







ORIGINAL ARTICLE

# Development of Medial Longitudinal Arch in Children Aged 3-10 Years

## 3-10 Yaşındaki Çocuklarda Medial Longitudinal Arkın Gelişimi

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### Note:

The research project was approved by the Bioethics Commission of the Meram Medical University (Protocol number ID: 14567952-050 / 580). In the study, all of the procedures that took place were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

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### ABSTRACT

**Purpose:** It is very important to follow the development of the medial arch in children and to detect it in the early period in case of developmental deficiency. The aim of this study is to determine the development of medial arch in children by investigating the change in plantar contact area ratio and pressure with age.

**Materials and Methods:** 51 (16 girls, 35 boys) healthy children (3-10 years old) whose consent was obtained by their families with the randomization method evaluated on the foot sole pressure measuring device were included in our study. For evaluation, medial and lateral of the anterior part of the foot, medial and lateral of the middle part, and medial and lateral of the posterior part of the foot were divided into six. In our study, the ratio of the contact surfaces of the determined areas of the foot to the entire foot sole area and the sole pressure per unit surface were statistically evaluated according to age. The obtained data were analyzed with descriptive statistics and percentage analyzes in the SPSS 11 package program.

**Results:** As a result of the statistical analysis, no statistically significant difference was found between the plantar pressure and contact area ratio values of the right and left foot regions ( $p>0.05$ ). In the analysis of the plantar pressure value according to age, there was no significant difference between the 9th and 10th ages of 3,4 and 5 years of age only in the medial of the midfoot ( $p>0.05$ ). In plantar contact area ratios; While there was a significant increase in the medial part of the anterior part of the foot and the lateral part of the posterior part of the foot above the age of 8, there was a significant decrease in the medial part of the middle part of the foot ( $p<0.05$ ).

**Conclusion:** According to the results we obtained, it was determined that 8 years of age is important in the development of MLA and with the development of the arch, foot contact is transferred from the medial of the anterior part of the foot to the lateral part of the posterior part of the foot.

**Keywords:** child, medial longitudinal arch, base contact area ratio, base pressure

### ÖZ

**Amaç:** Çocuklarda medial arkın gelişiminin takip edilmesi ve gelişim yetersizliği durumunda erken dönemde tespiti oldukça önemlidir. Bu çalışmanın amacı çocuklarda MLA gelişiminin ayak plantar temas alan oranının ve basıncının yaş ile değişiminin araştırılarak belirlenmesidir.

**Gereç ve Yöntem:** Çalışmamıza ayak taban basınç ölçüm cihazında değerlendirmesi yapılan randomizasyon yöntemi ile aileleri tarafından onamları alınmış 51 (16 kız, 35 erkek) sağlıklı çocuk (3-10 yaş) dahil edildi. Değerlendirme için ayağın ön kısmının medial ve lateral, orta kısmının medial ve lateral ve arka kısmının medial ve lateral olarak altıya ayrıldı. Çalışmamızda ayağın belirlenen bölgelerinin temas yüzeylerinin tüm ayak taban alanına göre oranı ve birim yüzeye düşen taban basınçları istatistiksel olarak yaşa göre değerlendirildi. Elde edilen veriler SPSS 11.0 paket programında tanımlayıcı istatistikler ve yüzdeler analizleri ile incelendi.

**Bulgular:** Yapılan istatistiksel analiz sonucunda sağ ve sol ayak bölgelerinin plantar basınç ve temas alan oran değerleri arasında istatistiksel olarak anlamlı fark bulunmadı ( $p>0.05$ ). Plantar basınç değerinin yaşa göre analizinde ise sadece orta ayağın medialinde 3,4 ve 5 yaşlarının 9 ve 10. yaşlarla anlamlı fark çıkmamıştır ( $p>0.05$ ). Plantar temas alan oranlarında ise; ayağın ön kısmının medial ve ayağın arka kısmının lateralinde 8 yaş üstünde anlamlı artış varken, ayağın orta kısmının medialinde anlamlı azalış dikkat çekmiştir ( $p<0.05$ ).

**Sonuç:** Elde ettiğimiz sonuçlara MLA gelişiminde 8 yaşın önemli olduğu ve arkın gelişimiyle ayak temasının ayağın ön kısmının medialinden, ayağın arka kısmının lateraline aktarıldığı belirlenmiştir.

**Anahtar Kelimeler:** çocuk, medial longitudinal ark, taban temas alan oranı, taban basıncı

## Introduction

The foot has a complicated anatomy that performs a multiple biomechanical function. It is strong enough to carry the human body and flexible enough to adapt to the ground. Anatomic rotational deviations affect posture. It allows to move in comply with the ground by absorbing the ground reaction force during walking (1). One of the most common orthopedic problems in childhood is flexible pes planus (FPP). When body weight is on the feet, medial longitudinal arch (MLA) collapses or disappears. This is defined as FPP. FPP which is seen in toddlers with normal motor development is considered physiological. The fact that the MLA begins to go up with age provides that it

takes the anatomical position of the foot. It is significant to detect in early period to follow up the development process of the medial arch and developmental disability of medial arch in children (1,2)

The space that is caused by the absence of MLA elevation in children is filled with a characteristic fat pad on medial to the middle part of the foot. Located in the medial of the middle part of the foot, this fat pad protects the pediatric foot against overload in walking and static position. Foot skeleton continues to ossify until the age of 5. While foot is growing fat pads become smaller and foot develops toward the front (2).

Deformities that develop according to the position of the MLA directly affect the foot biomechanics. Decreasing in longitudinal arch is the primary manifestation of flatfoot, resulting in the bodyweight to medial side of the foot during standing and walking. Flatfoot has therefore been regarded not only as a problem of the static alignment of ankle and foot structures, but as a dynamic functional abnormality of the lower extremities. This overloading mechanism resulting from the flattened MLA is transferred to proximal areas such as knees, hip and lower back (3).

In pes cavus deformity, it is characterized by an extremely high MLA and is typically defined as a highly curved or supinated foot type. The high arch may be located along the medial border of the foot or across the entire midfoot. The forefoot may be pronated or in neutral rotational alignment in relation to the hindfoot. In addition, although the hindfoot is usually in varus alignment, it can be in neutral, varus, valgus, calcaneus (dorsiflexed), or equinus (4).

Anthropometric data have become extremely important in terms of designing and developing different products in a globalizing world. Anthropometric data that are related to the foot is used in comfortable and safe shoe designs which especially improves health (5). Also, the dynamic foot structure in children is also closely related to the shoe industry. Designs must be suitable to changing foot structure for the manufacture of the right shoes (6).

There are limited number of studies on foot pressure distribution in children (7). Objective information about the foot structure and mechanics of movement is obtained by evaluating the plantar pressure (7,8). Plantar load distribution changes with age in children. The highest pressure is detected under the big toe in toddlers whereas the highest pressure is detected in the hind foot at the age of 7 (9). The plantar pressure distribution also changes during the motor development process (2,9-10).

After a comprehensive literature search, we could not find any studies evaluating the development of MLA in children by using baropodometer to examine the change of the base contact area ratio and plantar pressure values of the foot parts according to age. Therefore, the main purpose of the study is to exhibit change in plantar surface contact area and plantar pressure in children aged 3-10 years and age-related development of MLA.

### Material-Method

Permission with the number 14567952-050/580 was obtained from Necmettin Erbakan University Meram Medical Faculty Ethics Committee. 51 (16 girls, 35 boys) healthy children (3-10 years old) who do not have neurological and orthopedic problems that are evaluated in the plantar pressure measuring device and selected by randomization method and received consent from their families were included in our study.

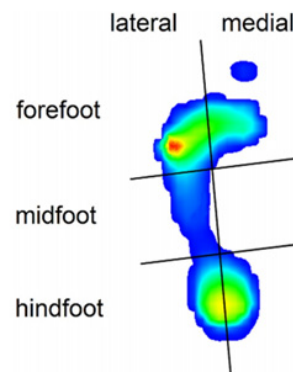
Age, gender, height and weight were recorded for all patients.

### Data collecting

The body weights of the people included in the study were measured with a Swan RGZ160 medical scales that also can make height measurement. Height measurement was performed with the same device with a sensitivity of 0.5 cm, barefoot, standing upright and deep inspiration. Body mass index (BMI) was obtained by dividing the body weight in kg to the height in meters.

Baropodometer measuring device which belongs model Diasu health technologies company in 2014 is used for the study. This device can generate data while walking and in fixed double standing. Device pressure platform and surface sensing platform include power unit, monitor, monitor-platform connections. The walking platform has 200 X 50 cm width. There are totally 25,600 sensors on the platform. It contains an average of 4 sensors in the cm<sup>2</sup>. The device achieves images with a maximum frequency of 100 fps and minimum frequency of 30 fps. It works on 0.9 A power. Initially, all children were asked to walk on the platform with bare feet at a comfortable, self-selected pace to practice, after which three full walking trials were recorded. Average data which belongs to are recorded walks were evaluated.

For the evaluation, the plantar area of the foot was divided into three parts by software similar to the literature (10). Posterior of the foot (0% - 30% length), the midfoot (30-60% length), and anterior of the foot (60-100% length). Lasse et al. (2020) similar to the research These three parts were divided into subunits, medial and lateral. 6 parts were obtained by dividing the anterior, middle and posterior parts of the foot into medial and lateral each (11) (Figure 1).



**Figure 1.** Sections of the sole of the foot performed pedobarographic analysis (11).

Total contact surface area of both feet (cm<sup>2</sup>), maximum pressure (g / cm<sup>2</sup>) value (highest pressure value in the area), average pressure, (g / cm<sup>2</sup>) value (average pressure value in the area), maximum plantar pressure values of each foot region and the ratio of the

contact surfaces of each zone to the entire plantar contact area and base pressures per unit surface were evaluated statistically by age. The average data of three trials were evaluated statistically by age. Contact area is defined as the standing area in one step (12). Maximum and average plantar pressures represent the maximum and average load in an area under the foot in one stride (13).

In view of the fact that the foot grows with age, base contact area of determined each foot zone was not evaluated in cm<sup>2</sup> value. It is evaluated by proportioning according to the area of the entire foot contact in percentages. Thus, the base contact area of each zone was evaluated according to age, proportioning to the percentage of the contact area of the whole foot.

### Statistical analysis

The data obtained was evaluated with descriptive statistics and percentile analyses in the SPSS 11 package program. Student t test was used to evaluate the differences in plantar pressure and contact area of the right and left foot. One way ANOVA test was used to compare separately plantar pressure and contact area data between age groups. Significant differences which are in parameters were considered as  $p < 0.05$ .

### Results

Statistical descriptive values were obtained by the Descriptive Statistics method. A total of 51 children that is eight in the age group of three, seven in the age group of four and six from all age groups from five to ten years old were included in the study (16 girls, 35 boys).

The body weight average was found as  $23.43 \pm 11.00$  kg (min: 10.00 kg, max: 72.00 kg), the height average  $113.33 \pm 0.184$  cm (min: 60 cm, max: 160 cm). Average Body Mass Index (BMI) was  $17.76 \pm 5.03$  kg / m<sup>2</sup> (min: 8.90 kg / m<sup>2</sup> max: 31.70 kg / m<sup>2</sup>).

Foot total contact surface area (CSA) was  $104.48 \pm 23.79$  cm<sup>2</sup> (min: 13.25 cm<sup>2</sup>, max: 147.20 cm<sup>2</sup>), maximum pressure (Max P)  $1187.77 \pm 262.06$  g / cm<sup>2</sup> (min: 302.10 max: 1407.90 g / cm<sup>2</sup>) and mean pressure (Mean P)  $678.14 \pm 186.42$  g / cm<sup>2</sup> (min: 312.40, max: 1,104.50 g / cm<sup>2</sup>) (Table 1).

**Table 1.** Demographic data of all participants

	Min.	Mak.	Average $\pm$ SS
Weight (kg)	10.00	72.00	23.43 $\pm$ 11.00
Height (cm)	60.0	160.0	113.33 $\pm$ 0.184
BMI	8.90	31.70	17.76 $\pm$ 5.03
CSA (cm <sup>2</sup> )	13.25	147.20	104.48 $\pm$ 23.79
Max. P (g/cm <sup>2</sup> )	302.10	1407.90	1187.77 $\pm$ 262.06
Mean P (g/cm <sup>2</sup> )	312.40	1104.50	678.14 $\pm$ 186.42

(BMI; Body Mass Index. CSA; contact surface area. Max. P; maximum pressure.

Mean P; mean pressure)

**Table 2.** Statistical evaluation of plantar pressure difference of foot regions according to age in children included in the study.

ZONE	FOOT AREA	LEFT		RIGHT			
		p	Significant difference between ages	p	Significant difference between ages		
MEDIAL	ANT.	0.000	3-7, 3-8, 3-9, 3-10	0.000	3-6, 3-7, 3-8, 3-9, 3-10,		
			4-7, 4-10		4-7, 4-8, 4-9, 4-10,		
			5-10,		5-7, 5-8, 5-9, 5-10,		
			6-10,		6-9, 6-10		
			MIDDLE		0.002	3-7, 3-8	3-7, 3-8,
						4-7,	4-8,
	POST.	0.000	3-6, 3-7, 3-8, 3-9, 3-10	3-7, 3-8, 3-9, 3-10,			
			4-7, 4-8, 4-9, 4-10	4-7, 4-8, 4-9, 4-10,			
			5-8, 5-9, 5-10	5-7, 5-8, 5-9, 5-10,			
			6-10,	6-10,			
			7-10,	7-10,			
			8-10,	8-10,			
LATERAL	ANT.	0.000	3-7, 3-8, 3-9, 3-10,	0.000	3-7, 3-8, 3-9, 3-10,		
			4-7, 4-8, 4-9, 4-10,		4-7, 4-8, 4-9, 4-10,		
			5-7, 5-8, 5-9, 5-10		5-7, 5-8, 5-9, 5-10		
			6-9, 6-10		6-9, 6-10,		
			MIDDLE		0.000	3-7, 3-9, 3-10	3-7, 3-9, 3-10,
						4-9, 4-10,	4-9, 4-10,
	POST.	0.000	3-7, 3-8, 3-9, 3-10,	3-8, 3-9, 3-10,			
			4-7, 4-8, 4-9, 4-10,	4-8, 4-9, 4-10,			
			5-7, 5-10,	5-7, 5-10,			
			6-10,	6-10,			
			8-10,	8-10,			
			8-10,	8-10,			

In the examination using the Independent-Samples Test, no statistically significant difference was found between the plantar pressure and area values on the right and left in the 6 zones of the foot ( $p > 0.05$ ).

One-way Anova test was used to compare plantar pressure data between age groups separately.

Accordingly, a significant difference was found between ages in all regions in terms of pressure difference ( $p < 0.05$ ) (Table 2).

It takes attention that there is no significant difference right and left medial-middle foot plantar pressure in between the ages of 3-5 and at the age of 9 and 10. A significant difference was found between all ages in the other zones except the medial of the middle of the foot ( $p < 0.05$ ).

Children that is included in the study, the contact area of in eht children each foot zone was proportional to the total foot contact area and the contact area in% was determined.

Oneway Anova test was performed to compare the ratio data of plantar contact area among age groups. Accordingly, in the medial of all feet; in the front and middle zones and in the lateral of all feet in posterior zones significant difference between contact area according to ages ( $p < 0,05$ ) (Table 3).

**Table 3.** Statistical analysis of the rates of foot contact by zones in participating children according to age

ZONE	LEFT		RIGHT		
	FOOT AREA	P	Significant difference between ages	P	
MEDIAL	ANT.	<b>0.000</b>	3-8, 3-9, 3-10	<b>0.002</b>	3-10
	MIDDLE	<b>0.001</b>	3-9, 3-10,	<b>0.000</b>	3-7, 3-8, 3-9, 3-10
			4-9, 4-10		4-7, 4-8, 4-9, 4-10,
			5-9, 5-10		5-9, 5-10,
			6-9, 6-10		6-9, 6-10
			7-9, 7-10	8-9	
	POST.	0.420		0.368	
	ANT.	0.108		0.373	
	MIDDLE	0.474		0.283	
	LATERAL	POST.	<b>0.008</b>	3-9, 3-10,	<b>0.002</b>
				4-9, 4-10	
					5-9, 5-10,

According to the evaluation results; After the age of 8, there was a significant increase in the contact area ratio in the medial of the anterior part of the foot and the lateral part of the posterior part of the foot, while a significant decrease was detected in the medial part of the middle part of the foot ( $p < 0,05$ ). It was found that the contact area ratio did not change with age in other parts of the foot except these parts ( $p > 0.005$ ).

Whereas there was a significant increase in the medial-anterior and lateral-posterior part of foot above 8 years of age, a significant decrease was determined in the

medial-middle part of foot ( $p < 0.05$ ). Accordingly, it was observed that contact area rate does not change with age in other parts of the foot except these parts. ( $p > 0.005$ ).

## Discussion

It is known that child's foot completes its development with growth. It is not correct that is evaluated like an adult foot with regard to orthopedic evaluations in this process (14). The main purpose of this study is to generate age-specific foot characteristics data for children aged 3-10 years. The study we conducted for this purpose is the first study to research on a sample of preschool and primary school children.

Berstscht et al. (2004) stated in her study on children that the structure of the middle foot changes with age, and this change is directly related to the development of MLA (2). During motor development processes such as standing and walking in children, it has been reported that MLA rises from the ground as the fat pads in the feet decrease (15).

Our work has several strengths. First, we collected data from a sample of preschool and primary school children aged 3-10 years ( $n = 51$ ). Second, to evaluate the detailed plantar pressure distribution variable, the underfoot zone was divided into zones and each section was evaluated individually. Third, since the preliminary analysis showed significant differences between them, their results were examined separately, especially for the left and right feet. Fourth, the relationship between age groups was examined for the analysis of age-related variability.

However, our study has a few limitations. First, foot characteristics in growing children and adolescents should be derived from longitudinal studies that allow us to evaluate natural changes in individual growth and development (16). Although we recorded height and weight values in our study, we ignored this relationship in statistical analyzes and kept the age variable in the foreground. Second, this study can be accepted as a preliminary study and can be studied on a larger sample by also considering the gender variable. Although we did not evaluate the structure and sex relationship, our additional findings did not show foot asymmetry between the feet. Participants did not report foot pain in the last 30 days, and the prevalence of overweight / obesity in our sample was very low (3.9%), so we completed our study assuming that the children were apparently healthy individuals with no foot problems.

A study with is in children aged 6-14 years conducted by Kasović et al. (2020) reported that there was no significant difference between mean pressure value and contact areas of the right and left foot (17). There was no statistically significant difference between the right and left plantar area pressure and area values of the 6 zones of the foot in our study. Similarly, our study

supports Kasović et al (2020).

The posterior of the foot is the first part of the foot that touches the ground while walking. Also, it absorbs the peak point that hits floor reaction forces. Therefore, the region where highest plantar pressure values are obtained is the foot zone (18). However, plantar pressure distribution across the plantar surface of the foot may change with the maturation of the foot during growth and development.

Some studies have reported that age and physical activity level can affect plantar pressure distribution in children (19,20). A study by Mickle et al. Reported that higher plantar pressure levels under the posterior region of the foot were associated with lower physical activity levels, while higher levels of plantar pressure under the anterior region of the foot were significantly associated with moderate, vigorous, and moderate-to-vigorous physical activity. Considering these studies, the variable of plantar pressure of the foot regions is important according to age and physical activity level.

In our study, we did not question the level of physical activity, but there was a significant difference in pressure difference between ages in all regions. In the analysis of the plantar pressure value medial to the middle of the foot according to age, 9-10. It was noteworthy that there was no significant difference between ages and 3-6 years. This situation is evaluated as the increase in plantar pressure value of the medial of the middle part of the foot at 7 and 8 years of age, and a decrease after the 8th age. In contrast to the medial part of the middle of the foot, the significant difference is quite distinct between all ages in all other foot regions.

Kothari et al. (2016) reported that decreased MLA causes knee, hip and back pain in children. In the study conducted by Pfeiffer et al. (2006) On 948 children, it was reported that the arch reached the normal anatomic position with age when the MLA position was examined (22). Pfeiffer et al. (2006) found that MLA reduced in 54% of 3-year-olds and 24% of 6-year-olds (2). The arch physiologically reaches its anatomical position by factors such as decreased joint lacticity and increased the strength of the muscles that support MLA with the increase of age (22,23).

The MLA is located in the medial part of the middle of the foot. Consequently, the middle of the foot contact area gives information about the development of this arch. The results of our study support the development of MLA, and it was established that the ratio of the medial contact area of the middle part of both right and left feet to the whole foot contact area decreased after 8 years of age.

According to the results we have obtained; medial to the middle part of the foot; It was determined that the plantar contact area ratio (the ratio of the part of the region in contact with the ground to the entire

region) and contact pressure evaluations decreased after the age of 8 with the development of MLA. The resulting compensation mechanism transferred the foot contact medially to the anterior part of the foot and lateral to the posterior part of the foot. So we saw that with growth, MLA developed and foot pressure was transferred to anterior medial and posterior lateral fat.

## Conclusion

As a result, this study is the first study that examines pressure distribution values and contact area of the foot zones in children aged 3-10 and evaluates the development of MLA with these data. As a result; After the age of 8, it was found that with the development of the MLA, the plantar contact area ratio and contact pressure values of the medial part of the foot decreased, while the pressure was transferred to the medial of the anterior part of the foot and lateral to the posterior part of the foot.

Our results are going to be extremely beneficial including orthopedics and podiatrists for healthcare professionals who can identify children with foot dysfunction and make recommendations for specific orthopedic shoes or foot pads. In addition, we think that our data will help especially to identify preschool and primary school teachers' students who are at extreme risk and to monitor MLA in children and early treatment approach.

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## Conflict of Interests

The authors declare that are no conflict of interests.

## Author Contribution

Design: MTY, AK, NAY, SA, MED; Data Collection or Processing: NAY., HNK, DAS; Analysis or Interpretation: MTY, AK, NAY; Literature Search: HNK, DAS.; Writing: NAY, AKN

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