



Anthropometric measurements of foot length and shape in children 2 to 7 years of age

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Keywords: child, foot, anthropometry

Abstract

Background and purpose: A child's foot changes shape and proportions during growth so that it adapts to function. The purpose of this article is to determine foot length in children aged 2-7 years as a fundamental unit for measuring the growth of the foot, with which it will be able to compare other anthropometric measures of the foot. Determination of the shape of the foot and interpretation of the growth curve of the foot in length are important for standardization of the foot.

Materials and methods: The study was conducted on a sample of 2745 children, totalling 5490 feet. Of this, there were 1375 boys and 1370 girls. The population encompassed children aged 2 (1.50-2.49) to 7 (6.50-7.49) years and subjects were divided into 6 age groups. Foot length was measured by measuring tape, while shape was determined clinically.

Results: There is no difference in length and shape between the left and right feet of boys and girls across all age and sex groups, and the most common shape was the Egyptian foot shape. The foot grows most rapidly between the 2nd and 3rd year. From the 3rd to 6th years, the foot grows by approximately 1cm yearly, while in girls between the 6th and 7th year the foot grows 5mm.

Conclusions: Foot length is the basis for size comparison and determination of foot shape type. The results obtained demonstrate that the foot grows in length equally yearly and that there is no difference between the left and right feet.

INTRODUCTION

Length and shape of the foot has changed with evolution, adapting to the upright posture of man and the change in manner of weight bearing. The tarsus has increased by over 50% in length of the foot, and with the development of the transverse and longitudinal arches, a foot for walking and running developed, as opposed to climbing and grasping. The greatest changes in length and shape of the foot occur in the earliest years, where the foot must develop sufficiently in width to allow for balance while a child learns to walk (1,2,3). The length of the foot of a child during growth reaches its final dimensions more proportionally than any other element of the body during growth. The foot of a girl 1 year old and that of a boy 18 months old approaches 50% of their final length at the end of growth because a wide base of the foot compensates for the weakness and lack of muscle coordination in a child (4). Three main shapes of the forefoot have developed based on toe length and the relative proportion amongst the toes: Egyptian, square, and Greek. In the Egyptian type, the great toe is largest, followed by each

Table 1: Distribution of the study population according to age and sex.

Age – years	Boys		Girls		Total feet
	Right foot	Left foot	Right foot	Left foot	
1.50-2.49	149	149	242	242	782
2.50-3.49	181	181	214	214	790
3.50-4.49	263	263	221	221	968
4.50-5.49	245	245	196	196	882
5.50-6.49	288	288	259	259	1094
6.50-7.49	249	249	238	238	974
	1375	1375	1370	1370	5490

of the lesser toes. The great toe is shorter than the second toe in the Greek foot shape, while in the square foot shape the great toe and all lesser toes are practically inline. In children, the Egyptian foot type is commonest, followed by the Greek type, and very rarely the square type. Foot length in growing children is standardized in individual countries and varies according to geographic position and ethnic differences. Foot length is taken as a fundamental measuring unit which allows for following the growth of the foot, and can be used to compare other anthropometric measures which would be important for standardization of foot sizes in children.

STUDY GOAL

The goal of this study is to determine the length and shape of the foot in male and female children of preschool age (2-7 years) in the Republic of Croatia. Comparison between right and left feet in individual age/sex subgroups and interpretation of the growth curve of the foot in length were also performed.

STUDY POPULATION AND METHODS

The study is a continuation of the research presented in „Anthropometric measurements of the foot during growth“ (5) in which the group sample size of male and female children was defined as was an equal regional distribution of subjects established. The study encompassed preschool children living in the Republic of Croatia from the Zagreb County and the Split-Dalmatian County, and was conducted on a sample of 2745 children, totalling 5490 feet. Of this, there were 1375 boys and 1370 girls. The sample population encompassed children from 2 (1.50-2.49) to 7 (6.50-7.49) years and subjects were divided into 6 age groups. In the first age group (2 years of age) there were 242 girls and 149 boys; in the second age group (3 years of age) there were 214 girls and 181 boys; in the third age group (4 years of age) were 221 girls and 263 boys; in the fourth (5 years of age) were 196 girls and 245 boys; in the fifth age group (6 years of age) were 259

girls and 288 boys; and in the sixth age group (7 years of age) were 238 girls and 249 boys (Table 1).

Foot length was measured using measuring tape in the standing position while weight-bearing, while foot shape was determined clinically. The Kolmogorov-Smirnov test was used to describe the distribution of foot sizes. Statistical workup was conducted using the computer program STATISTICA, StatSoft, Inc., ver. 10.0

RESULTS

The distribution of lengths of the right and left foot in boys and girls of all 6 age groups was analysed in detail. No statistically significant difference was observed between lengths of right and left feet among girls and boys across all age groups. The foot grows fastest in length between ages 2-3 – by 1.8cm in girls and 1.6cm in boys. From the 3rd to 6th year, the foot grows rather uniformly, by about 1cm yearly, while the slowest growth took place in girls between their 6th and 7th year (Table 2,3). The dynamic of foot length growth is determined by an exponential curve. The difference in foot shape in individual sex-age groups are negligible. The Egyptian foot type was the most prominent across all groups, being equal in boys and girls (80% in boys, 79% in girls), the Greek type appeared in 15% of boys and 18% of girls, while the square type was found in only 5% of boys and 3% of girls (Table 4,5). No statistically significant difference was found in shape between right and left feet.

DISCUSSION

Few studies determining foot shape and length have been published in Croatian and the world literature in general. A group of authors in 1990 conducted a study in Croatia to determine the shape of feet (6). The study encompassed 500 randomly selected adult subjects. Their study showed that 90% of their study population had Egyptian type feet, and that 10% had the Greek type. These results are generally in accordance with our results. A Thai group of authors (7), in their study on a population

Table 2. Length of right foot (cm)

SEX	AGE (years)	N	\bar{X}	St. dev.	Min.	Max.	Q1	Med.	Q3
GIRLS	2	242	13.55	1.06	10.3	16.2	12.8	13.5	14.3
	3	214	15.36	1.13	12.5	19.1	14.5	15.3	16.1
	4	221	16.65	1.08	12.9	20.8	16	16.6	17.3
	5	196	17.76	1.09	15.5	20.8	17	17.7	18.45
	6	259	18.89	1.09	15.8	22.2	18.1	19	19.6
	7	238	19.66	1.21	16.5	23.2	18.9	19.5	20.4
BOYS	2	149	14.16	1.09	10.1	17.3	13.5	14.1	14.9
	3	181	15.74	1.22	11.2	18.8	15	15.7	16.6
	4	263	16.87	1.07	13.8	19.9	16.2	16.9	17.7
	5	245	18.00	1.04	15.2	21.8	17.4	18	18.7
	6	288	19.09	1.32	15.8	30.3	18.4	19	19.8
	7	249	19.95	1.43	16.5	29.8	19.1	20	20.8

of children aged 7-12 years, grouped foot shapes into 4 groups: short and stubby, small and narrow, small, and wide. The average length of the foot in boys aged 7 years was 17.5 cm, while in girls it measured 15 cm on average. In our study, the corresponding lengths of feet in boys and girls aged 7 years were 20 cm and 19.5 cm respectively, which is a significant difference from those of Thai children. The feet of Croatian boys are longer by 2.5 cm, while the feet of girls are longer by 4.5 cm. Foot length is taken as a basic reference unit which allows for follow up of foot length and is highly standardized for each country,

though it varies according to geographic localization and ethnic differences. Foot length is most often determined anthropometrically (1-12). The results of a study conducted on a population of 20,000 Chinese children showed that the most common foot shape was the intermediate type and that there is no significant change in foot shape after measuring length and width by 12 years of age (8). In this study, Ran et al. measured the average foot length in Chinese children aged 4-6 years, which measured 17.2 cm in boys and 16.9 cm in girls, which is roughly 1cm shorter than the lengths in same-aged

Table 3. Length of left foot (cm)

SEX	AGE (years)	N	\bar{X}	St. dev.	Min.	Max.	Q1	Med.	Q3
GIRLS	2	242	13.54	1.06	10.5	16.3	12.8	13.5	14.4
	3	214	15.35	1.12	12.6	19	14.5	15.3	16
	4	221	16.62	1.09	13	21	16	16.6	17.2
	5	196	17.72	1.09	15.3	20.6	16.9	17.65	18.4
	6	259	18.87	1.28	15.7	29.6	18	18.9	19.6
	7	238	19.62	1.20	16.5	23.2	18.9	19.55	20.4
BOYS	2	149	14.16	1.06	10.1	17.1	13.5	14.1	14.8
	3	181	15.74	1.20	11	19	15	15.7	16.5
	4	263	16.84	1.08	13.9	20	16.1	16.8	17.6
	5	245	17.95	1.10	12.8	21.6	17.2	17.9	18.6
	6	288	19.04	1.15	15.6	24	18.3	19	19.8
	7	249	19.92	1.32	16.3	24.1	19.1	19.9	20.7

Table 4. Foot shape in boys

AGE	FOOT SHAPE	RIGHT FOOT	LEFT FOOT	TOTAL	%
2	EGYPTIAN	122	122	244	81.88
	GREEK	23	23	46	15.44
	SQUARE	4	4	8	2.68
3	EGYPTIAN	155	155	310	85.64
	GREEK	18	18	36	9.94
	SQUARE	8	8	16	4.42
4	EGYPTIAN	231	231	462	87.83
	GREEK	24	24	48	9.13
	SQUARE	8	8	16	3.04
5	EGYPTIAN	197	197	394	80.41
	GREEK	52	52	70	14.29
	SQUARE	22	22	26	5.30
6	EGYPTIAN	214	214	428	74.31
	GREEK	54	54	108	18.75
	SQUARE	22	22	44	7.64
7	EGYPTIAN	179	179	358	71.89
	GREEK	52	52	104	20.88
	SQUARE	18	18	36	7.23

Table 5. Foot shape in girls

AGE	FOOT SHAPE	RIGHT FOOT	LEFT FOOT	TOTAL	%
2	EGYPTIAN	203	203	406	83.89
	GREEK	35	35	70	14.46
	SQUARE	4	4	8	1.65
3	EGYPTIAN	175	175	350	81.78
	GREEK	35	35	70	16.35
	SQUARE	4	4	8	1.87
4	EGYPTIAN	182	182	364	82.35
	GREEK	32	32	64	14.48
	SQUARE	7	7	14	3.17
5	EGYPTIAN	144	144	288	73.47
	GREEK	40	40	80	20.41
	SQUARE	12	12	24	6.12
6	EGYPTIAN	190	190	380	73.36
	GREEK	55	55	110	21.23
	SQUARE	14	14	28	5.41
7	EGYPTIAN	186	186	372	78.15
	GREEK	44	44	88	18.49
	SQUARE	8	8	16	3.36

Croatian children. In our country, a study measuring foot length has been conducted on a sample of 30 866 individuals for purposes relevant to the shoemaking industry (9). The average foot length in children aged 1 year measured approximately 12.5 cm, while at 7 years this value reached 20 cm, which is in accordance with our value for this age groups. In 2001, Prado-Leon and coauthors (10) published their results of anthropometric measurements in a sample of 4 759 Mexican children aged 6-11 years. Foot length was measured as well, among other things. At 6 years of age, the mean foot length of boys was found to be 18.5 cm, while in girls it was 18.2 cm. At 7 years of age, these measures reached 19.3 cm in boys and 19 cm in girls. Comparing this with our results, Croatian children have longer feet (boys and girls at 6 years of age averaged 19 cm; at 7 years, boys averaged 20 cm and girls averaged 19.5 cm) which are 5 mm longer in boys and 7 mm longer in girls. A group of authors from Malaysian (11) have also measured foot length in a group of Malaysian children aged 5 and 6 years. In their sample of 303 children, the average foot length for boys aged 5 years was 17.18 cm, while in girls it was 17.2 cm. At 6 years of age, foot length in boys measured 17.82 cm, while in girls it was 17.81 cm. Foot length of Croatian children is considerably longer than Malaysian children, particularly at 6 years of age – even at 5 years of age, Croatian boys' feet average 18 cm in length, while at 6 years it averages 19 cm. In girls at 5 years of age we averaged 17.7 cm, while at 6 years of age foot

length reaches 19 cm. In a pilot study in the Republic of Croatia in 2004, on a sample size of 1602 children aged 1 to 16 years, the Egyptian foot shape was most common, followed by the Greek type in 79 children, and only 2 children had square type feet (5). The average foot length at 1 year of age was found to be 12.65 cm, while at 7 years it reached 19.79 cm. In individual sex/age groups, there was no statistically significant difference between left and right feet. Of all of the studies which have to our knowledge been published in indexed journals in the past 20 years, and with which we have compared our results, we can conclude that preschool children in the Republic of Croatia have the longest feet.

CONCLUSION

Knowledge of anthropometric parameters for obtaining a standard foot dimensions for our population is required for normal growth and development of the foot. Obtaining anthropometric measurements for developing feet is very important because the data acquired from the measurements enables the production of ergonomic children's footwear. An ergonomic children's shoe allows for the foot to grow and develop unimpeded and prevents the development of foot deformities. In order to produce children's footwear, it is necessary to create shoe molds based on the specific foot shapes and sizes among the population of children. Shoes in Croatia today are produced based

on Italian, German and other molds, which do not necessarily cater to the unique foot dimensions of children in Croatia. Foot length is the basis for size comparison and determination of foot shape. The results obtained demonstrate that in male and female children from 2 to 7 years of age, the foot grows in length steadily every year and that there is no difference between the left and right feet. The most common shape is the Egyptian type, followed by the Greek type, and with a small contribution from the square type in all sex/age groups. This research study is a part of a database which will facilitate the monitoring and frequency of congenital and acquired foot deformities (eg. hallux valgus development). The research results will be used to define the standard average foot lengths and widths among children in Croatia.

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