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Research Article

Morphofunctional Features of the Feet in Children with Scoliosis, Depending on their Constitutional, Gender and Age Characteristics

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Abstract

In this article, we examined the anthropometric data of the feet of children with scoliosis from 3 to 12 years old. A total of 136 people of both sexes with asthenic, hypersthenic and normothermic body types, divided into four age periods (the early childhood (3-5 years), the first childhood (6-7 years), the second childhood (8-11 years) and adolescence (12 years)) were under observation The longitudinal arch of the foot in children was detected by means of computerized plantography using K-coefficient. All children were subdivided into 3 somatotypes (hypersthenic, normosthenic and asthenic). The results of the study show that in the period of early childhood, the K coefficient has the same value in both boys and girls. During the first childhood in asthenics, as well as in hypersthenic, the K coefficient decreases both in girls and boys by the same amount. The K-coefficient was increased at the boys of all somatotypes in the period of the second childhood in comparison with the previous period and becomes slightly higher than this indicator of the girls. In this period the K-coefficient was increased at the girls of normosthenic ($p<0,05$) and hypersthenic ($p>0,05$) somatotypes, but was decreased in asthenics ($p>0,05$). In teenagers the K-coefficient continues to increase at the persons of the both sexes of all types of the somatotypes in comparison with the previous period.

Keywords: *Scoliosis, children, longitudinal arch of foot, computerized plantography, linear parameters of foot.*

Introduction

The spine serves as a support for the muscles and internal organs of a person. But now very often there are disorders of the musculoskeletal system, such as flat feet and various scoliosis. The lowering of the arches of the foot both across and along indicates flat feet - a pathology that changes the shape of the human foot and violates its cushioning properties [1].

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The study of the structure and function of the foot of children, both in normal and pathological conditions, is still a difficult task. The foot is the most important structural segment of the human musculoskeletal system, providing its static-locomotor function, and represents a complete morphofunctional object on which the motor function of a person depends (2, 3). The most important design feature of the human foot is its vaulted structure. In the longitudinal direction, the foot forms a vault of various geometric configurations: in the anterior section along a parabola, and in the posterior section along arcs of circles of different radii. The points of support of the foot are: the heel hillock and the heads of the metatarsal bones, mainly the first and fifth. In humans, due to the activity of the muscles, the points of support can change. In the transverse direction, the arch represents a hyperbola [4]. Features of its anatomical structure of the bone, ligamentous and muscular apparatus determine the spring, balancing and locomotor functions. N. F. Averyanova-Yazykova (2002, 2005) distinguishes five longitudinal and one transverse arch of the foot [5]. All the longitudinal ones start from a single point on the calcaneus, and then the lines of the arches are directed forward along the tarsal bones to the five metatarsals and to the corresponding phalanges. The components of the arch of the foot are ligaments, aponeuroses and muscles. The role of the muscular environment in the formation of the arches is determined by the fact that when they contract, the base of the arches is held, and also, attaching to the aponeurosis and ligaments, the muscles stretch them, providing additional strength. It is due to the arches of the foot, the elastic vibrations of which protect the body from rough shocks and concussions when walking and jumping.

There are a large number of methods for diagnosing the condition of the arches of the foot (clinical, graphic, radiographic, etc.), which are designed to solve this problem, but none of them can answer all the questions. Improving these methods with the involvement of all the achievements of scientific and technological progress is an urgent problem at the present time.
Among the various deformities of the lower extremities, the most common is flat feet, characterized by flattening of the longitudinal and transverse arches of the foot in combination with rotation around the longitudinal axis, as well as its withdrawal. The predominance of flat feet in the structure of foot pathology indicates the need to improve the methods of diagnosing this condition. Early diagnosis of flat feet is very important when conducting dispensary examinations of children in preschool and school educational institutions, for the timely prediction of health disorders.

From the available literature sources, it is known that the longitudinal arch of the foot and its spring function in children are formed by the end of the 4th year of life [6]. However, we assume that the longitudinal arch of the foot continues to form in subsequent age periods, including adolescence.

Objective: to determine the dynamics of the anatomical parameters of the foot in the formation of its longitudinal arch in children.

Materials and Methods

We have worked on the creation of a research method using a software and hardware complex to assess the condition of the foot.

Many of the existing methods of foot examination are expensive and quite time-consuming. Therefore, there is a need for a qualitative change in the most "popular" and simple, from a technical point of view, methods, taking into account the specifics of the work of doctors, teachers and educators, which will facilitate the solution of the tasks set. To perform plantography, we have developed and successfully applied a new method for diagnosing flat feet, based on the analysis of foot images obtained using an upgraded software and hardware complex for assessing the morphofunctional state of the human body (digital 3D photometrograph).

The image of the foot was obtained using a computer photoplantograph using the technology of projection transposition photometry, the body of which is reinforced and able to withstand the weight of the human body. The measurement is performed in a standing position. The subject puts both feet on the surface of the 3D computer photoplantograph first, and then alternately each one separately, the object (foot) is photographed sequentially from all sides (front, back, sides, top), which allows you to get the required number (6 pcs.) of rating images with minimal preliminary positional and manual marking.

The developed diagnostic program analyzes the obtained images of the foot by the graphoanalytic method, which is widely used in medical practice. In this case, the program selects several key points on the image of the foot, and then calculates the distances between the points, as well as the angles by which the degree of longitudinal and transverse flat feet is determined. The diagnostic results are displayed on the screen and can be exported to the Microsoft Word word processor for later saving and printing.

The image of the foot was displayed on a computer monitor, and its processing was carried out using the graph-calculation method. A variety of indicators were calculated that characterize the state of the anterior middle and posterior parts of the foot, including the angle of deviation of 1 and 5 fingers, the K coefficient, the heel angle, after which the program issued an individual report on each foot of the child.

In our work, we conducted a study of the morphofunctional state of the feet in humans at different age periods. In modern science, there is no generally accepted classification of the periods of human growth and development and their age limits. The age periodization was based on a scheme that has a significant distribution, and proposed by the VII Symposium on the problem of age-related anatomy, physiology and biochemistry in Moscow (1965), convened by the Institute of Physiology of Children and Adolescents of the USSR Academy of Medical Sciences.

A total of 136 people of both sexes of asthenic, hypersthenic and normosthenic body types in four age periods: early childhood (3-5 years), first childhood (6-7 years), second childhood (8-11 years) and adolescence (12 years) were monitored. In the course of the study, a population-centric approach was used to identify body types. From the literature, a method is known for determining the type of constitution based on the measurement of such indicators as body weight, height and chest circumference. Tables are compiled in which the subjects are divided into groups depending on their age, and two subgroups are distinguished in each age group: boys and girls. Within each subgroup, the Pinier index is determined for each child by the equation ($J=L-(P+T)$, where L is body length (cm), P is body weight (kg), and T is chest circumference (cm)) [7]. The average value of the Pinier index for each age and gender is determined, after which the mean square (sigmal) deviation is determined. The variation series of a feature (the Pinier index) is divided into three categories based on the square deviation (σ). At the same time, if the Pinier index indicator fits into the value $M \pm 1\sigma$, then the child belongs to the normosthenic body type (the first category). If the value of this index is less than $M-1\sigma$, the child's physique is assessed as hypersthenic (second category), whereas if the Pinier index is more than $M+1\sigma$, the child's physique is assessed as asthenic (third category). If the value of this index is less than $M-1\sigma$, the child's physique is assessed as hypersthenic (second category), whereas if the Pinier index is more than $M+1\sigma$, the child's physique is assessed as asthenic (third category).

The linear (length, width, height) and angular (angles I, V of the toes and heel angle) parameters of the foot were determined. We also studied changes in the support function (based on changes in the parameters of the surface of the entire foot and its three divisions) and the spring function (K coefficient, Stritter, Weisflogg indices) of the foot.

The coefficient K, which determines the state of the middle part of the longitudinal arch of the foot, was calculated by the formula: K=x/y, where x is the width of the painted part of the print along the line VV’, y is the width of the outer part of the longitudinal arch of the foot.

At K from 0 to 0.5-the foot is hollow, at K from 0.51 to 1.10-the foot with a normal arch, at K from 1.11 to 1.20-the foot with a reduced arch, at K from 1.21 to 1.30 – the 1st degree of flat feet, at K from 1.31 to 1.50 – the 2nd degree of flat feet, at K from 1.50 and above - the 3rd degree of flat feet.

Heel angle HC'K, determines the condition of the posterior part of the longitudinal arch of the foot. If the angle HC'K is greater than or equal to 5°, the condition of the foot is normal. If the angle of the HC'K is less than 5° - the stop is flat.

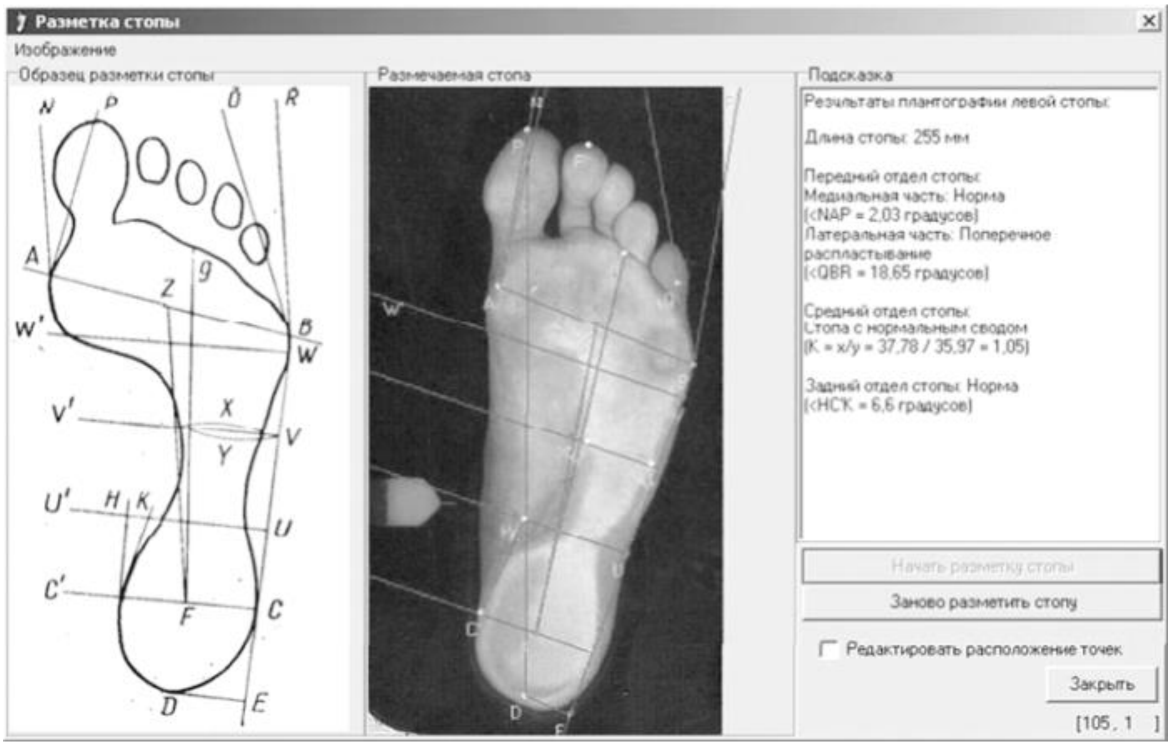

Figure 1. The Window for Calculating the Anatomical and Functional Parameters of the Foot

The length of the anterior and posterior sections, cut off by the lines WW' and UU', respectively, also determines the degree of flattening of the top. If these sections are elongated, it means that the foot is flat even in the normal state of the middle section.

The method presented above for determining the state of the foot, identifying and evaluating possible manifestations of transverse and longitudinal flat feet was the basis for the computer diagnostic method used in this work. Figure 1 shows the program window for calculating the morphofunctional state of the foot.

Analyzing the print obtained on the monitor screen, it becomes clearly noticeable that the surface of the foot adjacent to the scanner surface looks lighter in the image. Thus, there is enough information in the image of the foot to get the area of the surface of the foot adjacent to the scanner. To determine the area, the program uses the definition of the foot contour and counting the points lying inside the contour [8, 9]. Each of the sections of the supporting surface of the foot is highlighted by the program in its own color.

Excel in the Windows XP environment. The following average indicators of the foot were analyzed: the total length, as well as the length of its anterior, middle and posterior sections; the angle of deviation of 1 and 5 fingers; the K coefficient, which determines the state of the longitudinal arch in its middle section; the heel angle HC'K, which indicates the state of the longitudinal arch in its posterior section; the total area, as well as the areas of its anterior, middle and posterior sections.

Table 1

Dynamics of the K Coefficient and the Rate of its Growth (Decline) Depending on the Period of Ontogenesis

Age, unit of measurement	**Asthenics**		**Hypersthenics**		**Normosthenics**	
	G	*B*	*G*	*B*	*G*	*B*
3-5 years (absolute value)	0,86	0,86	0,86	0,86	0,88	0,88
6-7 years (absolute value)	0,75	0,75	0,75	0,75	0,7	0,69
Growth (decline) rate in %	87,21	87,2	87,21	87,2	79,55	78,4
	0,72	0,78	0,82	0,83	0,78	0,85
8-11 years (absolute value)	83,72	90,7	95,35	96,5	88,64	96,6
Growth (decline) rate in %	0,78	0,92	0,95	0,94	0,82	0,87
	90,7	107,0	110,47	109,3	93,18	98,9

The analysis of the dynamic (time) series was reduced to the calculation of the following indicators: absolute growth (or decrease); growth rate (or decrease); growth rate. The absolute increase is the difference between the next level and the previous one. The growth rate is the ratio of the next level to the previous one, multiplied by 100%. The growth rate is the ratio of the absolute increase (decrease) to the previous level, multiplied by 100%.

Results and Discussion

The first interesting fact that drew attention to itself when analyzing the obtained quantitative data was the obvious unevenness of plantographic age-related changes in almost all indicators of the state of the feet. These facts were considered separately from three positions:

1) Unevenness in time — the different rate of change in indicators (growth) over the years;
2) Unevenness by department-differences in the timing and intensity of gains by department of the foot;

3) Lateral dissymmetry-differences in the rate of plantographic changes of the left and right feet.

Thus, when considering the dynamics of changes in three integral indicators of foot size (height H, length L, and total surface area S), heterogeneities were determined by about 3.2 — 3.4% annually up to 13 years, when the increase in total foot length slowed down to 1 of their increase. The total length of the foot L increased between 7 and 8 years by 2.3%, by 9 years-by 8.3 %.

The average annual increase in the height of the foot H was 62 % by 8 years, 7 % by 9 years, and between 10 and 12 years H ranged from 58.2-60.6 mm with almost no dynamics.
The maximum increase in the area of effective foot support was observed between 8 and 9 years (15.9 %). Subsequently, the area of effective foot support (S) fluctuated around values from 40 to 48 cm^2, again increasing by 4.2% by the age of 12 years of the child's life.
Thus, the data obtained indicate that the formation of feet in children during their life from 3 to 12 years in time occurs unevenly.

The regular increase in the linear parameters of the foot in the period from 3-12 years is uneven in the age of children and in the departments of the foot: the maximum annual changes are observed in 7-9 years in the anterior part of the foot (phalanges of the fingers) and in 12 years — in all its departments, but with a predominance of an increase in the middle parts of the foot (metatarsal bones) and its height (the distance between the horizontal plane and the navicular bone) by 11.3 % [10, 11].

In the period from 8 to 12 years, there is a tendency to lateral dissymmetry: the size of the left foot increases more intensively in comparison with the right. In boys, the left foot increases from 8 years — 203.73 ± 1.26, from 12 years (239.31 ± 2.61) mm; the right foot— 203,86 ± 1,87 — (239,99 ± 2,59) mm.

In girls, the left foot increases from 8 years — 203.11 ± 2.51, from 12 years (237.89 ± 2.42) mm; the right foot— (202,41 ± 1,98) — (237,57 ± 2,28) mm.

Uneven development of various parts of the foot is accompanied by an annual increase in the angles of deviation (between the axis of the finger and the line connecting the heads of the I and V metatarsal bones) I and V toes by 2.3-1.5 degrees and a decrease in the heel angle by about 3.2-3.4 degrees annually until 12 years, when the increase in the total length of the foot slows down to 1% annually. The period of change of growth vectors from the predominant increase in the anterior parts of the foot to the increase in the middle and posterior parts falls on the age period of 10-12 years.

The area of contact of the plantar surface of the foot with the horizontal surface increases in the interval of 8-9 years by 15.9%, the area of the right foot is less than the area of the left in both sexes [in boys, the left foot is (44.75 ± 1.48) cm^2, the right foot is (42.03 ± 1.89) cm^2; in girls, the left foot is (43.34 ± 2.82) cm^2, the right foot is (42.18 ± 2.82) cm^2], increasing by 4.2% by the age of 12, while the area of the right foot is less than the area of the left foot in both sexes [boys left foot — (47.81 ± 1.56) cm^2, right foot — (51.89 ± 1.01) cm^2; girls left foot — (45.36 ± 2.02) cm^2, right foot — (47.31 ± 1.96) cm^2].

Children with a developing dolichomorphic physique are characterized by a more pronounced deviation of the I finger, reduction of the V with a slowdown in the elevation of the longitudinal arch of the foot, which can be considered as a transitional variant from the norm to a clinically diagnosed flat foot [2]. Children with an emerging brachymorphic physique are characterized by a relative delay in the outward deviation of the I finger and the reduction of the V finger (more pronounced for the right foot), a less intense outward deviation of the calcaneus with age, and a relatively more intense formation of the longitudinal arch of the foot.

For children with the emerging dolichomorphic type, the main variants of the foot structure associated with the emerging somatotype and the child's sex can be identified from the age of 12. The mesomorphic type is characterized by the most uniform overcoming of the critical period in the formation of the foot at the age of 12 years and the practical absence of extreme variants of the structure of the foot.

According to our observations, in the period of early childhood, the K coefficient has the same value in both boys and girls. During the first childhood in asthenics, as well as in hypersthenics, the K coefficient decreases both in girls and boys by the same amount (Table 1). It decreases more significantly in normosthenics. The differences between these neighboring age groups are statistically significant.

For children with the emerging dolichomorphic type, the main variants of the foot structure associated with the emerging somatotype and the child's sex can be identified from the age of 12. The mesomorphic type is characterized by the most uniform overcoming of the critical period in the formation of the foot at the age of 12 years, and similar changes were observed by Chinese researchers A. K. Leung et al. (2005), who studied the contact pressure coefficient, calculated as the ratio of the loaded surface of the middle part of the foot to its total loaded surface without taking into account the fingers [12].

The coefficient considered by them decreased from 4 to 10 years of life, then remained unchanged until 12 years, and subsequently increased to 15-16 years. T. Cappello and K. M. Song (1998) believe that at birth children have a pliable form of physiological flat feet, and normalization of the longitudinal arch of the arch of the foot occurs in the first decade of life or later [13].

According to our data, the K coefficient in the period of second childhood in boys of all somatotypes increases in comparison with the previous period and becomes slightly higher than this indicator for girls. Differences between neighboring age groups are statistically significant only for normosthenics. In girls, this coefficient increases in normosthenics ($p<0.05$) and hypersthenics ($p>0.05$), but decreases in asthenics ($p>0.05$).

In adolescence, the K coefficient continues to increase in comparison with the previous period in both sexes (in normosthenics, hypersthenics and asthenics): in girls, by 4.54 ($p<0.05$), 15 ($p<0.05$) and 6.98% ($p>0.05$), respectively, and in boys – by 2.3, 12.8 and 16.3% ($p<0.05$), respectively, remaining the largest among them. This is also indicated in the study of P.S. Igbigbi et al. (2005), who found the presence of a higher index of the arch of the foot in men compared to women [14].

The value of the K coefficient in the asthenic body type in adolescents exceeds this value of the period of early childhood, which indicates a significant decrease in the longitudinal arch of the foot. Consequently, we see that the formation of the longitudinal arch of the foot, and hence its spring function, is adversely affected by belonging to the asthenic body type in men and to the hypersthenic body type in women.

Conclusion

Throughout the entire period of early childhood, the formation of the longitudinal arch of the foot continues, as evidenced by a decrease in the K coefficient ($p<0.05$). Starting from the period of second childhood, boys have higher indicators of the K coefficient, indicating a lower location of the longitudinal arch of the foot, compared to girls. The adolescent period is characterized by the ontogenetic completion of the formation of the longitudinal arch of the foot, its most pronounced somatotypic and gender differences. The obtained morphometric information contributes to the timely detection of the occurrence of longitudinal and transverse flat feet in children with scoliosis, provides the choice of the correct conservative and surgical treatment, design and manufacture of corrective dentures.

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