; *b,* Chippaux–Smirak index; *c,* Staheli index; *d,* Cavanagh, and Rodgers index; *e,* Irwin index

The Chippaux–Smirak index was calculated by the ratio of the anemia area width in the midfoot and forefoot, *B/A* × 100%. The Staheli index was calculated by the ratio of the width of the anemia area in the midfoot and rearfoot, *B/C* × 100% (Fig. 2*b, c*) [8].

The Cavanagh and Rodgers index was equal to the ratio of the area of the midfoot to the area of the entire footprint, excluding toe imprints, *SB/SA* × *SB* × *SC* [8]. The Irwin index was determined as the ratio of the area of the medial unloaded edge of the foot to the area of the anemia site, excluding footprints, *SA/SB* (Fig. 2*d, e*) [7].

Weasis v. 4.0.1 software package was used for graphical image processing (angulometry and calculation of distances and areas), and IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA) was used for statistical data processing. The data obtained were processed using nonparametric methods of statistical analysis, including descriptive and correlation statistics [$CI_{95\%}$].

Descriptive statistics data of the studied parameters are presented in Table 1.

According to Table 1, the width of the interquartile range for the studied attributes was not high, and for most parameters (except for the bodyweight, Irwin index, and rearfoot valgus), the coefficient of variation did not exceed 33%, which indicates sample homogeneity. However, an insignificant degree of data diffusion (coefficient of variation <10%) was noted for the Friedland index and clinical angle of the longitudinal arch, which indicates the patient homogeneity according to the main clinical criteria (degree of foot flattening).

RESULTS

The results of the correlation analysis are presented in Table 2.

As shown in Table 2, for the studied plantographic parameters, no moderate, and strong correlations with the clinical parameters analyzed were established. In addition to the expected strong correlations between age, bodyweight, and height, the largest number of statistically

Table 1. Descriptive statistics of the parameters analyzed

Parameter	M (Q_1; Q_3)	Coefficient of variation, %	*n*
Age	8 (9; 11)	23.4	152
Bodyweight	37.5 (31; 46)	33.9	152
Height	132 (140; 150)	10.4	152
Valgus of the rearfoot	11.85 (9.1; 14)	32.6	152
Dahle angle	142.95 (137.43; 148)	5.3	152
Friedland index	29 (26.9; 30.78)	8.6	152
Schwartz and Clarke angle	49 (43.13; 53)	24.7	152
Chippaux–Smirak index	36.8 (31.15; 41.83)	29.9	152
Staheli index	63.6 (53.33; 71.38)	30.8	152
Cavanagh and Rodgers index	24.05 (22.03; 25.59)	17.1	152
Irwin index	22.9 (19.35; 26.58)	36.8	152

Note: M (Q_1; Q_3), median (1st and 3rd quartiles); *n*, number of cases.

Table 2. Correlation matrix of the studied parameters (Spearman coefficient)

Parameters	Age	Weight	Height	Valgus	Dahle angle	Friedland index	Schwartz and Clarke angle	Chippaux–Smirak index	Staheli index	Cavanagh and Rodgers index	Irwin index
Age	1	**0.68**	**0.85**	–0.00	–0.36	–0.44	–0.09	–0.07	–0.04	–0.02	–0.02
Weight	0.68	1	**0.81**	–0.03	–0.23	–0.35	0.04	0.15	0.22	0.22	–0.10
Height	0.85	0.81	1	–0.00	–0.32	–0.47	–0.01	–0.05	–0.01	–0.03	0.01
Valgus	–0.00	–0.03	–0.00	1	–0.12	–0.25	–0.13	–0.05	–0.20	–0.01	–0.07
Dahle angle	–0.36	–0.23	–0.32	–0.12	1	**0.56**	0.20	–0.22	–0.10	–0.27	0.25
Friedland index	–0.44	–0.35	–0.47	–0.25	0.56	1	0.12	–0.29	–0.16	–0.27	0.23
Schwartz and Clarke angle	–0.09	0.04	–0.01	–0.13	0.20	0.12	1	–0.25	–0.22	–0.24	**0.53**
Chippaux–Smirak index	–0.07	0.15	–0.05	–0.05	–0.22	–0.29	–0.25	1	**0.86**	**0.89**	**–0.65**
Staheli index	–0.04	0.22	–0.01	–0.20	–0.10	–0.16	–0.22	0.86	1	**0.81**	**–0.52**
Cavanagh and Rodgers index	–0.02	0.22	–0.03	–0.01	–0.27	–0.27	–0.24	0.89	0.81	1	**–0.66**
Irwin index	–0.02	–0.10	0.01	–0.07	0.25	0.23	0.53	–0.65	–0.52	–0.66	1

Note: Moderate and strong correlations are marked in bold. [light grey] — correlation is significant at the level of 0.05 (two-tailed); [dark grey] — correlation is significant at the level of 0.01 (two-tailed).

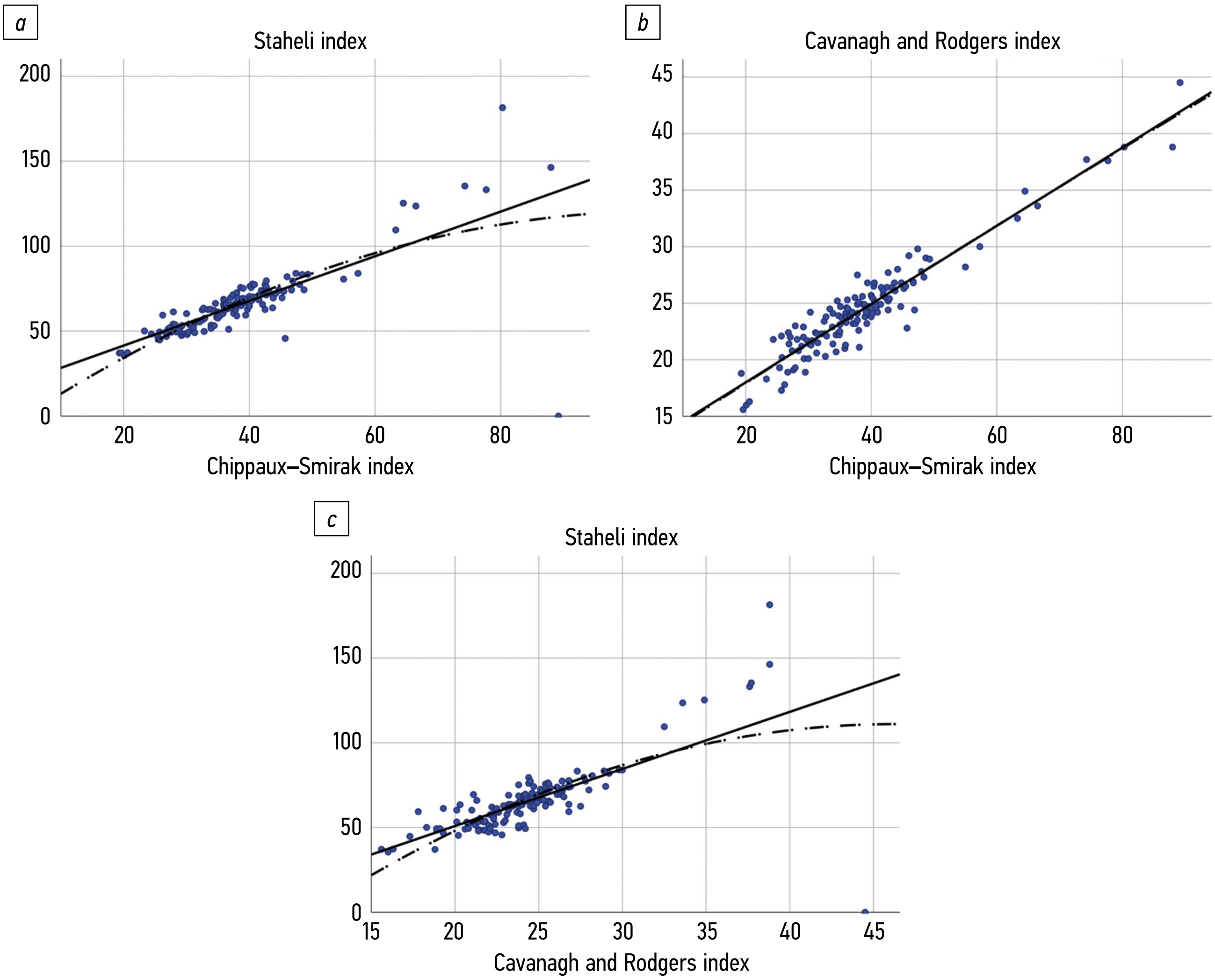

Fig. 3. Graphs of regression models between plantographic indices with strong correlations

significant moderate and strong correlations with other plantographic parameters was revealed for indices that included the anemia area on the plantogram to the footprint area (Irwin index and Cavanagh and Rodgers index). In the range of the plantographic indicators characterizing linear and angular values, the Chippaux–Smirak index showed statistically significant moderate and strong correlations.

To determine the nature of strong correlations between plantographic parameters, a regression analysis was performed, and its graphs are presented in Fig. 3.

According to Fig. 3, the nature of the relationship between the studied parameters approaches to the linear regression model (straight line on the graphs), and the graphs of the quadratic regression model (dotted line on the graphs) differ slightly from the linear one when paired with the Staheli index (Fig. 3*a, c*). Moreover, for the pair of attributes "Cavanagh and Rodgers index–Chippaux–Smirak index," the graph of the quadratic regression model coincides completely with the graph of the linear regression model, which characterizes this relationship as linear. The range of deviations of values from the graphs of the regression models for attributes paired with the Staheli index (Fig. 3*a, c*) enables these models to describe the relationship between the attributes with a lesser degree of significance [the coefficient of determination (R^2) for pairs with the Staheli index did not exceed 0.58]. In addition, for the values of paired indices "Cavanagh and Rodgers index–Chippaux–Smirak index," no significant deviation from the regression model plot was noted, which enables us to describe their mutual influence with a high degree of significance ($R^2 = 0.90$).

DISCUSSION

Plantographic indices can be angulometric, linear, and planar/area indices. Geometrically, angular indices are the least accurate because the angle is constructed from three points, which, in the case of an irregularly shaped figure, does not always enable us to characterize accurately its shape. Linear indices are more accurate than angulometric indices; however, they also cannot always characterize the area of the anemia site to the area of the entire footprint. Planar indices revealed the maximum reliability because they enable us to calculate accurately the loaded and unloaded parts of the foot. Based on the data obtained, planar indices (Cavanagh and Rodgers index and Irwin index) are the most informative for diagnosing platypodia using plantography, which help determine most accurately which part of the plantar surface of the foot is under load (anemia area). Nevertheless, the wide application of these indices is quite difficult because of the complexity of calculating footprint areas. However, given the strong positive linear relationship between the Cavanagh and Rodgers index and the Chippaux–Smirak index, which explains 90% of the cases ($R^2 = 0.90$), data obtained from the calculation of the Chippaux–Smirak index can be interpolated to the Cavanagh and Rodgers index. Thus, among the studied linear and angular plantographic indices, the Chippaux–Smirak index is the closest to planar ones.

The diagnostics of platypodia is challenging. Platypodia in pediatric patients at a certain age can often be considered a variant of the normal foot. However, many factors influence the development of pathological forms of platypodia [9–11]. Platypodia do not always lead to functional disorders and pain syndrome in both the foot and other parts of the musculoskeletal system [3]. Various criteria do not enable us to draw a precise boundary between variants of the foot shape. When considering various evaluation criteria, the incidence of platypodia naturally changes, which determines the need to unify the diagnostic criteria and their complex application, which requires the use of special scales and indices, e.g., FPI and specialized questionnaires [12].

CONCLUSION

In the clinical study, the plantographic criteria for the foot shape showed weak correlation with the main criteria characterizing the foot shape (rearfoot valgus, clinical angle of the longitudinal arch of the foot, and Friedland index), which does not allow interpolating the plantography data to the clinical evaluation data of the foot shape. Among plantographic angles and indices analyzed, indices characterizing the anemia site on the plantogram (Cavanagh and Rodgers index, Irwin index) and the Chippaux–Smirak index showed statistically significant moderate and strong correlations with other indices, which make them more useful in assessing the foot shape according to the plantogram.

ADDITIONAL INFORMATION

Funding. The study had no external funding.

Conflicts of interest. The authors declare no conflicts of interest.

Ethical considerations. The study was approved by the local ethical committee of the H.I. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery of the Ministry of Health of Russia, Minutes of the Meeting No. 21-1 of 01/18/2021.

Parents of the students provided informed voluntary consent for the examination of pediatric patients and participation in a scientific study.

Author contributions. *A.V. Sapogovskiy* created the study design and the database, collected the data, enrolled the patients in the database, analyzed the results, and wrote the text of the article. *A.V. Ovechkina* controlled the implementation of the study and edited the text of the article. *I.A. Abramov, A.I. Shubina* collected the data and enrolled the patients in the database. *O.E. Agranovich* edited the article text. *T.G. Budkevich* obtained the informed voluntary consent from the parents of students for the examination of pediatric patients and participation in scientific research.

All authors made a significant contribution to the study and preparation of the article, read, and approved the final version before its publication.

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