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Evaluation of the medial longitudinal arch: a comparison between the dynamic plantar pressure measurement system and radiographic analysis

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Objectives: The measurement of the medial longitudinal arch (MLA) of the foot is a controversial issue in orthopedics. Several methods have been developed to define and determine the MLA, but none of them are universally accepted. The purpose of this study was to compare some statically obtained radiographic angles with the dynamic plantar pressure distribution measurement system for the evaluation of the MLA in healthy individuals.

Methods: A total of 95 subjects (72 females, 23 males; mean age 37.8 years; range 11 to 85 years) were retrospectively evaluated. All the subjects were referred to the pedobarography laboratory for varying causes, had foot radiographies, and were evaluated as having normal feet. On standard lateral weight-bearing radiographs of the foot, the lateral talocalcaneal angle, talo-first metatarsal angle, talohorizontal angle, and calcaneal pitch angle were measured. The plantar pressure distribution was measured by the EMED-SF system. To evaluate the MLA, the arch index method was used. The arch index was calculated by the ratio of the pressure area of the midfoot to the sum of the forefoot, midfoot, and the hindfoot areas. Correlations between the radiographic angles and the arch index were analyzed by the Pearson correlation test.

Results: The mean values of the lateral talocalcaneal angle, talo-first metatarsal angle, talohorizontal angle, and calcaneal pitch angle were 43.2, 7.2, 29.5, and 41 degrees, respectively. The mean value of the arch index was 0.12 (range 0.04 to 0.17). There was no significant correlation between the arch index and gender ($r=-0.10$, $p>0.05$). The talo-first metatarsal ($r=0.38$) and talohorizontal ($r=0.19$) angles were found to be in significant correlation with the arch index ($p<0.05$), whereas the talocalcaneal ($r=-0.16$) and calcaneal pitch ($r=-0.10$) angles did not show correlation with the arch index ($p>0.05$).

Conclusion: The arch index method is a simple and reproducible pedobarographic measurement for the evaluation of the MLA. However, the angles measured on statically obtained radiographs and showing correlations with the arch index may give similar results concerning the MLA. Both static and dynamic methods can be utilized in the evaluation of the MLA.

Key words: Anthropometry; dermatoglyphics; foot/radiography; reference values.

Foot problems such as pes cavus and pes planus are frequently seen in orthopedic practice. The height of the medial longitudinal arch (MLA) is the most important reference in determining the presence or the degree of pes cavus and pes planus. The MLA is formed by an osseous, ligamentous, and tendinous complex and its configuration is dependent on age and genetic factors.[1]

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Assessment and measurement of the MLA has been a controversial issue in orthopedics.[2,3] There is no universally accepted clinical or radiographic method of determining the height of the MLA. Clinical examination is examiner-dependent and subjective. There are many techniques proposed for an objective measurement of the MLA.[2-5] These can be classified as direct and indirect methods. Direct methods include anthropometric measurements and radiographic evaluations,[2,3] while indirect methods include footprint and photographic analyses.[4,6] Although footprint analysis is a simple, cost-effective and easily available method, some authors contend that footprint analysis, due to its static nature, does not always reflect the real MLA of the foot and gives inaccurate results.[4,7,8]

Today, several radiographically determined angles are considered in the evaluation of the arch of the foot. However, this technique is a static method and does not demonstrate the dynamic nature of the foot. Walking is a complex, dynamic process. Recently, a dynamic method, pedobarography, has become popular to evaluate foot problems.[1,4,5,7,9]

In this study, we hypothesized that the dynamic method of pedobarography and the static method of radiographic measurements should yield different results in the evaluation of MLA. In an attempt to determine differences between the dynamic and static methods, we aimed to seek correlations between pedobarographic measurements and radiographic measurements of the lateral talocalcaneal, talo-first metatarsal, talohorizontal, and calcaneal pitch angles. To our knowledge, there is no study comparing these methods in healthy individuals in a wide range of age group.

Cases and methods

In this retrospective study, 95 subjects (72 females, 23 males; mean age 37.8 years; range 11 to 85 years) were evaluated. All the subjects were referred to the pedobarography laboratory for varying causes, had foot radiographies, and were evaluated as having normal feet.

A lateral weight-bearing roentgenogram was obtained for each foot with a standardized method described by Simons.[10] The films were taken on a wooden platform with the medial border of the hindfoot parallel to the cassette. All the angles were measured as described by Simons[10] and Vanderwilde et al.[11] The following four lines were used to describe the angles: a) calcaneal line along the plantar surface of the calcaneus; b) talar line (the longitudinal axis of the talus joining the points marked in the middle of the superior and inferior parts of the distal and proximal talus); c) metatarsal line (the line joining the midpoints of the superior and inferior cortices of the first metatarsal); d) horizontal line (the line between the most plantar process of the calcaneus and the metatarsal head of the fifth metatarsal) (Fig. 1).

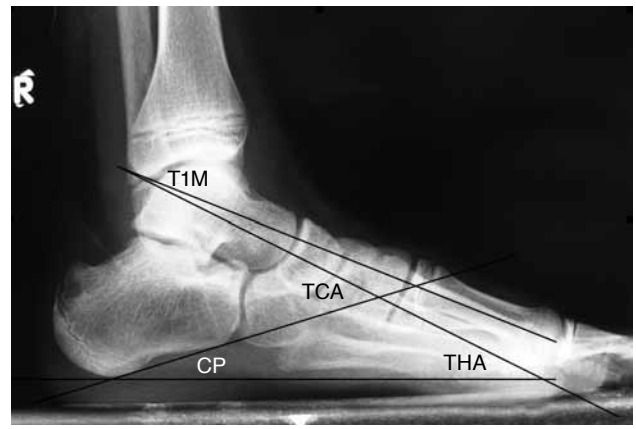

Fig. 1. The angles measured on a lateral roentgenogram. TCA: Talocalcaneal angle; T1M: Talo-first metatarsal angle; CP: Calcaneal pitch angle; THA: Talohorizontal angle.

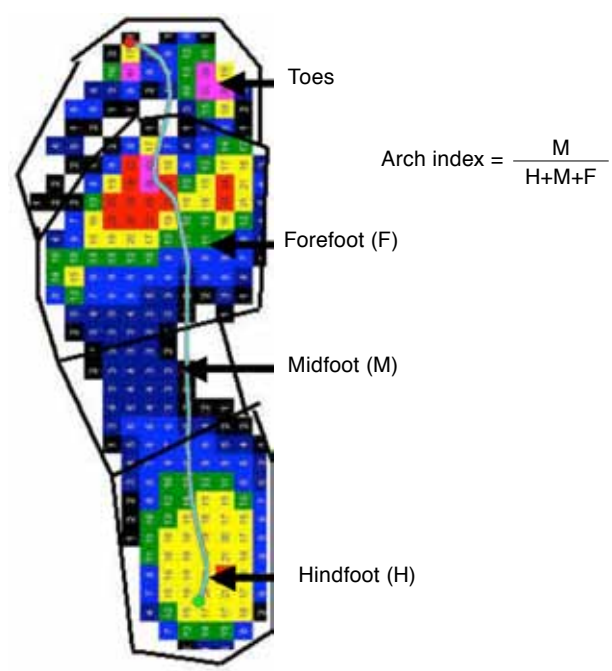

Fig. 1. Pressure view of the four regions called masks divided by the EMED-SF system. The arch index is calculated by dividing the area of the middle foot to the total area of the forefoot, midfoot, and hindfoot.

Table 1
The lowest, highest, and mean values of the arch index and angles

	Lowest	Highest	Mean	Standard deviation
Arch index	0.04	0.17	0.12	0.04
Talocalcaneal angle (°)	26.0	64.0	43.2	7.2
Talo-first metatarsal angle (°)	-10.0	32.0	7.2	7.2
Talohorizontal angle (°)	3.0	50.0	29.5	7.6
Calcaneal pitch angle (°)	18.0	66.0	41.0	6.9

On lateral radiograms, we measured the most commonly used four angles for the measurement of the MLA:

a) Lateral talocalcaneal angle. It decreases with equinus or varus angulation of the hindfoot and increases with pes calcaneus and valgus heel.[11]

b) Talo-first metatarsal angle. On cavus foot, the angle presents as increasing negative values depending on the severity of the deformity, and as increasing positive values in flatfoot. Many authors consider this angle the most important one to describe the arch height.[11]

c) Talohorizontal angle. It provides information on the inclination of the talus.[11]

d) Calcaneal pitch angle. The alignment of the hindfoot is determined by this angle. It increases in cavus deformity, and decreases in flatfoot.[11]

Plantar pressure measurements were made by the EMED-SF system (Novel GmbH, Munich, Germany). It has a 44.5 x 22.5 cm platform with two integrated-capacitive sensors per cm^2 sampling data at 71 Hz. The platform was integrated into a wooden walkway of 7 x 1 m covered with a thin layer of leather. All subjects walked on the platform bare feet and with their regular speed and step length. The pressure recordings were then transferred to the Novel-ortho software (Novel GmbH) for further analysis.

For evaluation of the height of the MLA, we used a method similar to the 'arch index' method described by Cavanagh and Rodgers.[7] These authors measured the arch index by dividing the length of the foot without toes into three equal parts as the forefoot, midfoot and hindfoot. They defined the arch index as the division of the pressure area of the midfoot to the total length. In our method of determining the arch index, the pressure pictures were divided into four parts called 'masks' by a commercial software (Automask, Novel-ortho, Germany), including the toes, forefoot, midfoot, and hindfoot. The mask of the toes is eliminated and the remaining masks are calculated by the system. On pressure pictures, the boundaries of the forefoot, midfoot, and hindfoot mask areas are determined by the Automask software, by the lines drawn at 50% and 69% of the total length of the foot. The boundary between the toes and the forefoot is defined by the peak pressure gradients of these two areas. The arch index was calculated by the ratio of the pressure area of the midfoot to the sum of the forefoot, midfoot, and the hindfoot areas (Fig. 2).

Correlations between the angles and the arch index were analyzed by the Pearson correlation test.

Results

The mean values of the lateral talocalcaneal, talo-first metatarsal, talohorizontal, and calcaneal pitch angles were 43.2, 7.2, 29.5, and 41 degrees, respectively (Table 1). The mean value of the arch index was 0.12 (range 0.04 to 0.17). The results of the correlation analysis are shown in Table 2. There was no significant correlation between the arch index and gender ($r=-0.10$, $p>0.05$). The talo-first metatarsal ($r=0.38$) and talohorizontal ($r=0.19$) angles were found to be in significant correlation with the arch index ($p<0.05$), whereas the talocalcaneal ($r=-0.16$) and calcaneal pitch ($r=-0.10$) angles were not ($p>0.05$).

Table 2
Correlation of the arch index with gender and foot angles

	r	*p*
Gender	-0.10	>0.05
Talocalcaneal angle	-0.16	>0.05
Talo-first metatarsal angle	0.38	**<0.05**
Talohorizontal angle	0.19	**<0.05**
Calcaneal pitch angle	0.10	>0.05

Discussion

The medial longitudinal arch is the major component affecting foot functions. Evaluation of the arch is controversial. It is essential to evaluate the arch definitely for correct diagnosis and appropriate decision making for reconstructive procedures. False positive diagnoses derived from both clinical examination and radiographic or pedobarographic measurements of the arch may result in unnecessary use of arch supports and orthopedic boots, and thus economic loss and psychological side effects.

Currently, there are many methods for evaluating the MLA both statically and dynamically.[2,4-7,9,12,13] Due to its simplicity and reproducibility, footprint analysis is one of the most popular methods to assess the MLA.[7]

Although footprints are widely used by several authors for analysis and description of the MLA, there is not a universally accepted method for measurements and analysis. Many methods have been defined for both static and dynamic measurements.[4,5,7,9,12,13] Cavanagh and Rodgers[7] claimed that static (standing) footprints were of less value than dynamic (walking) footprints in reflecting arch changes. They defined the arch index and calculated it as the ratio of the middle area of the foot to the whole footprint area after eliminating the are of the toes.[7] Staheli et al.[2] defined the arch index as the ratio of the width of the foot in the area of the arch to that of the heel. Other methods have also been used to define the medial arch.[4,5,13] Chen et al.[14] reported that the subarch angle showed significant correlations with radiographic parameters in children with flatfeet and could be easily and accurately obtained from a capacitive forceplate. Conversely, there are authors who claim that footprints are unreliable because they are easily influenced by soft tissue changes.[8,15] Footprints are also used for screening studies.[16-18]

Several static parameters have been investigated to predict the medial arch either directly or indirectly in dynamic settings such as walking or running.[1,7,12-14] Some reports contend that the dynamic behavior of the arch can be assessed by the methods of static measurements,[1,14] while some claim the opposite.[8,15] Controversy exists as to which method is reliable, easy, reproducible, clinically useful and meaningful. In our study, we evaluated the correlation of some routinely obtained angles on roentgenograms in clinical practice with pedobarographic measurements. We also investigated whether these statically derived angles corresponded to the arch of the foot during dynamic foot posture. Although several reports exist comparing radiographic and pedobarographic data, they have been mostly conducted with small case series of pathologic feet and of specific age groups.[1,14] To our knowledge, there is no study in the literature performed in healthy individuals of a wide age range. Inclusion of a wide age range of individuals represents an advantageous feature of the study in terms of better compatibility of our data with the patient population that we encounter in our daily practice. On the other hand, this wide age range may be a disadvantage because reference points obtained from static radiographic measurements may differ from those of adults in the pediatric age group due to cartilaginous structure of the tarsal bones.

Talar inclination is commonly used to describe the MLA. The talo-first metatarsal and talohorizontal angles are routinely used for determining talar inclination. Increased talar inclination with pronation of the talus above the calcaneus results in a decrease in the arch height.[11] The lateral talocalcaneal and calcaneal pitch angles are usually used for the evaluation of the hindfoot.[6,11] Similar to our study, Saltzman et al.[4] found that the calcaneal pitch angle showed the least correlation with the clinical measurements of the arch height. Kanatlı et al.[1] found significant correlations between the arch index and the talo-first metatarsal and talohorizontal angles in 38 children with flexible flatfeet. Our study showed similar results in normal feet of individuals of a wide age range. In our study, the arch index obtained from dynamic pedobarographic measurements showed significant correlations with the talo-first metatarsal and talohorizontal angles ($p<0.05$). In our opinion, evaluation of the arch by the arch index method is a reliable, simple, and reproducible dynamic pedobarographic technique. The angles showing significant correlations may provide information about the MLA of the foot, as may the arch index method of footprint analysis.

The dynamic pedobarographic measurement systems have several advantages over radiographic measurements. Repetitive X-ray analyses especially in follow-up of pediatric patients with feet pathologies such as pes planus may cause problems in the long-term such as exposure to cumulative radiation. The radiograms should be obtained with correct po-

sition and technique to ensure correct determination of the angles. On the other hand, dynamic systems may not be available in all clinics. Therefore, the talo-first metatarsal and talohorizontal angles obtained on good-quality, correct-positioned foot radiographs may provide sufficient data to evaluate the MLA.

In conclusion, the arch index method is correlated with the radiographically obtained talo-first metatarsal and talohorizontal angles and it is easily and simply calculated by the EMED-SF system. Although pedobarographic methods are valuable, reproducible and reliable in defining the MLA of the foot, the talo-first metatarsal and talohorizontal angles also give helpful information on the height of the arch where a pedobarograph is not available. The talo-first metatarsal and talohorizontal angles obtained statically may predict dynamic posture of the foot. Contrary to common belief, both static and dynamic methods can be used effectively for the determination of the medial arch of the foot.

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