Assessment of the Medial Longitudinal Arch in children with Flexible Pes Planus by Plantar Pressure Mapping

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Introduction : **Plantar Pressure mapping was introduced as a new modality for assessment of the height of the medial longitudinal arch of the foot. Therefore, the aim of this study is to correlate the plantar pressure mapping readings of arch index contact force ratio (AICFR) in children with flexible pes planus with radiographic measurements and static plantar footprints in order to determine the reliability of pressure mapping as a modality for the assessment and follow up of the flat foot deformity.**
Patients and methods : **Radiographic measurements, foot prints, and pressure mapping scans were recorded for each foot at initial presentation and at latest follow up in 28 children (56 feet) with flexible pes planus.**
Results : **A positive correlation of pressure mapping results was found with the talo-first metatarsal angle, the calcaneal pitch angle, as well as the footprint scans (P < 0.001).**
Conclusion : **This study demonstrated that plantar pressure mapping is a reliable and effective tool in screening, diagnosis, and follow up of children with flexible pes planus.**

Keywords : plantar pressure maping ; flexible pes planus ; medial longitudinal arch in children.

INTRODUCTION

The medial longitudinal plantar arch (MLA) has crucial functions in foot biomechanics. It does for instance act as a foothold and shock absorber during walking. An increase or reduction of MLA (pes cavus or flatfoot, respectively) can interfere with these functions and can lead towards muscular imbalance, articular misalignment, compensatory pronation of the foot, and gait abnormalities *(17)*.

The MLA can be assessed by different methods. These include pure clinical observation and quantitative techniques, which involve direct and indirect anthropometrical measuring methods.

The *clinical evaluation of posture* is subjective, thus affecting its use in scientific studies. Moreover, it does not allow for a concise follow-up of the changes related to a treatment potentially altering the shape of the foot. *Radiographic analysis* overcomes the problem of being non quantitative but is relatively expensive. Furthermore, exposure to radiation represents a risk for children. This makes radiographic based techniques less applicable for large-scale studies involving a pediatric population.

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Static plantar prints can be easily obtained with a pedograph. They are inexpensive, simple, fast, and non-invasive. This technique does allow obtaining a permanent register of morphological features of the foot. The MLA measurement in plantar prints has already been correlated with radiographic assessment and has therefore been the method of choice in recent works in different populations *(10,17)*. Nevertheless some investigators did report deceptive results in the use of footprint measurements in predicting arch height. This might be related to inaccuracy of data collection and variations of the weight-bearing conditions when collecting the footprints *(3,12,14)*.

Although *Pressure mapping* is still not widely used in orthopedic practice, yet the study of plantar pressure measurement did receive a considerable amount of attention in the assessment and treatment of various orthopedic disorders. However, so far only few studies correlated the measurements derived from plantar pressure mapping with those from radiographic assessment of arch height and foot structure, nor with data from footprints.

The clinical application of foot pressure assessment systems has been the subject of many studies *(5,6,7,8,12,13,18)*. Pedobarography as a measurement of foot pressure was started in the early 1980's. Since then a growing interest evolved. Especially in those studies focusing on biomechanics, diabetic foot, orthopedic surgery and orthosis-shoe modification. Nevertheless, the amount of studies related to foot pressure in children remains sparse. This despite the fact that pressure analysis could contribute to provide exact information on the functioning of the foot in youngsters. Seen differences in morphology and anatomy of the foot in growing children when compared to adults, one can expect differences in function of the foot in a paediatric population when compared with adults *(8)*.

Therefore, the aim of this study is to correlate the plantar pressure mapping readings of arch index contact force ratio (AICFR) in children with flexible pes planus with radiographic measurements and static plantar footprints. This in order to report on the reliability of pressure mapping as a modality for the assessment and follow up of the flat foot deformity.

PATIENTS AND METHODS

A total of 28 children (56 feet) with flexible pes planus presenting to the foot clinic in Ain Shams University Hospital between years 2011 and 2014 were enrolled in this study. The mean age was 7 years (age range 4 to 11 years). 17 patients were males and 11 were females. Radiographic measurements, foot print, and pressure mapping scans were recorded for each foot at initial presentation and at latest follow up. The current study was approved by the local ethical committee.
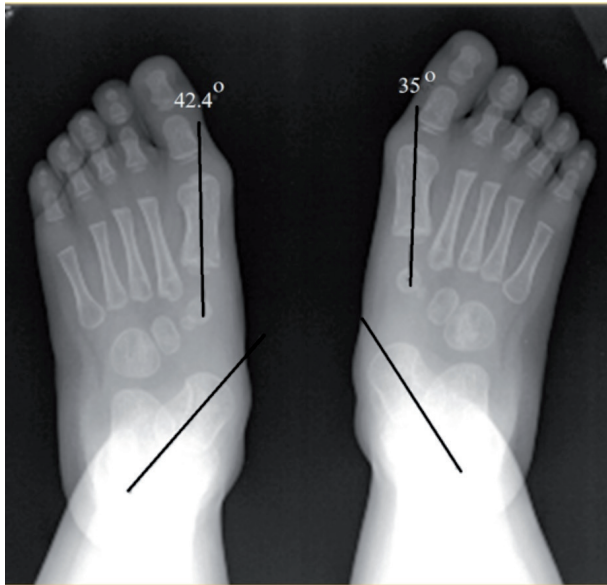
Radiographic Measurements

Radiographic parameters included measurement of the talo-first metatarsal angle (TFM) , calcaneal pitch angle (CP) , and talo-calcaneal angle (TC) on standing lateral view of the foot. The talo-navicular angle (TN) and AP talo-first metatarsal angle (APT-FM) were measured on standing anteroposterior view. (Fig. 1)

The Talo–first metatarsal angle (TFM) shows the degree of inclination of the talus in relation to the first ray. It was used as a measure for the relationship between the hind and the forefoot, this to quantify the medial longitudinal arch. Cavus deformity causes the angle to have an increasing negative value, whereas in flat feet, the angle will become increasingly positive. Some authors have used this angle to describe the arch height *(1,15,17)*.
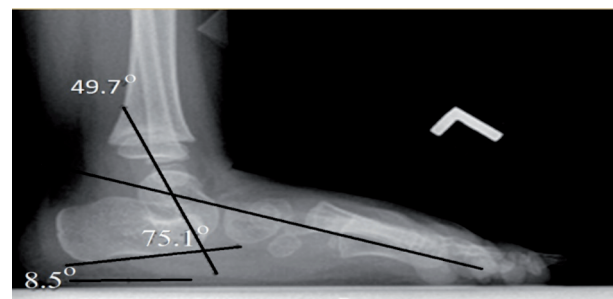
Fig. 1. — Standing lateral view of the left foot showing the radiographic measurement of the TFM = 49.7° (Intersection of the long axis of the talus and first metatarsal),
CP = 8.5° (Intersection of the long axis of the calcaneus and horizontal ground line), and TC = 75.1° (Intersection of the long axis of the talus and calcaneus) angles.

Fig. 2. — Standing anteroposterior view of both feet showing the radiographic measurement of the APTFM angle.


Fig. 3. — Staheli Index SI = b/c; where (b) is the width of the MLA,s area; (c) is the maximal width of the heel print, being (c) parallel to (b) *(21)*.

The Calcaneal pitch angle (CP) represents the alignment of the hindfoot. Some authors did use it to describe the arch height. Cavus deformity increases and flat foot decreases the CP angle. CP was used to quantify the degree of plantar flexion of the calcaneus.

The talocalcaneal angle (TC) describes the angular deformity of the rear foot. The angle decreases when there is equinus or varus angulation of the hindfoot and increases when there is calcaneus or valgus angulation of the hindfoot *(15,19)*.

The talo-navicular angle (TN) represents the degree of talar head coverage by the concave articular surface of the navicular. It was used to quantify the forefoot abduction based on the talo-navicular relationship.

Similarly, the AP talo-first metatarsal angle (APTFM) has been used used as a measure of forefoot abduction. It has shown especially useful in younger children in whom the ossific nucleus of the navicular is not yet visible (Fig. 2).

Footprint Measurements

Footprints were acquired using a pedograph in bipedal position with bilateral weight bearing. The prints were recorded and assessed from a static Harris mat imprint. Furthermore static footprints were recorded for each foot in half body weight–bearing position. For each foot, the widest part of foot at the level of the the medial longitudinal arch and the heel were measured. The former value was then divided by the latter to calculate the Staheli index (SI), as described by Staheli et al. *(21)* (Fig. 3). According to Staheli et al., the normal values have broad range from 0.3 to 1.0 through adulthood *(10,11,22,23)*.

Plantar Pressure Mapping Measurements

Barefoot pressure mapping was taken by the use of MatScan®, from Tekscan, Boston, USA. MatScan is a computerized system that one allows to obtain data with respect to plantar pressure, force and area. It has 2228 sensors with 1.4 sensors/ cm2 with a scanning speed of 100 Hz.

A standardized posture was used in each subject. The feet were positioned shoulder width apart and even with each other on a foot template. The hands are positioned on the wall in order to prevent truncal rotation. A plumb line was used to avoid any truncal listing.
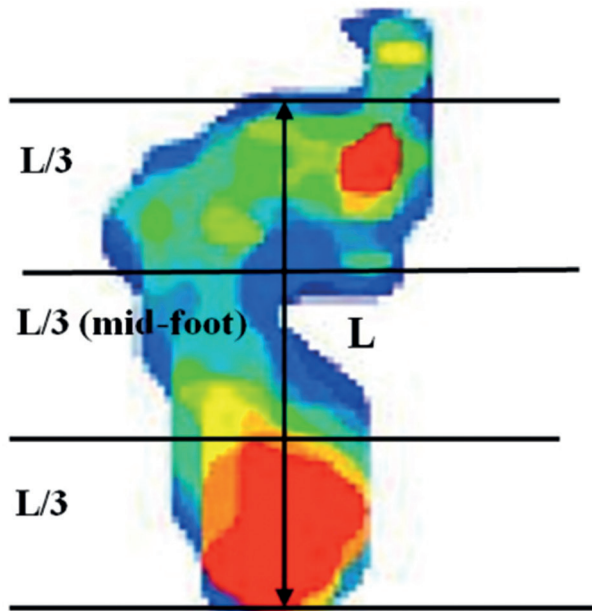
Fig. 4. — Pressure Mapping Scan Image.
The point of the second toe and the mid-heel joined together to form (L) the length of footprint, excluding the toes. The length of footprint was then divided into three equal parts with the mid-foot being the middle part of the three.
Arch index = Midfoot area / Total foot area

Bipedal static pedobarographs during standing were collected recording all the peak pressure values at each sensor location.

A static pedobarograph parameter was developed by adopting the Arch Index AI (Cavanagh and Rodgers, 1987) *(2)* approach. The Harris mat with pressurized film did allow providing quantifiable data

for analysis of the arch index contact force ratio (AICFR) described below.

The point of the second toe and the mid-heel joined together to form (L), the foot axis. A third point was then marked on the foot axis L at his most posterior position on the footprint. To determine the most anterior point of the axis L the toes are ignored. Subsequently the encased length of the foot axis (between its most anterior and most posterior position) within the main body of the footprint was divided into three equal lengths (Fig. 4). This divides the footprint in a fore, mid and rear foot portion.

Based on the area that had been activated (contact area) and the pressure recorded by individual pressure sensors, the load applied on the midfoot (and the other areas of the foot) was calculated. The Arch Index Contact Force Ratio (AICFR) is then calculated by dividing the Contact Force on the midfoot area by the Contact Force on the Total Foot Area. It does represent the ratio of the midfoot loading to the total loading of the contacted foot with the toes ignored *(12)*. (Mean for the flatfoot patient: > 0.26).

Arch index contact force ratio (AICFR) = Contact Force on Mid foot area / Contact Force on Total foot area. (Fig. 5) illustrates pressure mapping image recordings of flat feet versus normal feet.

Data analysis

Means and standard deviations were obtained for all dependent measures. The strengths of associa-
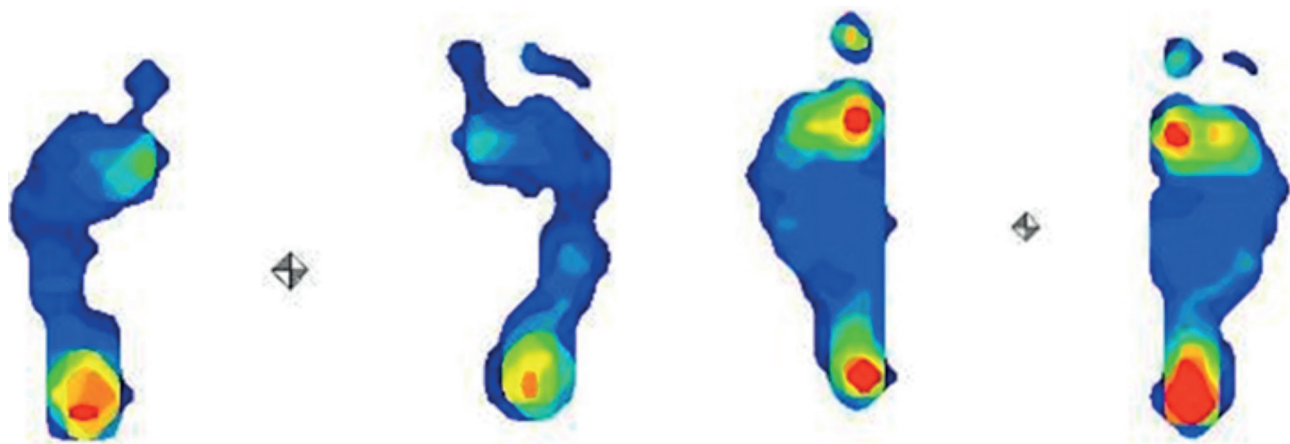
Fig. 5. — Pressure Mapping Scan Images. (Left) Normal Feet, (Right) Flat Feet.

tions between results of pressure mapping scans, radiographic data, and footprints were assessed with Pearson correlation coefficients. Pearson correlation coefficients were calculated for AICFR measured by pressure mapping, SI, Staheli Index measured by footprint scans, and the five radiographic parameters used in the assessment of flat foot. Ninety five percent confidence intervals were determined for all summary correlation statistics. Statistical analysis was performed using the SPSS 16.0 statistical package.

RESULTS

The results are summarized in table 1 and table 2. Of the five radiographic parameters the TFM and CP angles did show the highest correlation (0.310 and 0.326) with the pressure mapping readings for the arch index (AICFR). The correlation between AICFR and TFM angle is illustrated by the scattergram in (Fig. 6).

The footprint readings of SI also had significant correlation with the AICFR (0.414).

Table I. — Mean and standard deviations for all dependent measurements.

(No= 56 Feet)	Mean	Minimum	Maximum	Std. Deviation
TFM	17.5	.20	36.2	5.63
CP	14.3	1.5	24.5	3.82
TC	49.9	27.1	66.5	5.87
TN	28.6	5.4	52.3	7.38
APTFM	15.2	2.9	32.5	5.28
AICFR	39.5	2.2	63.2	14.04
SI	1.23	.63	1.84	.21

Table II. — Radiographic Measurements, Staheli Index (SI) versus (AICFR) (N=56 feet), Pearson,s Correlation Coefficients (95% Confidence Interval).

	(No = 56 Feet)	TFM	CP	TC	TN	APTFM	SI	AICFR
TFM	Pearson Correlation	1	-.303(**)	.444(**)	.351(**)	.242(**)	.497(**)	.310(**)
	Sig. (2-tailed)	.	**.000**	**.000**	**.000**	**.001**	**.000**	**.000**
CP	Pearson Correlation	-.303(**)	1	.510(**)	-.114	-.127	-.373(**)	-.326(**)
	Sig. (2-tailed)	**.000**	.	**.000**	**.115**	**.074**	**.000**	**.000**
TC	Pearson Correlation	.444(**)	.510(**)	1	.134	-.007	.010	-.035
	Sig. (2-tailed)	**.000**	**.000**	.	**.062**	**.924**	**.891**	**.631**
TN	Pearson Correlation	.351(**)	-.114	.134	1	.307(**)	.340(**)	.058
	Sig. (2-tailed)	**.000**	**.115**	**.062**	.	**.000**	**.000**	**.432**
APTFM	Pearson Correlation	.242(**)	-.127	-.007	.307(**)	1	.161(*)	.038
	Sig. (2-tailed)	**.001**	**.074**	**.924**	**.000**	.	**.027**	**.604**
SI	Pearson Correlation	.497(**)	-.373(**)	.010	.340(**)	.161(*)	1	.414(**)
	Sig. (2-tailed)	**.000**	**.000**	**.891**	**.000**	**.027**	.	**.000**
AICFR	Pearson Correlation	**.310(**)**	**-.326(**)**	-.035	.058	.038	**.414(**)**	1
	Sig. (2-tailed)	**.000**	**.000**	**.631**	**.432**	**.604**	**.000**	.

** Correlation is significant at the 0.01 level (2-tailed).
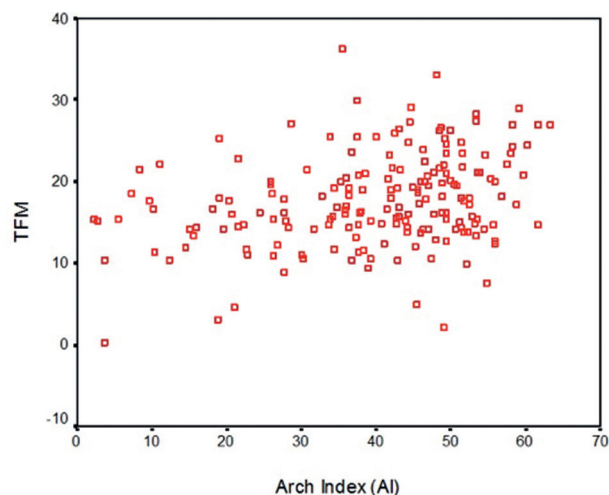* Correlation is significant at the 0.05 level (2-tailed).

Fig. 6. — Scattergram for Arch Index (AICFR) versus TFM angle.

DISCUSSION

By convention Pes Planus (flatfoot) refers to loss of the normal medial longitudinal arch (MLA) of the foot. However, next to the loss of MLA other anatomical abnormalities are present. These might include a valgus posture of the heel; medial and plantar tilting of the talar head; eversion of the calcaneus at the subtalar joint; forefoot abduction at the midtarsal joint; and supination of the forefoot relative to the hindfoot [16].

The MLA modifies significantly with growth and maturation. Flexible flatfoot and hypermobility can be considered normal developmental profiles. MLA tends to be lower in children (idiopathic flatfoot, or postural flatfoot) and mostly it is asymptomatic. The MLA accentuates naturally when approaching adolescence, normally without need for orthopedic treatment. In children's feet, the structural components of the MLA are not completely developed as yet and are therefore unprepared to adequately support weight.

The height of the medial longitudinal arch of the foot has been one of the primary criteria when classifying foot structure. The radiologic measures of medial longitudinal arch structures were defined as gold standards by Saltzman et al.(20) These radiologic measures are the lateral talo-first metatarsal angle, the calcaneal pitch angle, and the lateral talo-calcaneal angle.

Some authors did use footprint analysis as an alternative in order to describe the longitudinal arch of the foot. It has been reported as a cost-effective, and readily available method in the evaluation of flat feet [10].

Methods/indices already proposed for MLA assessment based on plantar prints are the Cavanagh and Rodgers Arch Index (AI), the Chipaux-Smirak Index (CSI), the plantar print Alpha Angle (AA), and the Staheli Index (SI). They were reported to provide a good repeatability and inter- and intra-observer reliability.

Nevertheless, there are ample studies with respect to the correlation between these different methodologies and their application in different populations. They are often inconclusive [10,17]. There might be different reasons for this. One might for instance expect that in children, the presence of soft tissues and fat pad under the plantar skin influence the midfoot surface area and calculations such as the arch index. These anatomical difficulties might mask the age of MLA formation when using indices based on plantar prints [17].

Cobey and Sella found footprint measures to be inconsistent with radiographic measures of arch height [3]. Hawes and coworkers reported a poor correlation between MLA footprint parameters and the direct measurement of the soft-tissue height.(9) Cureton articulated the conceptual problem with using footprints to measure MLA height, "no one would attempt to measure the height of a building by measuring its width." [4]

More recent, plantar pressure mapping has been the main focus of several studies. They investigate the influence of various factors on foot structure and development in terms of medial longitudinal arch formation. Factors such as age, obesity, foot pathology, effect of orthotic use, and outcome of surgery have been studied.

Eleftherios 2001, established a baseline comparison for plantar pressures in preschool healthy children during daily activities and recommended future studies to examine children with various foot pathologies which are attributed to high plantar pressures [7]. Hakan et al. 2004, concluded that appreciation of normal plantar pressure values in adolescents is important in

monitoring the development stages of foot, in the assessment of foot disorders, and in making proper footwear modifications in accordance to age *(8)*.

Dowling et al. 2004, studied the effect of obesity on plantar pressure distribution in 10 obese matched to 10 non-obese children and found that obese children generated significantly higher forces over a larger foot area and experienced significantly higher plantar pressures compared to their non-obese counterparts *(6)*.

Rai et al. 2006, monitored the plantar pressure changes during bipedal standing in 66 subjects with normal and pathologic feet and concluded that plantar pressure measurement techniques are useful in the analysis and understanding of the biomechanics of the human foot and found that orthotics attenuated the peak pressure and distributed it uniformly on the plantar area of the foot *(18)*.

Davitt et al. 2001, used plantar pressure mapping to detect changes after distal calcaneal lengthening in children and adolescents. Significant changes were reported throughout the foot after lengthening. *(5)*

In 2004 Leung et al. adopted a new parameter, the Contact Force Ratio (CFR), which was derived from the electronic sensor collected dynamic footprint to reflect foot function. With an electronic pedobarograph or pressure sensing mat, it was possible to capture static or dynamic plantar pressure at different instants of the stance phase. It was found that the CFR measurement had significant correlation ($r = 0.785$) to the measurement of the navicular drop *(12)*.

Our current study supports the reliability of plantar pressure mapping as a useful adjunct to the standard (footprint and radiological) methods used in the evaluation of pes planus in a paediatric population., Our data do show a significant correlation between the arch index contact force ratio (AICFR) (measured by pressure mapping) and the radiological TFM, CP angles ($p < 0.001$) as well as the Staheli Index measured on footprints

However, until now the role of foot pressure measurement remains almost entirely academic and did so far not become part of routine orthopaedic assessment. Despite its application in more extensive studies on important clinical problems

such as diabetes and rheumatoid arthritis, as well as the design of insoles, it has not yet been integrated into daily clinical practice.

Despite the current situation our study is in support of a more widespread use of plantar pressure mapping technique. Seen its reliability this technique provides a more objective clinical assessment of the paediatric patient. This might be of specific value when comparing pre- and post treatment status. In the future the further development of small portable easily-operated apparatus for plantar pressure measurement, might be in favour of a more routine use in the outpatient clinic.

In summary, we conducted a study evaluating the reliability and validity of pressure mapping as a method of assessment of the medial longitudinal arch in a paediatric population with flexible pes planus. Arch Index Contact Force Ratio measurements from pressure mapping scans were shown to correlate well with radiographic and footprint indices. Our study suggests that pressure mapping measurements yield reliable and valid approximations of MLA structure. Our findings are in support for the application of plantar pressure mapping technique when investigating foot structure in various disorders of the musculoskeletal and nervous system. An added diagnostic and therapeutic value is in support of a more routine clinical use of pressure mapping.

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