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COMPUTER PLANTOGRAPHY AS A DIAGNOSTIC METHOD FOR CONGENITAL CLUBFOOT IN CHILDREN

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Examination of the anatomical and functional states of feet in children with congenital clubfoot is an urgent priority that has significant theoretical and practical value. The purpose of the study was to investigate the morphological and functional parameters of the foot to evaluate the degree of affection of its support function in congenital clubfoot using the technique of computer plantography. Plantographic characteristics of the feet were determined in 65 children with this disorder, aged from 4 to 16 years. The mathematical processing of plantographic characteristics of the feet was performed using the following; the calcaneo-axial and the calcaneo-metatarsal angles and the angle between the outer tangents on the basis of what were defined border values of angles, depending on the severity of foot deformities. The proposed method of analysis of the foot plantogram is statistically significant for the classification of congenital clubfoot with different degrees of severity: mild, moderate, and severe. This technique is an addition to the clinical and X-ray methods and allows the evaluation of functional support for the feet.

Keywords: foot, clubfoot, plantography.

Introduction

Congenital clubfoot is one of the most challenging and widespread foot abnormalities in children. The complexity and variability of the anatomical organization of a foot affected by congenital clubfoot together with impaired support function demands the need for complex approaches for its diagnosis and timely correction. This is vital for the prevention of the child's locomotor system disorder progression. The assessment of the affected foot's functional parameters is crucial because this primarily concerns the support function [1]. Data on the correlation between the support function of a foot and its geometric features is relevant in the choice between conservative or surgical treatment as well as in the design and manufacturing of corrective devices [2].

One must consider that in the case of congenital clubfoot, it is not always possible to draw a distinction between the initial stages of foot deformity and numerous variations of normal feet because of a colossal variety of foot forms, lack of clear understanding of the anatomical and functional norms of the foot, the vague definition of foot insufficiency, and the complexity of registration of the foot's functional parameters that affect walking [3]. Thus, the definition of individual typological changeability of intact foot morphology and function remains relevant. A screening examination of the morphofunctional condition of the foot requires high-precision modern hardware and software systems that provide a visualization of the required parameters of the foot and feature significant capacity [4]. The computer plantography method [5] has been recently used to diagnose foot conditions. It records static and kinetostatic foot deformities in the standing position. Computer plantography provides an objective perspective on the severity of deformity and not only allows the reproduction of foot loading boundary malformation but also shows load distribution in different regions of the foot.

The literature provides various methods for the objective assessment of foot condition using plantograms. However, most of these methods are designed to assess flatfoot, while a universal method of plantographic assessment of clubfoot is yet to be developed. Thus, there is an urgent need for the examination of anatomofunctional foot conditions in children diagnosed with congenital clubfoot using computer plantography. This observation served as the motive for this research.

Purpose of the research

This research aimed to examine the morphofunctional parameters of the foot in children diagnosed with congenital clubfoot to assess the severity of support function impairment according to the structural and functional disorders of the foot.

Materials and methods

To assess the functional disorders of the foot in patients diagnosed with congenital clubfoot, plantographic characteristics were determined in 65 children aged 4–16 years. Forty-eight of the children had ambilateral foot affection and 17 had unilateral affection (7 cases on the right and 10 cases on the left). Thus, 113 feet with varying degrees of clubfoot severity (mild, moderate, and severe) were examined. The control group included 23 healthy children (46 feet) of the same age who had their feet examined in the same manner to determine normal plantographic characteristics. The examination of the support function of the foot was performed using stationary clinical equipment (Podoscan hardware and software foot deformity diagnosis system), which includes a feet scanner, a set of appliances, and a personal computer that registers and processes information. Preliminary development of the clubfoot severity diagnosis procedure using the platography method was based on determining the correlation between the bones of the deformed foot and its plantar prints. Therefore, a three-dimensional (3D) model of the foot plantogram was created by combining the computer plantogram with a 3D model of the foot skeleton according to anatomic landmarks. The 3D model of the foot skeleton was created using multispiral computed tomography (Fig. 1). In this case, the images of I–V toe phalangettes and the heel bone concurred with the prints of I–V toe cushions and the heel.

To refine the congenital clubfoot plantographic analysis method, we used existing techniques for the calculation of plantographic characteristics [6, 7], which were modified for application to the foot deformity under examination. The analysis of extreme cases of clubfoot using plantography was not performed because it was impossible to detect typical identification points on the footprints when the deformity was extremely severe (Fig. 2).

The algorithm for foot plantogram analysis was as follows. Identification points were set on the footprints and then connected with lines (Fig. 3, 5):

1. Tangents were drawn to the outer surface of the footprint through points **N** and **M**—the most protruding points on the outer boundary of the front and back regions of the foot, respectively {2.1 [EN] Verify English word/phrase choice}.

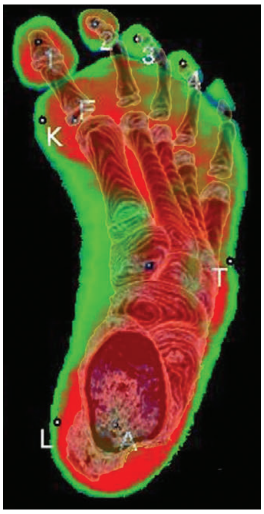
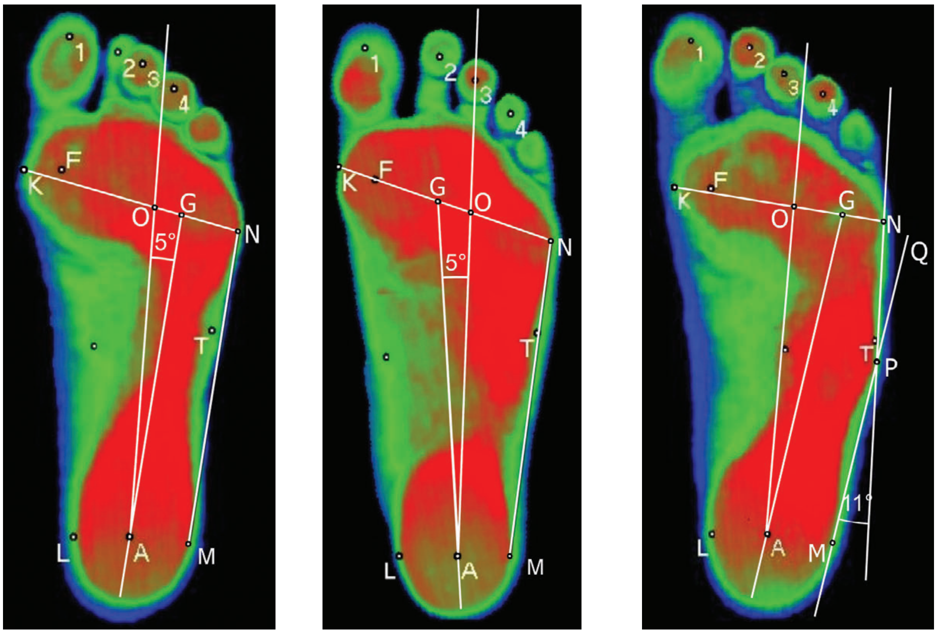


Fig. 1. 3D model of the congenital clubfoot plantogram

Fig. 2. Plantogram of a patient with congenital ambilateral clubfoot (left, severe; right, extreme)



A B C

Fig. 3. Variants of the norm for the angular values of plantograms: A) outer disposition of the heel symmetry axis in relation to the foot axis; B) inner disposition of the heel symmetry axis in relation to the foot axis; and C) tangents to the outer part of the foot form a small angle

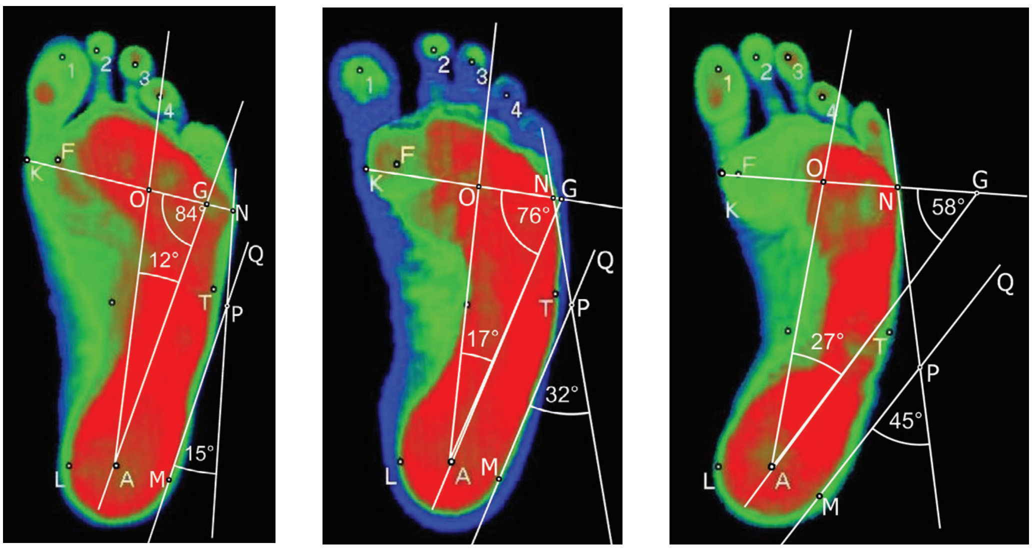
2. A **line across the transverse arch of the foot**, i.e., "metatarsal" line **(K-N)** connecting points **N** and **K**—the most protruding point on the inner boundary of the front region of the foot.

3. A **foot axis (A-O)** was drawn through point **A** at the center of the footprint and point **O** located on the line across the transverse arch of the foot at 40% of its length counting from the outer boundary of the plantogram. The foot axis **(A-O)** is the reference line for all other lines regardless of the shape of the foot's plantar surface.

4. A **heel axis (A-G)** was drawn.

5. Angular characteristics of the foot were measured as follows:

- **OAG angle was the calcaneo-axial angle** located between the foot axis **(A-O)** and the heel symmetry axis **(A-G)**. It not only defined the true position of the heel in the horizontal plane but also the general configuration and position of the foot. In the aspect under examination, the adduction of the back region of the foot was assessed.
- **AGK angle was the calcaneo-metatarsal angle** located between the heel symmetry axis **(A-G)** and the metatarsal line **(K-N)**. It defined the amount of arc inclination of the foot in the horizontal plane.



A B C

Fig. 4. Clubfoot severity assessment according to plantograms: A) I, mild; B) II, moderate; C) III, severe

– **NRQ angle was the angle between outer tangents** formed by tangents **(N-P)** and **(M-Q)**. It defined the adduction of the front region of the foot.
– Based on the angular characteristics of the foot, the following parameters were assessed: 1) severity of the adduction of the front region of the foot; 2) severity of the adduction of the back region of the foot; and 3) severity of arc inclination of the foot.

Statistical analysis of the results was performed using a Microsoft Excel statistical programs package, which included calculation of the arithmetical mean of the variation series "M," its root-mean-square deviation "m," and 95% of the confidence interval. The statistical significance threshold was set at $p < 0.05$.

Results

In the plantograms of normal feet of healthy children, tangents drawn through the most protruding points on the outer boundary of the front and back regions of the foot generally converge in one common tangent line **(N-M)**. In our case, the boundary of the print was incurvate in the middle region and did not protrude over this line (Fig. 2, A). If the outer boundary of the foot approached the common tangent in the middle region (Fig. 2, B) or the tangents formed an angle (Fig. 2, C) with an insignificant average value (0.1 ± 0.11), then this was considered a variant of the norm.

In most cases, the foot axis **(A-O)** lay between the projections of the heads of the III and IV metatarsals. According to our data, in 57% of all cases, the heel symmetry axis **(A-G)** more often extended outwards from the foot axis (Fig. 3, A); therefore, the values of the calcaneo-axial angle **OAG** are marked with a "plus" sign. In 43% of cases, this line extended inwards from the foot axis (Fig. 3, B); therefore, the values of the calcaneo-metatarsal angle are marked with a "minus" sign.

For the parameters of plantographic characteristics in healthy children, see Table 1.

The results presented in Table 1 served as the initial data for the comparative assessment of the angular values of plantographic characteristics at varying degrees of clubfoot severity.

In the plantograms of feet with congenital clubfoot, the outer boundary of the print was strongly rounded and protruding outwards, and the slope of the inclination correlated with the severity of clubfoot (Fig. 4).

We were unable to draw a common tangent for the whole outer boundary of the print because of its arc inclination. The tangents **(N-P)** and **(M-Q)** formed a significant angle. In this case, there was a mutual dislocation of the line across the transverse arch of the foot **(K-N)** and the heel axis **(A-G),** which caused the calcaneo-metatarsal angle **AGK** to decrease, which in turn correlated with the

Table 1

Plantographic characteristics of feet of healthy children

Plantographic characteristics	Angular values (M ± m)		
Calcaneo-axial angle (in relation to the axis) (°)	Inwards from the foot axis	Outwards from the foot axis	Mean value
	−2.4 ± 0.21*	+2.3 ± 0.42*	−0.1 ± 0.11*
Calcaneo-metatarsal angle (°)	101.8 ± 0.91*		
Angle between outer tangents (°)	6.1 ± 0.39*		

The symbol * indicates the definitely changing values with certainty ($p < 0.05$) compared to similar values with clubfoot

Table 2

Platographic characteristics of the feet of children diagnosed with congenital clubfoot

Plantographic characteristics	Angular values (M ± m)		
	Severity of clubfoot		
	mild	moderate	severe
Calcaneo-axial angle (in relation to the axis) (°)	+13.6 ± 2.21	+18.9 ± 0.34*	+23.3 ± 0.68*
Calcaneo-metatarsal angle (°)	88.9 ± 1.21*	76.6 ± 0.90*	66.5 ± 1.04*
Angle between outer tangents (°)	12.8 ± 1.10*	31.9 ± 1.38*	40.6 ± 1.16*

The symbol * indicates the definitely changing values with certainty ($p < 0.05$) compared to similar values with other degrees of clubfoot severity

Table 3

Border values of angles for plantographic characteristics in children diagnosed with congenital clubfoot

Plantographic characteristics	Norm	Severity of clubfoot		
		Mild	moderate	severe
Calcaneo-axial angle (in relation to the axis)	−5° – +10°	+10° – +15°	+15° – +20°	+20° – +30°
Calcaneo-metatarsal angle	105° – 100°	100° – 85°	85° – 75°	75° – 55°
Angle between outer tangents	0° – 10°	10° – 20°	20° – 30°	30° – 50°

increase in the severity of clubfoot. The heel axis itself, at any degree of clubfoot severity, went outside of the foot axis **(A-O)** (Table 2).

Table 2 shows that the values of plantographic characteristics of feet with clubfoot definitely differed from the similar parameters in healthy feet. The differences between the mean angular values at various degrees of clubfoot severity were also veracious, apart from the values of calcaneo-axial angles **OAG** at mild and moderate degrees of deformity (+13.6 ± 2.21° and +18.9 ± 0.34°, respectively). This can be explained by the fact that with a mild degree of clubfoot severity, the root-mean-square deviation "m" of the calcaneo-axial angle is extremely large compared with the arithmetic mean "M," which indicates a significant spread in values of the plantographic characteristic in question.

Mathematical analysis showed that plantographic characteristics in children diagnosed with congenital clubfoot definitely differed in terms of the severity of deformity. Therefore, to make calculations easier, we defined the border values of angles for plantographic characteristics in children diagnosed with congenital clubfoot depending on the severity of deformity (Table 3).

The suggested procedure for the calculation of plantographic characteristics allows for the diagnosis of clubfoot via screening as well assessing the effectiveness of clubfoot rehabilitation treatment and prognosis, which is particularly valuable when assessing the functioning of the foot after surgical treatment.

Conclusions:

1. The suggested procedure for footprint analysis allowed us to specify and objectify the severity of support function disorder (mild, moderate, and severe) with congenital clubfoot.

2. The determined morphofunctional features of the foot in children diagnosed with congenital clubfoot depended on the severity of its anatomical deformities, which were assessed based on the angular characteristics of the foot and showed significant deviations from the norm.

3. The method of diagnosis with the mathematical processing of plantographic characteristics was statistically veracious for the classification of congenital clubfoot of various degrees of severity, which was not only an informative addition to the clinicoradiological method but also allowed the assessment of the support function of the feet.

References

1. Wong RA, Lusard MM. Evidence-based approach to ortotic and prosthetic rehabilitation. *Ortotics and Prosthetic in Rehabilitation*. Elsevier: 2007;109-134.
2. O'Connor K, Bragdon G, Baumhauer JF. Sexual dimorphism of the foot and ankle. *Orthop Clin North Am*. 2006;37(4):569-574. doi:10.1016/j.ocl.2006.09.008.
3. Krishan K, Kanchan T, Sharma A. Sex determination from hand and foot dimensions in a North Indian population. *J Forensic Sci*. 2011;56(2):453-459. doi:10.1111/j.1556-4029.2010.01652.x.
4. Перепелкин А.И., Мандриков В.Б., Краюшкин А.И. Влияние дозированной нагрузки на изменение структуры и функции стопы человека: монография. – Волгоград: Изд-во Волг. ГМУ, 2012. [Perepelkin AI, Mandrikov VB, Krayushkin AI. Vliyanie dozirovannoi nagruzki na izmenenie struktury i funktsii stopy cheloveka: Monografiya. Volgograd: Izd-vo Volg. GMU, 2012. (In Russ).]
5. Краюшкин А.И., Перепелкин А.И., Смаглюк Е.С., Сулейманов Р.Х. Характеристика анатомофункциональных параметров стоп юношей с использованием компьютерной плантографии // Вестник новых медицинских технологий. – 2011. – № 2. – С. 258. [Krayushkin AI, Perepyolkin AI, Smaglyuk YeS, Suleimanov RH. The characteristics of anatomical and functional parameters of young men's feet with by means of computer plantography. *Journal of New Medical Technologies*. 2011;(2):258. (In Russ).]

6. Клычкова И.Ю. Система комплексного лечения детей с врожденной косолапостью: дис. … д-ра мед. наук. СПб., 2013. 432 с. [Klychkova I.Y. Sistema kompleksnogo lecheniya detei s vrozhdennoi kosolapost'yu [dissertation]. Saint-Petersburg; 2013:432. (In Russ).]
7. Наумочкина Н.А., Никитюк И.Е. Вовлечение спинного мозга в патологический процесс при родовых повреждениях плечевого сплетения (биомеханическое исследование) // Врач-аспирант. – 2013. – № 1.3 (56). – С. 388–396. [Naumochkina NA, Nikityuk IE. Involvement of spinal cord into pathological process in childbirth brachial plexus injury (biomechanical study). *Vrach-aspirant*. 2013;1.3(56):388-396. (In Russ).]

КОМПЬЮТЕРНАЯ ПЛАНТОГРАФИЯ КАК МЕТОД ДИАГНОСТИКИ ВРОЖДЕННОЙ КОСОЛАПОСТИ У ДЕТЕЙ

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Исследование анатомофункционального состояния стоп у детей с врожденной косолапостью является актуальной задачей, решение которой имеет существенное теоретическое и практическое значение. Цель исследования — изучение с помощью методики компьютерной плантографии морфофункциональных параметров стопы для оценки степени нарушения ее опорной функции при врожденной косолапости. Были определены плантографические характеристики стоп с указанной патологией у 65 детей в возрасте от 4 до 16 лет. Проведена математическая обработка плантографических характеристик стоп: пяточно-осевого и пяточно-пучкового углов, угла между наружными касательными, на основании чего были определены границы значений угловых величин в зависимости от степени тяжести деформации стоп. Предложенный метод анализа плантограмм стоп статистически достоверен для классификации врожденной косолапости различной степени тяжести: легкой, средней и тяжелой, что является дополнением к клинико-рентгенологическому методу и позволяет оценивать опорную функцию стоп.

Ключевые слова: стопа, косолапость, плантография.

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