Check for updates

УДК 617.586-007.58-07:614.1
https://doi.org/10.17816/PTORS7241-50

THE VARIABILITY OF THE FLATFOOT FREQUENCY DEPENDING ON THE DIAGNOSTIC CRITERIA AND THE METHOD OF STATISTICAL ANALYSIS

© ***V.M. Kenis[1], A.Ju. Dimitrieva[2], A.V. Sapogovskiy[1]***

[1] The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia;
[2] North-Western State Medical University named after I.I. Mechnikov, Saint Petersburg, Russia

Received: 27.03.2019 Revised: 27.05.2019 Accepted: 06.06.2019

Background. Flatfoot frequency in children varies from 0.6% to 77.9%. This wide-range data is associated with lack of uniform diagnostic criteria and method of statistical analysis.

Aim. This study aimed to demonstrate the variability in flatfoot frequency in the same population using different indices of footprint and methods of statistical analysis.

Material and methods. This study included 317 school-age children. Children with orthopedic and foot pathology were excluded. The main evaluation methods were clinical examination, computer plantography with footprint index calculation (Staheli index, Chippaux–Smirak index, Clarke's angle, podometric index, arch height index), and statistical analysis (descriptive statistics methods with Kolmogorov–Smirnov and Shapiro–Wilk criteria, data definition according to the law of normal distribution with standard deviation and quartile assessment).

Results. According to the law of normal distribution (with a double standard deviation), our study demonstrated that the flatfoot frequency using the plantar footprint indices varies from 1.6% to 4.8% in 7–17-year-old children and using the medial footprint indices, from 1.28% to 2.8% in the same age. Quartile assessment method showed a flatfoot frequency of 5.85%–28.33% with plantar foot indices and 5.7%–15.43% with medial footprint indices.

Conclusion. The different plantographic indices and methods of statistical analysis demonstrated that the frequency of a flattened longitudinal arch of the feet in a population may differ significantly. Thus, the frequency of flatfoot determined on the basis of indices calculated on the medial footprint is 1.7–1.8 times lower than that determined on the plantar footprint. In addition, the frequency of flatfoot is 5.5–5.9 times lower than that determined by the quartile assessment.

Keywords: children; flatfoot; diagnostics; plantography; statistics.

ВАРИАБЕЛЬНОСТЬ ЧАСТОТЫ ПЛОСКОСТОПИЯ В ЗАВИСИМОСТИ ОТ КРИТЕРИЕВ ДИАГНОСТИКИ И СПОСОБА СТАТИСТИЧЕСКОЙ ОБРАБОТКИ

© ***В.М. Кенис[1], А.Ю. Димитриева[2], А.В. Сапоговский[1]***

[1] ФГБУ «Научно-исследовательский детский ортопедический институт им. Г.И. Турнера» Минздрава России, Санкт-Петербург;
[2] ФГБОУ ВО «Северо-Западный государственный медицинский университет им. И.И. Мечникова» Минздрава России, Санкт-Петербург

Поступила: 27.03.2019 Одобрена: 27.05.2019 Принята: 06.06.2019

Обоснование. Частота плоскостопия у детей, по данным литературы, варьирует от 0,6 до 77,9 %. Такой широкий диапазон данных связан с отсутствием единых критериев диагностики и способа статистической обработки.

Цель — продемонстрировать вариабельность частоты плоскостопия на примере одной и той же популяции при использовании различных плантографических индексов и способов статистической обработки данных.

■ For citation: Kenis VM, Dimitrieva AJu, Sapogovskiy AV. The variability of the flatfoot frequency depending on the diagnostic criteria and the method of statistical analysis. *Pediatric Traumatology, Orthopaedics and Reconstructive Surgery*. 2019;7(2):41-50. https://doi.org/10.17816/PTORS7241-50

Материал и методы. В исследование были включены 317 детей школьного возраста. Критерием невключения было наличие у ребенка ортопедической патологии, помимо патологии стоп. Применяли следующие методы — клинический осмотр, компьютерную плантографию с расчетом индексов по подошвенной поверхности (индекс свода Staheli, индекс Chippaux-Smirak, угол Clarke's) и по медиальной поверхности стоп (подометрический индекс, индекс высоты свода (arch height index)) и статистический (методы описательной статистики с определением критериев Колмогорова – Смирнова и Шапиро – Уилка, определение принадлежности данных закону нормального распределения с расчетом стандартного отклонения, квартильный способ оценки).
Результаты. Как показало наше исследование, частота плоскостопия согласно закону нормального распределения (с удвоенным стандартным отклонением) по данным индексов, рассчитываемых по подошвенной поверхности стоп, варьирует от 1,6 до 4,8 % во всех возрастных группах (7–17 лет); на основании оценки медиальной поверхности стоп — от 1,28 до 2,8 % в том же возрасте. Согласно квартильному способу оценки у тех же детей данный показатель составлял 5,85–28,33 % в соответствии с индексами, рассчитываемыми по подошвенной поверхности, и 5,7–15,43 % — в соответствии с индексами, рассчитываемыми по медиальной поверхности стоп.
Заключение. При использовании различных плантографических индексов и способов статистической обработки данных показатель частоты уплощенного продольного свода стоп в популяции может значительно отличаться. Так, частота плоскостопия, определяемая на основании индексов, рассчитанных по медиальной поверхности стоп, в 1,7–1,8 раза ниже по сравнению с частотой плоскостопия, определяемой по подошвенной поверхности стоп. Помимо этого, частота плоскостопия, рассчитанная согласно закону нормального распределения (с удвоенным стандартным отклонением), в 5,5–5,9 раза ниже частоты плоскостопия, определяемой с помощью квартильного способа оценки.

Ключевые слова: дети; плоскостопие; диагностика; плантография; статистика.

Introduction

Flatfoot is one of the most frequent causes of visits to the pediatric orthopedist. The condition is characterized by a decrease in the height of the longitudinal arch of the foot (with or without valgus deviation of the hind foot) [1, 2]. For most children below the age of 8- or 9-years flatfoot is the physiological norm, due to the increased extensibility of the ligamentous apparatus, adipose tissue in the area of the plantar surface, and immaturity of the neuromuscular apparatus. In most individuals a gradual increase in the height of the longitudinal arch is observed during the first decade of life [3–6]. To date, the question of which criteria should be used to diagnose flatfoot remains controversial. For example, according to the literature, pediatric flatfoot incidence ranges from 0.6% to 77.9% [6–8]. Such a wide scattering of data is associated both with the anatomic variability of a child's foot during growth and with the shortcomings of the diagnostic criteria [6, 9]. Thus, in their systematic review of the literature on the diagnosis of flatfoot in children, Banwell et al. (2018) identified a need for further research due to the lack of reliability and validity of the diagnostic methods currently in use [6].

Despite the reliability of the X-ray diagnostic method, it has a significant drawback in the form of radiation exposure [10]. Another widely used method for diagnosing flatfoot is plantography. The analysis of scanned images of feet (computer plantography) allows the calculation of useful indices. Currently, the most well-known and diagnostically valuable criteria are: the Staheli index (the ratio of the length of the line drawn in the narrowest part of the midfoot print and the line drawn in the widest part of the calcaneal region) [11–13]; the Chippaux-Smirak index (the ratio of the length of the line drawn in the narrowest part of the midfoot print and the line drawn in the widest part of the footprint, at the level of the heads of the metatarsal bones) [11, 14]; Clarke's angle (the angle between the tangents drawn from the most medially located point in the tarsus region to the concave part of the longitudinal arch and to the medial surface of the calcaneal region) [14, 15]; the arch index, (the ratio of the midfoot to the length of the foot, excluding the toes) [16, 17]; the podometric index (the ratio of the tuberosity height of the navicular bone to the foot length) [18]; and the arch height index (the ratio of the longitudinal arch height and the foot length (without toes), in percent) [19]. The literature also includes some indices that are rarely used when evaluating a plantographic imprint. These are Martirosov's K-index [20], the footprint evaluation index [21], the instep index [22], and the plantar footprint index [23].

When analyzing the methods of statistical analysis used to determine flatfoot incidence, we observed significant variability. The most popular statistical estimation methods used for determining flatfoot incidence are the law of normal distribution (in the calculation of average values one to two standard deviations are taken into account) and the quartile or centile method [25] [18, 24].

Based on the information outlined above, it is possible to formulate a research hypothesis: the diagnosis of foot-arch thinning, that is, flatfoot, and the determination of flatfoot incidence in the population directly depend on the plantographic indices and the method of statistical analysis used.

The purpose of this research was to demonstrate the variability of flatfoot incidence in the same sample of the population when different plantographic indices and statistical analysis methods are used.

Materials and methods

All studies were carried out in accordance with the principles of the Helsinki Declaration of Human Rights and written consent was obtained from all parents/guardians. Using a computer, we scanned 634 feet of school-age children: 298 feet of 149 children aged from 7 to 10 years; 210 feet of 105 children aged from 11 to 13 years; and 126 feet of 63 children aged from 14 to 17 years. The survey was carried out in a school located in the Pushkin district of St. Petersburg, Russia.

The main criteria for inclusion in the study were being aged between 7 and 17 years and the absence of a diagnosed orthopedic or neurological pathology, except for flatfoot.

Computer plantography was performed using the DiasledScan instrument–hardware complex (DiaService LLC, Russia). The Staheli arch index (the ratio of the length of line 2 to the length of line 3), the Chippaux-Smirak index (the ratio of the length of line 2 to the length of line 1), and Clarke's angle (4) were calculated using scanned images of the plantar surface of the feet (Fig. 1). The parameters of the arch, as determined by the medial surface of the foot, included the subometric index (the ratio of line 1 to line 2) and the arch height index (the ratio of the length of line 4 to the length of line 3) (Fig. 2).

Statistical analysis of the data was carried out using Statistica software produced by Statsoft. The normal distribution of the data was determined using the Kolmogorov–Smirnov and Shapiro–Wilk tests.

Results

We analyzed 634 feet of children aged 7 to 17 years to calculate mean values and standard deviations (from −2σ to +2σ) of the main plantographic indices (Table 1).

The data presented in Table 1 show a trend toward age dependence of indices in the groups investigated. Thus, the average indices change in a direction that quantitatively corresponds to an increase in the height of the longitudinal arch of the foot. For example, the average value of a parameter such as the Staheli index at age 7 to 10 years is within 0.53 ± 0.115, at age 11 to 13 years is within 0.49 ± 0.12, and at age 14 to 17 years is within 0.46 ± 0.09. This indicates that the arch of children's feet forms gradually. The same trend was observed for the other indices.

To determine the incidence of flatfoot among children in the sample group, this indicator was calculated for all indices investigated, according to the parameters obtained from the statistical analysis, and is shown in Table 1. The criterion for flatfoot in this case was the value of each index that lay outside of two standard deviations, corresponding to a decrease in foot-arch height. The results of this evaluation are presented in Table 2.

As can be seen from Table 2, the percentage of children suffering from flatfoot depends on the index used, but in general we can observe a tendency toward a decreasing incidence of flattened arches with age. For example, the flatfoot incidence according to the Staheli index varies between 3.79% at age 7 to 10 years and 1.6% at age 14 to 17 years. According to the

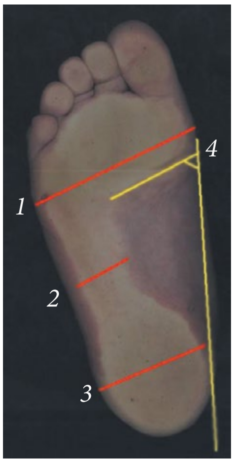

Fig. 1. Analysis of the plantar footprint (please see main text for details)

Fig. 2. Analysis of the medial surface of the foot (please see main text for details)

Table 1

Average values and standard deviations for the main plantographic indices according to the normal distribution law

Index	7–10-years-old			11–13-years-old			14–17-years-old		
	M	σ	−2σ...+2σ	*M*	σ	−2σ...+2σ	*M*	σ	−2σ...+2σ
SI R	0.53	0.115	0.3–0.76	0.49	0.12	0.25–0.73	0.46	0.09	0.28–0.64
SI L	0.54	0.13	0.28–0.8	0.5	0.11	0.28–0.72	0.46	0.09	0.28–0.64
CSI R	0.34	0.08	0.18–0.5	0.32	0.09	0.14–0.5	0.29	0.06	0.17–0.41
CSI L	0.34	0.08	0.18–0.5	0.32	0.08	0.16–0.48	0.3	0.05	0.2–0.4
PI R	12.67	3.48	5.71–19.63	13.13	3.58	5.97–20.29	14.18	3.19	7.8–20.56
PI L	12.52	3.41	5.7–19.34	13.18	3.64	5.9–20.46	13.66	3.73	6.2–21.12
CA R	52.2	7.58	37.0–67.4	53.4	7.75	37.9–68.9	58.4	5.25	47.9–68.9
CA L	52.7	6.8	39.1–66.3	53.4	6.63	40.14–66.7	56.9	3.7	49.5–64.3
AHI R	0.29	0.02	0.25–0.33	0.3	0.03	0.24–0.36	0.31	0.02	0.27–0.35
AHI L	0.29	0.02	0.25–0.33	0.3	0.03	0.24–0.36	0.31	0.03	0.25–0.37

Note. SI — Staheli index; CSI — Chippaux-Smirak index; PI — podometric index; CA — Clarke's angle; AHI — arch height index; R/L — right foot/left foot; M — arithmetic average value; σ — standard deviation.

Table 2

Flatfoot incidence (%) according to the double standard-deviation criterion

Index	Flatfoot incidence (%)		
	7–10-years-old	11–13-years-old	14–17-years-old
SI R	3.03	2.0	1.6
SI L	3.79	3.0	2.1
CSI R	3.27	3.0	1.9
CSI L	3.79	3.0	2.7
PI R	2.08	1.7	1.4
PI L	2.08	1.8	1.5
CA R	4.0	4.0	3.22
CA L	4.8	3.8	3.22
AHI R	2.8	2.7	1.28
AHI L	2.8	2.7	1.28

Note. See the abbreviations in the footnote for Table 1.

Chippaux-Smirak index, flatfoot incidence is in the range of 1.9% to 3.79%, again with a predominance at a younger age. Using Clarke's angle, the incidence of flattened arches of the feet varies from 3.22% to 4.8%. According to the subometric index, flatfoot incidence is in the range of 1.4% to 2.08%, with a predominance between the ages of 7 to 10 years. According to the arch height index, flatfoot can be diagnosed in 1.28% to 2.8% of cases. In general, the values of the longitudinal arch height calculated on the basis of the print of the medial surface of the foot are lower compared with the values calculated on the plantar surface. Nevertheless, in this case age dynamics were also noted.

Table 3

Average values and quartile deviations of the main plantographic indices

Index	7–10-years-old		11–13-years-old		14–17-years-old	
	M	IQR	*M*	IQR	*M*	IQR
SI R	0.53	0.41–0.58	0.49	0.4–0.56	0.46	0.41–0.58
SI L	0.54	0.4–0.56	0.5	0.42–0.59	0.46	0.41–0.58
CSI R	0.34	0.26–0.37	0.32	0.27–0.38	0.29	0.29–0.4
CSI L	0.34	0.26–0.37	0.32	0.29–0.4	0.3	0.3–0.42
PI R	12.67	8.11–11.36	13.13	8.9–12.46	14.18	10.2–14.3
PI L	12.52	7.67–10.74	13.18	9.16–12.83	13.66	9.8–13.72
CA R	52.2	36.5–51.1	53.4	30.2–42.2	58.4	58.2–81.5
CA L	52.7	33.8–47.27	53.4	32.3–45.2	56.9	62.2–87.2
AHI R	0.29	0.27–0.38	0.3	0.29–0.4	0.31	0.32–0.45
AHI L	0.29	0.27–0.38	0.3	0.29–0.4	0.31	0.31–0.44

Note. IQR — interquartile range (range of values between the 25th and 75th centiles). Other abbreviations are given in the footnote for Table 1.

The data obtained relating to the incidence of flatfoot reflect the methodological approach adopted, according to which the deviation of a quantitative attribute (index value) amounting to the value of two standard deviations from the average value is accepted as a preexisting pathology, since this method is used most often in biomedical research. However, the literature also offers other criteria for determining the normative values of the indices for flatfoot. To compare the results of flatfoot diagnosis by the indices studied and obtained using various methods of statistical evaluation, the average values of the calculated plantographic indicators were determined according to the quartile method (Table 3).

As shown by the data presented in Table 3, most indices indicate a trend toward increasing age dynamics in the sample group. The average values of the indices and the interquartile ranges vary in the direction corresponding to an increase in the height of the longitudinal arch of the foot.

We calculated flatfoot incidence in the sample group based on all of the indices investigated, according to their quartile distribution (Table 4).

As can be seen from Table 4, according to the Staheli index the incidence of a flattened longitudinal arch of the foot is between 9% and 28% with prevalence between the ages of 7 to 10 years. Based on the Chippaux-Smirak index, the proportion of children with flattened arches ranges from 5.75% to 25.76%, with a greater number of flattened arch cases among children of primary-school age. However, according to Clarke's angle, the incidence is between 2.27% and 3.82% among children aged 7 to 10 years and 21.3% to 21.51% among children aged 14 to 17 years. The indices of the medial surface of the foot also show a lower flatfoot incidence compared with the indices calculated based on the plantar surface. According to the subometric index, at the ages of 7 to 10, 11 to 13, and 14 to 17 years the flatfoot incidence is 14.76%, 13.28%, and 12.24%, respectively. According to the arch height index, the incidence of flattened arches of the feet varies from 5.7% to 14.49%, with prevalence among children of early school age. We did not observe any significant differences in the incidence of flattened arches between the right and left foot. However, according to all of the indices investigated, with the exception of Clarke's angle, flatfoot incidence tends to decrease with age.

Thus, in accordance with the data presented, it can be seen that the incidence of flattened foot arches depends on the index used and, to a large extent, on the method of statistical analysis used.

As an example, we present a bar graph to illustrate the variability in flatfoot incidence when determined using the Staheli index and Clarke's angle for different age groups according to the quartile evaluation

Table 4

Flatfoot incidence (%) according to the quartile distribution

Index	Flatfoot incidence (%)		
	7–10-years-old	11–13-years-old	14–17-years-old
SI R	25.76	21.0	16.13
SI L	28.33	14.0	9.68
CSI R	24.24	11.0	6.45
CSI L	25.76	9.0	5.75
PI R	15.43	14.28	13.79
PI L	14.76	13.28	12.24
CA R	3.82	3.0	21.51
CA L	2.27	2.0	21.3
AHI R	14.49	12.38	7.7
AHI L	13.15	11.7	5.7

Note. See the abbreviations in the footnote for Table 1.

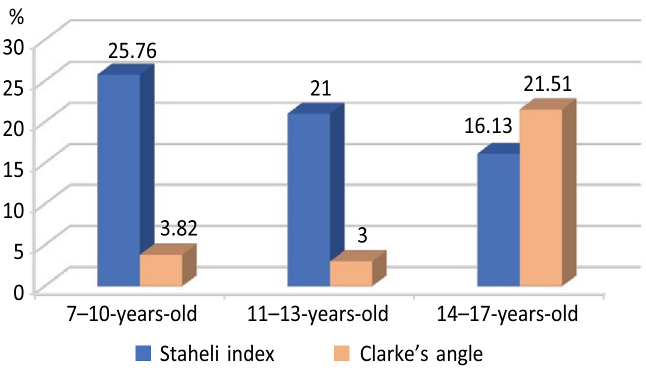

Fig. 3. Flatfoot incidence (%) according to the Staheli index and Clarke's angle for different age groups according to the quartile evaluation method

method. Flatfoot incidence among children aged from 7 to 10 years and from 11 to 13 years as calculated by the Staheli index is on average 7-times higher than flatfoot incidence among the same children as calculated using Clarke's angle. At the same time, the group aged 14 to 17 years showed the reverse trend with flatfoot incidence according to the Clarke's angle 1.3-times higher (Fig. 3).

Discussion

To date, the question of what the actual incidence of pediatric flatfoot is remains open. The variety of existing methods for assessing the shape and position of the foot leads to significant variability in the data presented in the literature. Thus, among the children of the same age, flatfoot incidence, according to different authors, ranges from 2.7% [23] to 40% [26]. This difference can be explained primarily by the method used to estimate the height of the longitudinal arch (clinical, plantographic, or radiological). The clinical method, in which the shape and position of the foot is visually assessed, is used most frequently. For example, Pfeiffer et al. used this method in their study to assess flatfoot incidence among preschool children; flatfoot incidence according to these authors ranged from 54% at age 3 years to 24% at age 6 years [27].

In addition to visual evaluation of the medial longitudinal arch height, the plantographic method of evaluation, which involves the calculation of numerous indices, is also used. García-Rodríguez et al. (1999) studied the height of the longitudinal arch of the foot of 1180 children aged 4 to 13 years using the plantographic method and found that in just 2.7% of cases the plantar footprint met the criterion of flatfoot [23]. In a similar study, Echarri et al. (2003) analyzed the feet of 1851 children in the Republic of the Congo. Flatfoot incidence was estimated using the Staheli and Chippaux-Smirak indices and Clarke's angle. For children aged from 3 to 8 years the incidence of flattened arches was 40% to 70% [26].

In addition to the variety of methods available for estimating the height of the medial longitudinal arch of the foot, there are also several possible methods for statistical analysis. Different researchers may also use different approaches to determining the boundaries of the statistical norm (for example, a multiplicity of standard deviations in the case of a normal distribution). Thus, when studying flatfoot incidence among children aged from 5 to 9 years, Hernandez et al. (2007) considered the arch of the foot to be flattened if the average value of the Staheli index exceeded two standard deviations [24]. Jaremenko (1985) adhered to a half-value of the standard deviation as his criterion for the detection of flattened arches [18].

In addition to the law of normal distribution, other methods of statistical analysis can be used to determine the frequency of occurrence of a given sign. For example, when assessing flattened foot-arch incidence, Cavanagh et al. (1987) used the quartile method, justifying this choice by the fact that the determination of the mean and standard deviation (providing that the data are normally distributed) implies a 15% incidence of flatfoot in the population (since the value of $M \pm 1\sigma$ covers approximately 70% of the population, flatfoot and high arches account for 15%) that, according to the authors, does not correspond to the the reality observed in clinical practice [25].

As shown by our study, the incidence of flattened longitudinal arches in a population can differ significantly when using different plantographic indices and different methods of statistical analysis. To analyze the available data, we used five different plantographic indices and two methods of statistical analysis. At the same time, based on the flatfoot incidence data obtained by us in the analysis of the same group of children, our results differed significantly. Thus, for example, flatfoot incidence, according to the law of normal distribution (with two standard-deviation) and based on the indices of the plantar surface of the foot, varied from 1.6% to 4.8% in all age groups (7 to 17 years); according to the evaluation of the medial surface of the foot it varied from 1.28% to 2.8% for the same age groups. According to the quartile evaluation method, for the same children, this indicator was between 5.85% and 28.33% in terms of the indices calculated based on the plantar surface, and 5.7% to 15.43% in terms of the indices calculated based on the medial surface of the foot.

Thus, the indices calculated based on the medial surface of the foot, in general, indicated a lower incidence of flatfoot among the sampled group of children. However, with respect to all indices, with the exception of the Clarke's angle as calculated using the quartile evaluation method, we observed a tendency of increasing height of the longitudinal arch of the foot with age. In our opinion, the increase depends on the width of the reference interval. According to our data, the range of averages calculated according to the law of normal distribution was shifted toward lower values (47.9°–68.9°) compared with the interquartile range (58.2°–87.2°). In his work, Clarke (1933) pointed out a flaw of the index due to the difficulty of determining it at an angle of more than 40°. This parameter therefore turned out to be unsuitable for older children [28].

In our opinion, each statistical analysis method has its own advantages and disadvantages. Thus, the advantage of using the law of normal distribution with double standard deviations is that the accuracy of the estimated average value of the indicator to be calculated is 95%. Its disadvantage is the dependence of flattened arch incidence on the value of the standard deviation, as well as the fact that the population of flatfoot incidence calculated is lower than that determined clinically.

The advantage of the quartile evaluation method is that flatfoot incidence, as calculated by this method, is close to that observed among patients during practical clinical work. Its disadvantage is its susceptibility to fluctuations depending on possible measurement errors, the variability of which may be high in the case of limited sample sizes.

Conclusion

According to our data, the incidence of flatfoot determined on the basis of the total indices calculated using the medial surface of the foot was 1.7–1.8-times lower compared with the flatfoot incidence as determined on the basis of the total indicesof the plantar surface of the foot. In addition, if the flatfoot incidence was calculated according to the law of normal distribution (with double standard-deviation) it was 5.5- to 5.9-times lower than the flatfoot incidence calculated using the quartile method of estimation.

Thus, we demonstrated the variability in flatfoot incidence by using the same sample but with different plantographic indices and different methods of statistical analysis. This confirms the hypothesis that we initially proposed. Consequently, both when evaluating data obtained from mass studies and in specific cases of diagnosing infantile flatfoot in clinical practice, it is necessary to correlate the indicators obtained with reference data available in the literature, taking into account the methodology adopted when obtaining them. All of the above emphasizes the important need for the development of a unified system for assessing the height of the medial longitudinal arch of the foot in the diagnosis of flatfoot among children, in order to avoid unnecessary conservative and surgical interventions, as well as obvious pathology considered to be the norm for the age. To summarize, we can conclude that in order to make a quantitative evaluation of foot-arch height and to determine flatfoot incidence in the population, it will first be necessary to develop uniform diagnostic criteria and a standard method for statistical analysis.

Additional information

Source of financing. The study was carried out with partial financial support from the Innovation Assistance Fund in the framework of the UMNIK program.

Conflict of interest. The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

Ethical review. The study was performed in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association and was approved by the local ethics committee of North-Western State Medical University named after I.I. Mechnikov under the Ministry of Health of Russia (Protocol No. 11 of November 1, 2017).

Legal representatives of the patients gave voluntary consent to participate in the study and for data to be published.

Contribution of the authors

V.M. Kenis supervised and participated in the development of the design and research methodology, and edited the text of the article.

A.Ju. Dimitrieva collected and processed the data, analyzed literary sources, and wrote the text of the article.

A.V. Sapogovsky edited the text of the article.

References

1. Evans AM. The paediatric flat foot and general anthropometry in 140 Australian school children aged 7–10 years. *J Foot Ankle Res*. 2011;4(1):12. https://doi.org/10.1186/1757-1146-4-12.

2. Кенис В.М., Лапкин Ю.А., Хусаинов Р.Х., Сапоговский А.В. Мобильное плоскостопие у детей (обзор литературы) // Ортопедия, травматология и восстановительная хирургия детского возраста. – 2014. – Т. 2. – № 2. – С. 44–54. [Kenis VM, Lapkin YA, Khusainov RKh, Sapogovskiy AV. Mobil'noe ploskostopie u detey (obzor literatury). *Pediatric traumatology, orthopaedics and reconstructive surgery*. 2014;2(2):44-54. (In Russ.)]. https://doi.org/10.17816/ptors2244-54.

3. Nemeth B. The diagnosis and management of common childhood orthopedic disorders. *Curr Probl Pediatr Adolesc Health Care*. 2011;41(1):2-28. https://doi.org/10.1016/j.cppeds.2010.10.004.

4. Перепелкин А.И., Мандриков В.Б., Краюшкин А.И., Атрощенко Е.С. К вопросу о формировании продольного свода стопы у детей // Волгоградский научно-медицинский журнал. – 2016. – № 1. – С. 32–36. [Perepelkin AI, Mandrikov VB, Krayushkin AI, Atroshchenko ES. To the question of the formation of the longitudinal arch of the foot in children. *Volgogradskiy nauchno-meditsinskiy zhurnal*. 2016;(1):32-36. (In Russ.)]

5. Sadeghi-Demneh E, Azadinia F, Jafarian F, et al. Flatfoot and obesity in school-age children: a cross-sectional study. *Clin Obes*. 2016;6(1):42-50. https://doi.org/10.1111/cob.12125.

6. Banwell HA, Paris ME, Mackintosh S, Williams CM. Paediatric flexible flat foot: how are we measuring it and are we getting it right? A systematic review. *J Foot Ankle Res*. 2018;11:21. https://doi.org/10.1186/s13047-018-0264-3.

7. Didia BC, Omu ET, Obuoforibo AA. The use of footprint contact index ii for classification of flat feet in a Nigerian population. *Foot Ankle*. 2016;7(5):285-289. https://doi.org/10.1177/107110078700700504.

8. Gould N, Moreland M, Alvarez R, et al. Development of the child's arch. *Foot Ankle*. 2016;9(5):241-245. https://doi.org/10.1177/107110078900900506.

9. Uden H, Scharfbillig R, Causby R. The typically developing paediatric foot: how flat should it be? A systematic review. *J Foot Ankle Res*. 2017;10(1). https://doi.org/10.1186/s13047-017-0218-1.

10. Weimar WH, Shroyer JF. Arch height index normative values of college-aged women using the arch height index measurement system. *J Am Podiatr Med Assoc*. 2013;103(3):213-217. https://doi.org/10.7547/1030213.

11. Chang CH, Chen YC, Yang WT, et al. Flatfoot diagnosis by a unique bimodal distribution of footprint index in children. *PLoS One*. 2014;9(12):e115808. https://doi.org/10.1371/journal.pone.0115808.

12. Ezema CI, Abaraogu UO, Okafor GO. Flat foot and associated factors among primary school children: A cross-sectional study. *Hong Kong Physio J*. 2014;32(1):13-20. https://doi.org/10.1016/j.hkpj.2013.05.001.

13. Staheli LT, Chew DE, Corbett M. The longitudinal arch. A survey of eight hundred and eighty-two feet in normal children and adults. *J Bone Joint Surg*. 1987;69(3):426-428. https://doi.org/10.2106/00004623-198769030-00014.

14. Chen KC, Yeh CJ, Kuo JF, et al. Footprint analysis of flatfoot in preschool-aged children. *Eur J Pediatr*. 2011;170(5):611-617. https://doi.org/10.1007/s00431-010-1330-4.

15. Pauk J, Szymul J. Differences in pediatric vertical ground reaction force between planovalgus and neutrally aligned feet. *Acta Bioeng Biomech*. 2014;16(2):95-101.

16. Galli M, Cimolin V, Rigoldi C, et al. The effects of low arched feet on foot rotation during gait in children with Down syndrome. *J Intellect Disabil Res*. 2014;58(8):758-764. https://doi.org/10.1111/jir.12087.

17. Galli M, Cimolin V, Pau M, et al. Foot pressure distribution in children with cerebral palsy while standing. *Res Dev Disabil*. 2015;41-42:52-57. https://doi.org/10.1016/j.ridd.2015.05.006.

18. Яременко Д.А. Диагностика и классификация статических деформаций стоп // Ортопедия, травматология и протезирование. – 1985. – № 11. – С. 59–67. [Yaremenko DA. Diagnostika i klassifikatsiya staticheskikh deformatsiy stop. *Ortop Travmatol Protez.* 1985;(11):59-67. (In Russ.)]

19. Drefus LC, Kedem P, Mangan SM, et al. Reliability of the arch height index as a measure of foot structure in children. *Pediatr Phys Ther*. 2017;29(1):83-88. https://doi.org/10.1097/PEP.0000000000000337.

20. Nikolaidou ME, Boudolos KD. A footprint-based approach for the rational classification of foot types in young schoolchildren. *Foot*. 2006;16(2):82-90. https://doi.org/10.1016/j.foot.2006.02.001.

21. Stavlas P, Grivas TB, Michas C, et al. The evolution of foot morphology in children between 6 and 17 years of age: a cross-sectional study based on footprints in a Mediterranean population. *J Foot Ankle Surg*. 2005;44(6):424-428. https://doi.org/10.1053/j.jfas.2005.07.023.

22. Abolarin T, Aiyegbusi A, Tella A, Akinbo S. Predictive factors for flatfoot: The role of age and footwear in children in urban and rural communities in South West Nigeria. *Foot (Edinb)*. 2011;21(4):188-192. https://doi.org/10.1016/j.foot.2011.07.002.

23. García-Rodríguez A, Martín-Jiménez F, Carnero-Varo M, et al. Flexible flat feet in children: a real problem? *Pediatrics*. 1999;103(6):e84-e84. https://doi.org/10.1542/peds.103.6.e84.

24. Hernandez AJ, Kimura LK, Laraya MHF, Fávaro E. Cálculo do índice do arco plantar de staheli e a prevalência de pés planos: estudo em 100 crianças entre 5 e 9 anos de idade. *Acta Ortop Bras*. 2007;15(2):68-71. https://doi.org/10.1590/s1413-78522007000200001.

25. Cavanagh PR, Rodgers MM. The arch index: A useful measure from footprints. *J Biomech.*1987; 20(5):547-51. https://doi.org/10.1016/0021-9290(87)90255-7.

26. Echarri JJ, Forriol F. The development in footprint morphology in 1851 Congolese children from urban and rural areas, and the relationship between this and wearing shoes. *J Pediatr Orthop B*. 2003;12(2):141-146. https://doi.org/10.1097/00009957-200303000-00012.

27. Pfeiffer M, Kotz R, Ledl T, et al. Prevalence of flat foot in preschool-aged children. *Pediatrics*. 2006;118(2):634-639. https://doi.org/10.1542/peds.2005-2126.

28. Clarke HH. An objective method of measuring the height of the longitudinal arch in foot examinations. *Res Q Am Phys Educ Assoc*. 1933;4(3):99-107.

Information about the authors

Vladimir M. Kenis — MD, PhD, D.Sc., Deputy Director for Development and International Relations, Head of the Department of Foot Pathology, Neuroorthopedics and Systemic Diseases. The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia. https://orcid.org/0000-0002-7651-8485. E-mail: kenis@mail.ru.

Владимир Маркович Кенис — д-р мед. наук, заместитель директора по развитию и внешним связям, руководитель отделения патологии стопы, нейроортопедии и системных заболеваний ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России, Санкт-Петербург. https://orcid.org/0000-0002-7651-8485. E-mail: kenis@mail.ru.

Alyona Ju. Dimitrieva — PhD Student of Chair of Traumatology and Orthopedics for Children. North-Western State Medical University named after I.I. Mechikov, Saint Petersburg, Russia. https://orcid.org/0000-0002-3610-7788. E-mail: aloyna17@mail.ru.

Andrei V. Sapogovskiy — MD, PhD, Senior Research Associate of the Department of Foot Pathology, Neuroorthopedics and Systemic Diseases. The Turner Scientific Research Institute for Children's Orthopedics, Saint Petersburg, Russia. https://orcid.org/0000-0002-5762-4477. E-mail: sapogovskiy@gmail.com.

Алена Юрьевна Димитриева — очный аспирант кафедры детской травматологии и ортопедии ФГБОУ ВО «СЗГМУ им. И.И. Мечникова» Минздрава России, Санкт-Петербург. https://orcid.org/0000-0002-3610-7788. E-mail: aloyna17@mail.ru.

Андрей Викторович Сапоговский — канд. мед. наук, старший научный сотрудник отделения патологии стопы, нейроортопедии и системных заболеваний ФГБУ «НИДОИ им. Г.И. Турнера» Минздрава России, Санкт-Петербург. https://orcid.org/0000-0002-5762-4477. E-mail: sapogovskiy@gmail.com.