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CORRELATION BETWEEN CLINICAL AND RADIOGRAPHIC PARAMETERS OF THE FEET IN CHILDREN WITH FLATFOOT

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Background. Flatfoot in children is one of the most common reasons for visiting an orthopedic specialist. The main criteria in determining various types of flatfoot are clinical (severity of arch flattening, hindfoot valgus, and degree of the foot dorsiflexion) and radiographic (angular values calculated from lateral and anteroposterior radiographs). The primary assessment of the degree of flatfoot is based on the clinical criteria. Detection of changes in the foot shape is the reason for the radiographic assessment.

Aim. This study aimed to determine and analyze the relationship between clinical and radiological parameters of the feet in children with flatfoot.

Materials and methods. The study group included patients with flatfoot observed in the outpatient clinic of H. Turner National Medical Research Center within the period from 2018 to 2020. The study population consisted of 30 children (53 feet) with flexible flatfoot and 65 children (111 feet) with flatfoot and short Achilles tendon. The patients were 10 (8.3; 12) years old. Clinical parameters (valgus value, longitudinal arch angle, and degree of foot dorsiflexion) and radiographic data (Kite's angle, Meary's angle, calcaneal pitch, talotibial angle, longitudinal arch angle, talonavicular coverage angle, and forefoot adduction angle) were analyzed. Statistical differences were determined between groups of patients with flexible flatfoot and patients flatfoot and short Achilles tendon, and correlations between the studied parameters were identified.

Results. Strong correlations were revealed in the following pairs of criteria: lateral Kite's angle and lateral Meary's angle; talotibial angle and lateral Meary's angle; radiographic longitudinal arch angle and lateral Meary's angle; talotibial angle and lateral Kite's angle; foot dorsiflexion and foot dorsiflexion with great toe extension; and radiographic longitudinal arch angle and calcaneal pitch. Only moderate and weak correlations were found between clinical and radiographic parameters of the feet.

Conclusion. The relationship between clinical and radiographic parameters of the feet in patients with flatfoot is characterized by a moderate and weak correlation. Results suggest that the assessment of the clinical parameters of the feet in this population does not provide complete information about the degree of flatfoot.

Keywords: flatfoot; foot radiography; Achilles tendon shortening; feet clinical-radiographic parameters.

ВЗАИМОСВЯЗЬ КЛИНИКО-РЕНТГЕНОЛОГИЧЕСКИХ ПАРАМЕТРОВ СТОП У ДЕТЕЙ С ПЛОСКОСТОПИЕМ

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Обоснование. Плоскостопие у детей — один из самых частых поводов для визита к ортопеду. Основными критериями, определяющими различные варианты плоскостопия, являются клинические (выраженность уплощения свода, вальгус заднего отдела и степень тыльного сгибания стопы) и рентгенологические (угловые величины, рассчитываемые по боковым и переднезадним рентгенограммам). Первичную оценку степени плоскостопия проводят на основании клинических критериев. При обнаружении изменения формы стопы выполняют рентгенографию. В связи с этим актуальным представляется вопрос определения связей между клинической и рентгенологической картиной при плоскостопии.

Цель — определение и анализ связей между клинико-рентгенологическими параметрами стоп у детей с плоскостопием.

Материалы и методы. В исследовании участвовали пациенты, наблюдавшиеся в поликлинике центра им. Г.И. Турнера за период с 2018 по 2020 г. Из них — 30 пациентов (53 стопы) с мобильным плоскостопием и 65 пациентов (111 стоп) с плоскостопием в сочетании с укорочением ахиллова сухожилия. Возраст пациентов составил 10 (8,3; 12) лет. В настоящей работе проанализированы клинические параметры (величина вальгуса заднего отдела, угол продольного свода и степень тыльной флексии стопы) и рентгенометрические данные (угол Kite, угол Meary, угол наклона пяточной кости, таранно-большеберцовый угол, угол продольного свода, угол латерального смещения ладьевидной кости, угол приведения переднего отдела). Определяли статистические различия между группами пациентов с мобильным плоскостопием и с плоскостопием в сочетании с укорочением ахиллова сухожилия, а также корреляционные связи между изучаемыми параметрами.

Результаты. Сильные корреляционные связи были выявлены по следующим парам критериев: латеральный угол Kite — латеральный угол Meary, таранно-большеберцовый угол — латеральный угол Meary, угол продольного свода рентгенологический — латеральный угол Meary, таранно-большеберцовый угол — латеральный угол Kite, тыльная флексия стопы — тыльная флексия стопы с экстензией I пальца, угол продольного свода рентгенологический — угол наклона пяточной кости. Между клиническими и рентгенологическими параметрами стоп связь была умеренная и слабая.

Заключение. Между клиническими и рентгенологическими параметрами стоп у пациентов с плоскостопием существует умеренная и слабая корреляция. В связи с полученными данными оценка клинических параметров стоп при плоскостопии у детей не позволяет получить полную информацию о степени плоскостопия.

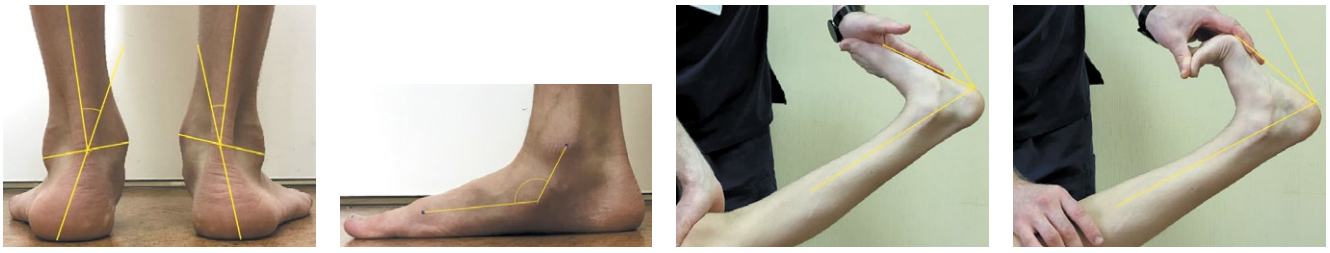
Ключевые слова: плоскостопие; рентгенография стоп; укорочение ахиллова сухожилия; клинико-рентгенологические параметры стоп.

Flatfeet in childhood is one of the most frequently discussed and debated topics. Many studies have shown that in most cases, arch flattening can be considered a physiological condition. An important criterion dividing flatfeet into different forms is the tarsal joints' degree of mobility [1]. Based on this classification, all flatfeet variants can be divided into rigid and mobile forms [2]. The main clinical criteria characterizing flatfeet (hindfoot valgus value and arch flattening severity) are common for mobile and rigid forms. The clinical assessment of foot dorsiflexion degree reveals a short Achilles tendon, one of the elements in assessing foot mobility. The most commonly used radiological parameters characterizing flatfeet are: the talo-I-metatarsal angle in anteroposterior and lateral radiographs (Meary angle), talocalcaneal angles in anteroposterior and lateral radiographs (Kite angle), talonavicular coverage angle, talotibial angle, and calcaneal pitch [3]. Studies have been conducted showing a relationship between foot angular parameters and patients' complaints with flatfeet [4]. However, the data characterizing the relationship between clinical and radiological parameters of the feet in children with flatfeet are fragmentary and presented in insignificant amounts [5, 6]. At a routine examination of a patient with flat feet, the orthopedist primarily focuses on the clinical picture: arch flattening severity and hindfoot valgus. The clinical examination results determine the indications for X-ray study. The initial assessment of flatfeet is performed based on clinical data, and the conclusion is made when analyzing the X-rays. Knowledge of the relationship between clinical and radiological parameters of the feet in children is crucial to detect and diagnose flatfoot in children.

Aim. This study aims to determine and analyze the relationship between clinical and radiological parameters of the feet in children with flatfoot.

Materials and methods

Patients' clinical and radiological data were analyzed to determine the relationship between clinical parameters of the foot and radiological criteria for flatfeet. The study group included 103 patients (188 feet), of which 36 patients (65 feet) had mobile flatfeet, 67 patients (123 feet) had flatfeet combined with a short Achilles tendon. All patients of both groups were observed



a *b* *c* *d*

Fig. 1. The method of measurement at the clinical examination: *a* — hindfoot valgus; *b* — clinical longitudinal arch angle; *c* — isolated foot dorsiflexion; *d* — dorsiflexion in the correction of subtalar joint stabilization

in the H. Turner National Medical Research Center outpatient clinic from 2018 to 2020. Written voluntary consent for participation in clinical studies and medical data publication was obtained from all patient representatives. The mean age of patients was 10 (8.3; 12) years. After preliminary statistical processing of the obtained data, outliers that could not be interpreted were removed. The study group consisted of 30 patients (53 feet) with mobile flatfeet and 65 patients (111 feet) with flatfeet combined with a short Achilles tendon.

Inclusion criteria were the presence of flatfeet and age from 7 to 13 years old. Exclusion criteria were the presence of neurological and systemic pathology, surgical treatment for foot deformities, history of severe foot injuries, congenital foot deformities, and tarsal coalitions.

The longitudinal arch angle, hindfoot valgus angle, and foot dorsiflexion degree with full extension of the knee joint were measured and analyzed during the clinical examination. The diagnosis of flatfeet was based on the clinical longitudinal arch angle value. A value of this angle less than 130° indicated flatfeet [7]. Foot dorsiflexion was performed in two positions: isolated foot dorsiflexion and dorsiflexion in subtalar joint eversion [8]. The clinical examination procedure is shown in Fig. 1.

The hindfoot valgus was measured by plotting lines of the lower leg axis and posterior part axis, which intersected in the center of the Achilles tendon on the line connecting the apices of the lateral and medial malleolus (Fig. 1, *a*). The clinical longitudinal arch angle is formed by the following points — the most prominent point of the medial malleolus, tuberosity of the scaphoid, and the center of the head of the first metatarsal bone (Fig. 1, *b*). Eversion correction and subtalar joint stabilization to assess the degree of foot dorsiflexion were performed with passive extension of the great

Table 1

Radiometric parameters of flatfeet analyzed in the study

Examined angle	X-ray view
Lateral Kite's angle	Lateral
Lateral Meary's angle	
Calcaneal pitch	
Talotibial angle	
Longitudinal arch angle	
Anteroposterior Kite's angle	Anteroposterior
Anteroposterior Meary's angle	
Talonavicular coverage angle	
Forefoot adduction angle	

a *b*

Fig. 2. Diagram illustrating how to plot angles on the foot X-ray image in the lateral (*a*) and anteroposterior (*b*) views (see the text for an explanation)

toe (J.H. Hicks biomechanical phenomenon — the correction of eversion stretching the plantar aponeurosis due to passive extension of the great toe). The foot dorsiflexion degree in the isolated form (Fig. 1, *c*), or with subtalar joint stabilization (Fig. 1, *d*) was determined by plotting the angle between the line that connected extreme points on the plantar surface of the hind and forefoot with those perpendicular to the line drawn from the center of the medial malleolus that ran parallel to the anterior edge of the tibia.

Radiographic values characterizing foot deformity severity were analyzed on X-ray images in standard views (anteroposterior and lateral ones) with the patient in the standing position. The analyzed parameters are presented in Table 1.

As shown in Table 1, the angles used in the study characterized the severity of the deformity in both the sagittal and frontal views. The technique for measuring these angles is shown in Fig. 2.

The angles on the lateral and anteroposterior foot X-ray images were plotted in by generally accepted rules, as shown in Fig. 2. In this case, Kite's angle (1) on the lateral X-ray image is formed by the line of the axis of the talus and the line drawn along the lower points of the calcaneus and the anterior process of the calcaneus. Meary's angle (2) is formed by the talus' axes and the first metatarsal bone. The calcaneal pitch (3) is the angle between the supporting surface line and the lower points of the calcaneal tuberosity and the anterior process of the calcaneus. The talotibial angle (4) is formed by the intersection of the talus and tibial bone axis. The longitudinal arch angle (5) was constructed according to the F.R. Bogdanov method and is located between the lower point of the naviculocuneiform joint and the lower points of the first metatarsal and calcaneus. Kite's angle (6) on the anteroposterior X-ray image is formed by the intersection of the lines of the axes of the talus and calcaneus. Meary's angle (7), as in the lateral X-ray image, is determined at the intersection of the axis of the first metatarsal bone and talus. The talonavicular coverage angle (8) was built along with the extreme points of the articular surfaces of the talus and scaphoid in the talonavicular joint. The forefoot adduction angle (9) was formed by the axis line of the second metatarsal bone. The perpendicular line was restored from the middle of the lines along the medial and lateral borders of the midfoot.

Both radiological and clinical parameters were measured in the software complex Weasis v. 3.5.4.

The data obtained were processed using descriptive statistical methods by calculating the medians and the 25th and 75th percentiles [Me (Q_1; Q_3)]. The normal distribution of data was assessed using the Kolmogorov-Smirnov test. Since most data did not correspond to the normal distribution, nonparametric statistical methods were used. The Mann-Whitney *U*-test was used to determine the differences in radiological and clinical parameters in the groups of patients with mobile flatfeet and flatfeet with a short Achilles tendon. A p-value < 0.05 was considered statistically significant. The Spearman correlation coefficient (ρ) was used to determine the relationship between clinical and radiological parameters in patients with flatfeet. The strength of the association was characterized by the following values of the correlation coefficient: $0.01 \le \rho \le 0.29$ — weak relation; $0.30 \le \rho \le 0.69$ — moderate relation; $0.70 \le \rho \le 1.00$ — strong relation. A positive or negative value of the coefficient characterized a positive or negative relationship, respectively. A regression analysis was performed in the form of the paired linear and quadratic regression model to assess the degree and variant of one feature's influence on another. The multiple determination coefficient (R^2) was used to estimate a sample's proportion characterized by the linear or quadratic regression model.

Results

The mean values of the studied parameters in groups of patients with mobile flatfeet and flatfeet combined with a short Achilles tendon are presented in Table. 2.

As shown in Table 2, statistically significant differences in the groups of patients by radiological and clinical criteria were noted only in the sagittal view. At the same time, the values of radiological parameters on the anteroposterior X-ray images did not have statistically significant differences in the patient groups, and the degree of hindfoot valgus was almost statistically significant.

The correlation matrix data were obtained and analyzed during the correlation. Spearman correlation coefficient values were identified according to the criteria by which strong and

Table 2

Clinical and radiological parameters of the feet in patients with flatfeet

Parameter	Mobile flatfeet	Flatfeet with a short Achilles tendon	Mann-Whitney *U*-test
Anteroposterior Kite's angle	29.4 (25.05; 34.05)	31 (27.4; 34.3)	0.23
Anteroposterior Meary's angle	16.1 (12.45; 20.25)	17.5 (12.9; 22.9)	0.21
Talonavicular coverage angle	25.3 (18.7; 30.7)	28.1 (21; 32.6)	0.09
Forefoot adduction angle	19.2 (16.4; 22.05)	18.6 (13.6; 21.6)	0.36
Lateral Kite's angle	49.9 (44.2; 54.7)	55.1 (49.5; 59)	<0.05*
Lateral Meary's angle	17.5 (9.8; 24.9)	30.9 (23.4; 39)	<0.05*
Calcaneal pitch	13.9 (9.2; 18.1)	9.9 (6.3; 13.6)	<0.05*
Talotibial angle	59.3 (52.4; 66.4)	48.6 (42; 55.2)	<0.05*
Longitudinal arch angle, X-ray	155.1 (146.7; 157.6)	164.3 (157.7; 168.3)	<0.05*
Longitudinal arch angle, clinical	128.7 (125.05; 129.55)	123.3 (120.05; 126.35)	<0.05*
Hindfoot valgus	15.7 (13.55; 18.6)	18.1 (14.8; 21.6)	0.05
Foot dorsiflexion	28.55 (23.73; 32.3)	15.85 (12.28; 21.3)	<0.05*
Foot dorsiflexion with great toe extension	16.05 (12.83; 19.38)	2.65 (–2.13; 6.1)	<0.05*

*statistically significant differences ($p < 0.05$).

Table 3

Correlation and regression analysis data of clinical and radiological parameters of feet in patients with flatfeet characterizing strong and moderate relationships

Parameter	Spearman's correlation coefficient, ρ	Determination coefficient, R^2	
		Linear model	Quadratic model
Lateral Kite's angle — lateral Meary's angle	0.780	0.621	0.621
Talotibial angle — lateral Meary's angle	–0.834	0.718	0.718
X-ray longitudinal arch angle — lateral Meary's angle	0.855	0.727	0.743
Talotibial angle — lateral Kite's angle	–0.741	0.562	0.562
Foot dorsiflexion — foot dorsiflexion with great toe extension	0.787	0.599	0.604
X-ray longitudinal arch angle — calcaneal pitch	–0.685	0.489	0.489
Clinical longitudinal arch angle — foot dorsiflexion with great toe extension	0.420	0.181	0.184
X-ray longitudinal arch angle — foot dorsiflexion with great toe extension	–0.467	0.200	0.204
Talotibial angle — foot dorsiflexion with great toe extension	0.340	0.118	0.120
Calcaneal pitch — foot dorsiflexion with great toe extension	0.312	0.106	0.107
Lateral Meary's angle — foot dorsiflexion with great toe extension	–0.436	0.176	0.177
Anteroposterior Meary's angle — talonavicular coverage angle	0.358	0.158	0.158
Hindfoot valgus — talonavicular coverage angle	0.303*	0.117	0.118

End of table 3

Parameter	Spearman's correlation coefficient, ρ	Determination coefficient, R^2	
		Linear model	Quadratic model
Hindfoot valgus — lateral Meary's angle	0.313*	0.074	0.075
Hindfoot valgus — lateral Kite's angle	0.304*	0.062	0.064
Lateral Meary's angle — talonavicular coverage angle	0.321*	0.090	0.090
X-ray longitudinal arch angle — clinical longitudinal arch angle	–0.631*	0.420	0.426
Talotibial angle — clinical longitudinal arch angle	0.338*	0.138	0.149
Talotibial angle — talonavicular coverage angle	–0.340*	0.088	0.089
Calcaneal pitch — clinical longitudinal arch angle	0.367*	0.161	0.162
Lateral Meary's angle — clinical longitudinal arch angle	–0.579*	0.341	0.344
Lateral Kite's angle — clinical longitudinal arch angle	–0.390*	0.155	0.163
X-ray longitudinal arch angle — talotibial angle	–0.600*	0.375	0.377
X-ray longitudinal arch angle — lateral Kite's angle	0.477*	0.226	0.229
Anteroposterior Meary's angle — forefoot adduction angle	–0.565*	0.354	0.356
Calcaneal pitch — lateral Meary's angle	–0.555*	0.351	0.351
Calcaneal pitch — talotibial angle	0.408*	0.219	0.219

*criteria with a two-side significance of 0.01.

moderate relationships were identified and are presented in Table. 3.

As shown in Table 3, six strong relationships ($\rho > |0.7|$) and 21 moderate links ($|0.30 \le \rho \le 0.69|$) were noted in the correlation analysis. At the same time, the coefficient of determination (R^2) did not exceed 0.74. This suggests that only 74% of the samples can be explained by the regression formula and shows the approximation is less than satisfactory. It can be noted that the determination coefficient values for the linear and quadratic models did not differ significantly; therefore, the nature of the relationships between the studied features approached the linear regression model.

A graphical representation of a strong correlation ($\rho > |0.7|$) is shown in Fig. 3.

Fig. 3 illustrates that the relationship between parameters can be explained by a linear regression model to a greater extent. Strong correlations were observed between the radiological parameters, except for the pair "foot dorsiflexion — foot dorsiflexion with great toe extension" (Fig. 3, *f*), which characterizes only the degree of foot dorsiflexion assessed by various tests. Three pairs of criteria (talotibial angle — lateral Kite's angle, talotibial angle — lateral Meary's angle, X-ray longitudinal arch angle — calcaneal pitch; Fig. 3, *a, c, e*) were characterized by a negative correlation. The following three pairs of criteria (lateral Kite's angle — lateral Meary's angle, X-ray longitudinal arch angle — lateral Meary's angle, foot dorsiflexion — foot dorsiflexion with great toe extension; Fig. 3, *b, d, f*) had a positive correlation. At the same time, no strong correlation was found between clinical and radiological parameters of the feet in patients with flatfeet.

The statistically significant correlations between the clinical and radiological parameters of the feet in children with flatfeet are displayed by a diagram of Tetrentyev correlation pleiades, which is shown in Fig. 4.

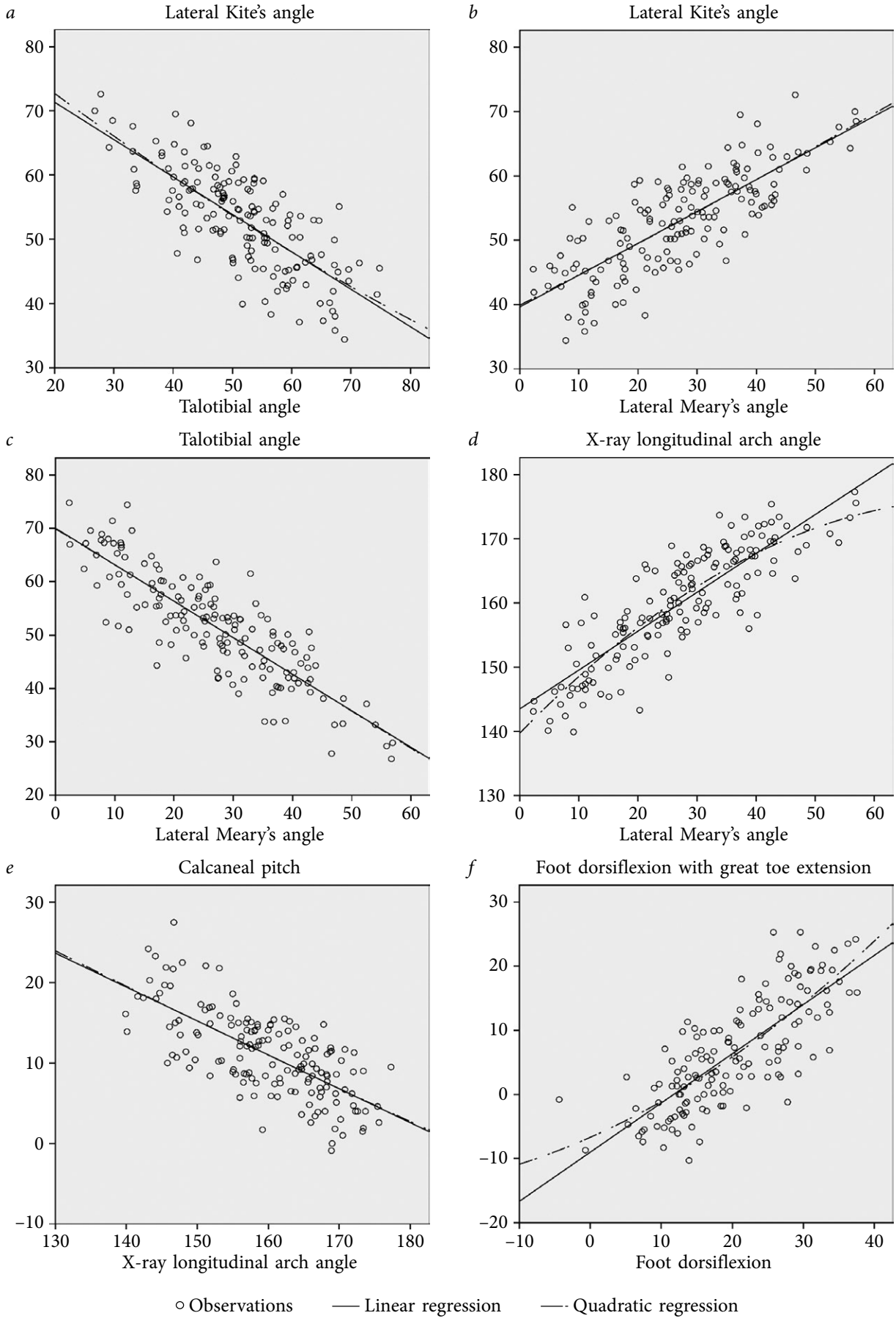


Fig. 3. Graphical representation of strong relations of clinical and radiological parameters of the feet in children with flatfeet according to the following pairs of criteria: *a, b* — lateral Kite's angle — talotibial angle/lateral Meary's angle; *c, d* — talotibial angle/X-ray longitudinal arch angle — talotibial angle; *e* — calcaneal pitch — X-ray longitudinal arch angle; *f* — foot dorsiflexion — foot dorsiflexion with great toe extension

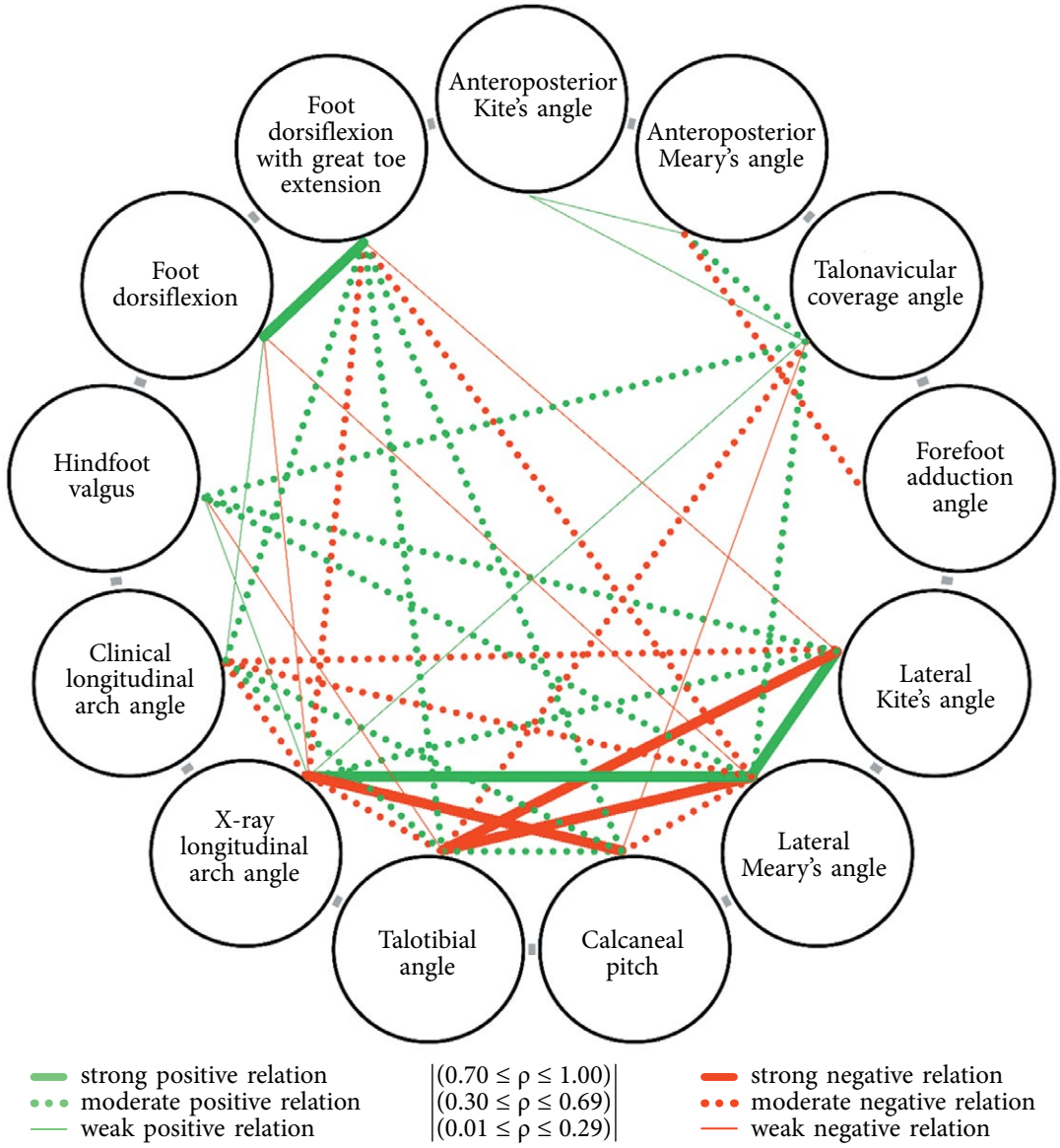


Fig. 4. Tetrentyev correlation pleiades. Different lines mark significant correlations [correlation is significant at the level of 0.1 (two-sided)]

As seen from Fig. 4, strong correlations were found between radiological parameters on lateral X-ray images of the feet. It is also possible that a strong relationship exists between the degree of foot dorsiflexion in different test variants. Foot dorsiflexion with great toe extension and clinical longitudinal arch angle were characterized by moderate relationships with radiological parameters of the feet in the sagittal view. On the other hand, the hindfoot valgus had only three moderate relationships with the talonavicular coverage angle, lateral Meary's angle, and lateral Kite's angle. The remaining relationships between the hindfoot valgus and clinical and radiological parameters were weak. X-ray parameters on anteroposterior X-ray images characterizing the severity of deformity (anteroposterior Meary's angle, anteroposterior Kite's angle, talonavicular coverage angle) had the least number of correlations with other parameters and only one moderate relationship with clinical parameters (talonavicular coverage angle — hindfoot valgus).

Discussion

Lee et al. revealed an inverse correlation between the hindfoot valgus and lateral Meary's angle ($r = -0.4$). A positive correlation was also found between the lateral Meary's angle and the lateral Kite's angle ($r = 0.68$) [9]. In our study, the relationship between the hindfoot valgus and the lateral Meary's angle was positive ($\rho = 0.313$), which is evident in the increase in the hindfoot valgus with an increase in the lateral Meary's angle. This

opposed value maybe because of the peculiarities of the measurement of hindfoot valgus measurements by the publication authors, which are not displayed in their study. In addition, the degree of the relationship between the lateral Meary's angle and the lateral Kite's angle in their study ($r = 0.68$) and our study ($\rho = 0.780$) was comparable.

On the other hand, Benedetti et al. found no significant relationship between these parameters except for a strong correlation between X-ray longitudinal arch angle (Costa-Bertani) and severity of flatfeet according to plantograms while studying the clinical and radiological parameters of the feet in children with flatfeet [5]. In our work, we also did not find strong correlations between clinical and radiological parameters of the feet in children with flatfeet. When comparing clinical and radiological assessment of the degree of the hindfoot valgus, de Cesar Netto et al. noted that radiographically, the hindfoot valgus is more pronounced compared with the clinical assessment [10], which also indicates specific differences in the radiological and clinical picture. This feature can be explained by the absence of strong relations and a small number of moderate relations between the clinical hindfoot valgus and the radiological criteria in our study.

Many researchers have shown that the most sensitive angle reflecting the severity of flatfeet is the lateral Meary's angle [4, 11]. In our work, this angle had the largest number of strong (3) and moderate (5) relations with other parameters, which allows us to single it out as one of the most important and sensitive radiological criteria for flatfeet. As a result of the study, it was determined that the radiometric criteria measured on lateral radiographs have the greatest relationship with the clinical parameters of the feet. For the magnitude of the talocalcaneal divergence and talo-I-metatarsal angle on anteroposterior radiographs (anteroposterior Kite's angle, Meary's angle), the least significant correlations with all the studied parameters were revealed.

In the present study, the criteria for the diagnosis of flatfeet were not determined since the assessment of the foot shape has multiple components. The norm depends on many factors, and its limits are often blurred. The main objective of our study was to compare the clinical data assessed by orthopedic surgeons in the child with flatfeet using X-ray data. The choice of the clinical longitudinal arch angle in the present work and the absence of differences in its interpretation in different age groups is due to the need to document the foot shape and the hindfoot valgus for subsequent comparison with an X-ray picture. This study design allowed us to compare the clinical criteria of flatfeet most often used in the routine practice of the orthopedist (degree of arch collapse, degree of hindfoot valgus, and value of foot dorsiflexion) with radiometric criteria characterizing the severity of foot deformity.

Conclusion

The investigated clinical and radiological parameters of flatfeet do not have strong correlations. For this reason, the use of only clinical data does not allow an adequate assessment of the nature and severity of flatfeet. The most significant correlations were noted between the following radiological parameters: the longitudinal arch angle, the talotibial angle, calcaneal pitch, the lateral Kite's, and Meary's angles. When analyzing radiographs of patients with flat feet, the angular indices measured on lateral radiographs, primarily Meary's angle, have the greatest diagnostic value, making it more significant when assessing the severity of the deformity. Of all the clinical criteria, the smallest number of significant relationships with radiological parameters was found for the hindfoot valgus and the degree of isolated foot dorsiflexion. Of the greatest importance in the clinical assessment of flatfeet is assessing the degree of foot dorsiflexion during stabilization of the subtalar joint since of all clinical criteria, only this parameter is characterized by the largest number of moderate relations. Based on the data obtained, the assessment of the degree of flatfoot when considering the hindfoot valgus and clinical longitudinal arch angle cannot be complete. Therefore, additional studies are required.

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Author contributions

A.V. Sapogovskiy — study design, database creation, data analysis, writing the text of the article.

A.E. Boyko — data entry, editing the text of the article.

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