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Original Article

The growth of foot arches and influencing factors

Ferial Hadipoetro Idris, MD, PhD

ABSTRACT

Background Foot arches are important components for body support. Foot arch deformity caused by growth abnormalities cause serious limitations in daily activities.

Objectives To determine the patterns of foot arch growth, factors influencing foot arch growth, and the timing for intervention in errant growth patterns.

Methods A cross-sectional study evaluated the foot arches of children aged 0-18 years according to age and sex. Subjects included had no evidence of physical abnormality other than flat foot, knock-knee, or bow leg. Subjects were grouped per year of age. Data on foot arch class, age, sex, weight, height, medial intercondylar distance, and medial intermalleolar distance were recorded. Chi-square test, correlation, binary and linear regressions, general linear model, and contrast matrix were performed.

Results In 8376 children aged 0-18 years, flat foot grade 3 had stable proportions in all age groups. Flat foot grade 2 and 1 had smaller proportions in older age groups than in younger ones. The proportions of normal foot was greater in older age groups. Boys at the age of 7 and girls at 9 have a small percentage of pes cavus. The mean foot arch measurements were consistent with flat foot grade 2 at age 0-3 years, flat foot grade 1 at 4 years, and normal foot at age 18. Median foot arch measurement of children 0-10 years old was consistent with flat foot grade 1, while that of children 11 years old was consistent with normal foot. Age and height gave positive influence. Based on these measurements we infer that the optimal time for intervention is 0-7 years for boys and 0-3 years for girls.

Conclusion The proportion of flat foot grade 3 is stable throughout age groups, that of flat foot grade 2 and 1 are smaller in older age groups, and that of normal foot is greater in older age groups. Overgrowth happens in very small percentages after age of 7 in boys and 9 in girls. Age, sex, height, weight, and growth of the knees are influencing factors **[Paediatr Indones 2005;45:111-117].**

Keywords: *foot arch growth, flat foot, pes planus, pes cavus*

Humans require feet that are able to support and lift the body. To serve this purpose, feet have concavities called foot arches. The foot arch is convex at the dorsal aspect and concave at the plantar aspect, both medially and laterally with longitudinal and transverse direction.[1-4] The degree (grade) of foot arch concavity is important as a component of daily physical activities such as standing, walking, jumping, and running. Foot arches that do not grow properly cause equilibrium problems, instability, continuous deformity, worn-out shoe soles, tiredness, overuse injury, and pain,[1,3,5-8] which bring limitations in daily activity, sports achievement, and in some occupations, especially military ones.[6,7,9-11]

Two forms of foot arch abnormality are flat foot (pes planus), in which the arch is lower than normal,[12-14] and pes cavus, in which the arch is higher than normal.[15] The prevalence of flat foot in adults is >20%.[12] Diagnosis of foot arch grade can be done by foot print. There are five grades of foot arch growth; the 1st grade is equivalent to flat foot grade 3, the 2nd grade to flat foot grade 2, the 3rd grade to flat foot grade 1, the 4th grade to normal foot, and the 5th grade to pes cavus.[16]

From the Department of Rehabilitation and Physical Medicine, Medical School, University of Indonesia, Cipto Mangunkusumo Hospital, Indonesia.

Reprint requests to: Ferial Hadipoetro Idris, MD, PhD, Department of Rehabilitation and Physical Medicine, Medical School, University of Indonesia, Cipto Mangunkusumo Hospital.

The lower extremity can be seen as one functional unit, in which many different components work in unity. Deviation of the foot can give impact on knee and vice versa. From a previous study, it is known that most children 0-2 years old have bow legs and those 2-7 years old have knock-knees.[17] The length, width, and height of a foot are different while sitting, standing, or standing on one leg.[18] The growth of the foot is influenced by age, sex, and race.[16,19-22] Race is a dynamic factor which is always involved in microevolution.[23] For the past 10,000 years, the Indonesian race was predominantly Mongoloid, followed by Austrome-lanesoid. However, nowadays the Caucasoid race has started to give influence,[24] so that the original race is no longer evident.[25-26] The growth of foot arches might also be influenced by age, sex, weight, height, and growth of the knees. Knowledge of foot arch growth is useful for prevention of further deformity, early diagnosis, management, and prediction of growth. To date, there no study has been conducted on foot arch growth and its influencing factors. The objectives of this study were to determine the pattern of foot arch growth from 0-18 years, factors influencing foot arch growth, and the timing for intervention of errant growth patterns.

Methods

This cross-sectional study was conducted in South Jakarta from February to July 2002. The required sample size was calculated to be 172 for each age group (in years) and sex. Subjects were chosen through 2-stage random sampling, and were grouped by year(s) of age and sex.

Subjects were recruited from maternity clinics, *posyandu* (community health posts), preschools, kindergartens, elementary schools, junior high schools, and senior high schools in South Jakarta. Subjects included were infants and children aged 0-18 years old without any abnormality other than flat foot, knock-knee, or bow leg. Newborns should also be full-term, <5 days of age, and weighing ≥ 2500 grams.

The instruments used were a Seca 890 mother-and-child weight scale, a Seca 220 height scale, a foot print basin, and modified calipers. Data obtained were foot arch class as dependent variable and age, sex, weight, height, medial intercondylar distance (IC), and medial intermaleollar distance (IM) as independent variables. Chi-square test, correlation, binary and linear regression, general linear model, and contrast matrix were employed where appropriate.

Ethical clearance for this study was obtained from the Medical Ethics Committee of the Medical School, University of Indonesia.

Results

There were 8376 children who met the inclusion criteria, consisting of 50.7% boys and 49.3% girls. Flat foot grade 3 (1st grade of foot arch growth) had a stable proportion throughout the ages of 0-18 years. The proportion of flat foot grade 2 (2nd grade of foot arch growth) decreased in line with increasing age up to the age of 10 years. The proportion of flat foot grade 1 (3rd grade of foot arch growth) decreased in line with increasing age up to the age of 14 years. In contrast, the proportion of normal foot arch (4th grade of foot arch growth) increased as the proportion of flat foot grade 1 decreased. At the age of 7 years for boys and 9 years for girls, pes cavus (the 5th grade of foot arch growth) was found, which had stable proportion. Flat foot was found in small proportions in the 18-year age group (**Figures 1** and **2**).

According to the mean grade of foot arch growth in boys as well as girls, at 0-3 years old children mostly had flat foot grade 2. At age 4 years, most children had flat foot grade 1. Most 18-year-olds had normal-shaped feet. The median grade of foot arch growth was consistent with flat foot grade 1 in children aged 0-10 years and with normal foot in those aged 11 years (**Table 1**).

Age and height seemed to have positive influence on foot arch growth. Body weight and medial intermalleolar distance had negative influence. Medial intercondylar distance had positive influence in boys but not in girls, but this difference was not significant. In 16.5% of boys and 19.7% of girls, the variability of the grade of foot arch growth was influenced by the variables studied. In the remaining children, this variability was caused by other factors.

Based on the data obtained, we developed a regression equation to determine the grade of foot arch growth for boys as follows:

Grade of foot arch growth (boys) =
2.549 + 0.06729 x age (years) – 0.03038 x IM (cm) + 0.02433 x IC (cm) + 0.003596 x height (cm) – 0.009886 x weight (kg).

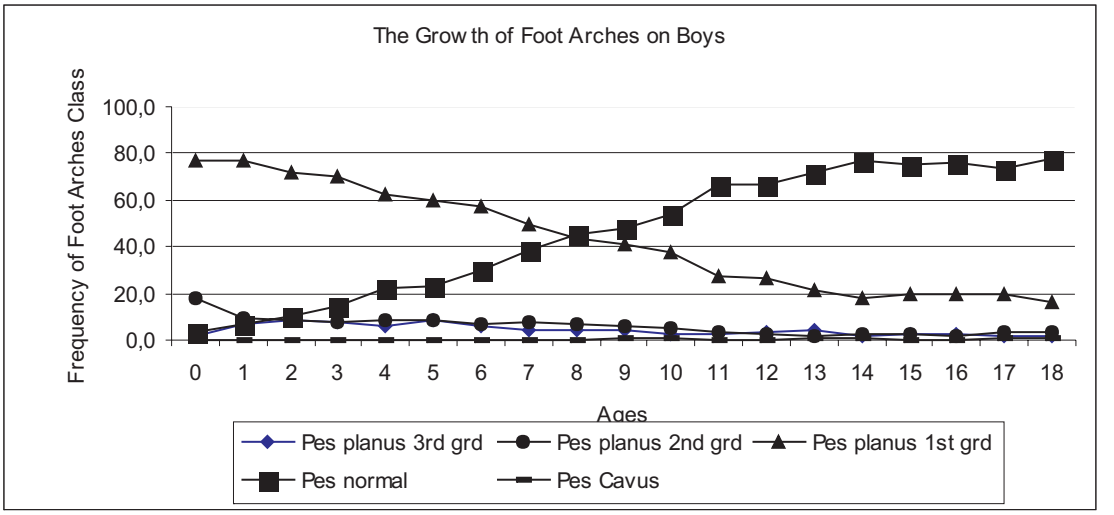

Figure 1. The growth of foot arches in boys

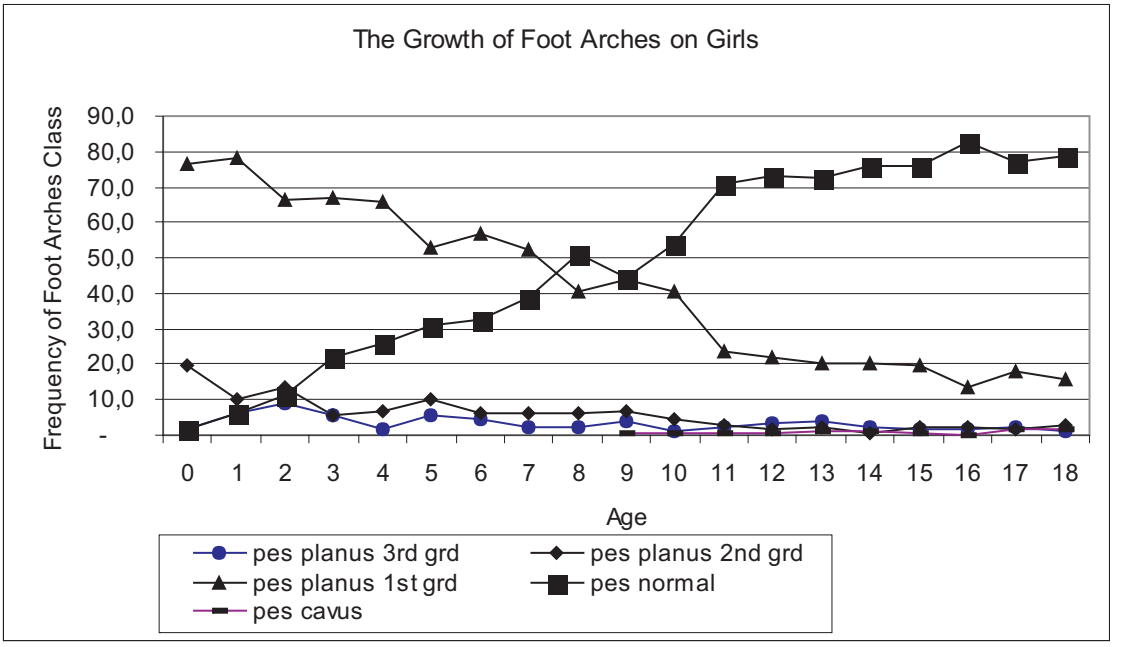

Figure 2. The growth of foot arches in girls

We also developed a similar equation for girls, as follows:

Grade of foot arch growth (girls) =
2.394 + 0.04912 x age (years) - 0. 02559 x IM (cm) + 0.02433 x IC (cm)+ 0.006680 x height (cm)- 0.008383 x weight (kg).

Tables 2 and **3** show regression coefficients of the growth of foot arches in boys and girls, respectively.

Based on these results, we infer that intervention for errant growth patterns could be done through the ages of 0-18 years, but should be started as soon as possible, particularly for flat foot grades 3 and 2. It should be started no later than age 14 years for flat foot grade 1, 1 year for flat foot grade 2, and as soon as possible after birth for flat foot grade 3. The optimal intervention time is probably before the ages of 6 years for boys and 4 years for girls.

TABLE 1. MEAN AND MEDIAN GRADE OF FOOT ARCH GROWTH IN EACH AGE GROUP

Age	n	Mean	95% Confidence interval		Standard	Median	Standard
			Lower bound	Upper bound	deviation		error
0	598	2.81	2.77	2.85	0.50	3	0.0205
1	194	2.84	2.75	2.93	0.64	3	0.0460
2	157	2.83	2.72	2.94	0.74	3	0.0577
3	162	2.91	2.80	3.03	0.80	3	0.0567
4	246	3.01	2.91	3.10	0.80	3	0.0476
5	504	2.98	2.91	3.05	0.77	3	0.0359
6	620	3.10	3.07	3.16	0.75	3	0.0309
7	574	3.23	3.16	3.29	0.76	3	0.0315
8	525	3.31	3.24	3.34	0.78	3	0.0335
9	519	3.35	3.28	3.42	0.71	3	0.0344
10	469	3.45	3.38	3.51	0.67	4	0.0328
11	503	3.59	3.53	3.65	0.67	4	0.0300
12	622	3.57	3.53	3.65	0.72	4	0.0289
13	567	3.62	3.51	3.62	0.74	4	0.0312
14	522	3.72	3.55	3.68	0.61	4	0.0270
15	703	3.68	3.67	3.78	0.63	4	0.0240
16	280	3.68	3.64	3.73	0.65	4	0.0391
17	392	3.67	3.61	3.76	0.64	4	0.0326
18	219	3.72	3.64	3.80	0.62	4	0.0423

TABLE 2. REGRESSION COEFFICIENTS OF THE GROWTH OF FOOT ARCHES IN BOYS

	Unstandardized coefficients (B)	Standard error	Standardized coefficients (ß)	t	P value
Constant	2.549	0.093		27.497	.000
Age	6.729E-02	0.008	0.416	8.502	.000
IM	-3.038E-02	0.007	-0.075	-4.307	.000
IC	2.433E-02	0.009	0.40	2.588	.010
Height	3.596E-03	0.001	0.143	2.925	.003
Weight	-9.886E-03	0.001	-0.224	-6.713	.000

TABLE 3. REGRESSION COEFFICIENTS OF THE GROWTH OF FOOT ARCHES IN GIRLS

	Unstandardized coefficients (B)	Standard error	Standardized coefficients (ß)	t	P value
Constant	2.394	0.078		30.886	.000
Age	4.912E-02	0.006	0.336	7.963	.000
IM	-2.559E-02	0.006	-0.076	-4.543	.000
IC	-3.240E-03	0.010	-0.005	-0.314	.754
Height	6.680E-03	0.001	0.276	6.697	.000
Weight	-8.383E-03	0.002	-0.184	-5.090	.000

Foot arches of 6-year old boys showed significant difference from those of 0-year-olds. This may imply that in boys, foot arches grow significantly between 0-6 years of age. While in girls, the difference was significant between 3-year-olds and 0-year-olds.

Discussion

The theory of foot arch growth cannot be separated from the ontogeny and philogeny theory of the human ability to stand on both feet.[1,26-28] Flat foot is an abnormality that needs intervention to minimize deformity and to prevent further disability.[1,3,5,9,28-35] Factors influencing foot arch growth are hereditary factors,[22-24] disease,[23] environment,[1,23] endocrine,[21-23] sex, race,[23,24,26] metabolic disorders, and mechanical pressure.[1,22,24,26,36-39] Girls have a lesser degree of inclination angle and greater valgus knee angle than boys, influencing the force transmission of pressure, traction, and rotation, which in turn influence foot arch growth.[28,39,40] During the growth period, we

recognize the presence of physiological flat foot, physiological genu varus, and physiolgical genu valgum.[1,4,12,14,41-49] Foot weight bearing on children would be better with lesser body weight and proper position of the foot.[41-47] Weight is important to measure growth rate.[50-51] Foot orthotics is needed to correct deformity.[52] This study found that weight and height influenced foot arch growth. The weight and height of the urban population is different from those of the rural population,[53] and children from low socio-economic status tend to have lower weight.[54] Results of this study can be applied for the urban population with Mongoloid race majority. As shown in **Figures 1** and **2**, the proportion of flat foot grade 3 was constant across age groups, meaning that it did not grow. The proportion of flat foot grade 2 decreased over the ages and was stable at age 10 years. Therefore, both flat foot grade 3 and grade 2 are in need for early intervention. The proportion of flat foot grade 1 decreased with increasing age, and became balanced with the increment of the normal foot curve. Hence, flat foot grade 1 needs only monitoring. This finding agrees with the statement that flat foot will correct itself physiologically at age 4-6 years.[13] Another study of 672 Caucasians in 1994 found a higher prevalence of flat foot among children aged 0-2 years, and faster foot arch growth through the ages of 2-6 years.[55] **Figures 1** and **2** showed that at age 7 years for boys and 9 years for girls flat foot was present, an evidence of the natural overgrowth of foot arches. This should be distinguished from foot arch overgrowth secondary to neuromuscular disorder (physiological versus congenital pes cavus).[15]

From a biomechanical point of view, pes cavus causes abnormal distribution of weight bearing, and therefore needs early intervention. The adverse influence of weight to foot arch growth is a reason to prevent overweight in children. The influence of weight could explain why a child's tarsal height is lower when standing on one leg is lower than when sitting.[18] This result differed from that of another study, which found that weight had no influence on navicular height.[56] Flat foot is also found in children with Down syndrome[57] due to ligament hyperlaxity, and this condition needs intervention by a rehabilitation medicine specialist. Our opinion on the timing of intervention is novel and may be different from previous opinions.

Our data suggest that flat foot grade 3 does not grow, grade 2 grows slowly, grade 1 grows approaching the normal shape up to the age of 14 years and becomes stable. Not all cases of flat foot will become normal. Age and height positively influence foot arch growth, while weight and medial intermalleoli distance are negatively so. The influence of medial intercondyle distance on foot arch growth is positive in boys but insignificant in girls. Intervention can be done throughout the ages of 0-18 years, but should be started as soon as possible for grades 3 and 2. The latest intervention times for flat foot grades 1, 2, and 3 are 14, 1, and 0 year old, respectively. The optimal intervention time is up to 6 years old for boys and up to 3 years old for girls.

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