Plantar aponeurosis thickness and foot arch index: Any significant structural relationship?

Abstract

Introduction: The Plantar fascia has been linked to the structural integrity of the human arch. However, no statistical relationship has been established. This work aimed at establishing a statisticostructural relationship between the plantar aponeurosis thickness (PAT) and the arch index. **Materials and Methods:** PAT was measured by ultrasound while foot anthropometric parameters were measured using the methods established by Huang *et al*. (2004) and Krishan (2007). **Results:** There was a significant meaningful correlation between PAT and arch index (r<0.05) and a significant negative correlation between PAT and Breadth at heel. There was no correlation between PAT and various aspects of length of the foot. **Conclusion:** This result infers that there is a direct structural and statistical relationship between the plantar fascia thickness and the foot arch index. This relationship can be very useful in the surgical release plantar fascia and management of plantar fasciitis.

Key words: Foot arch index, Nigeria, Plantar Fascia, Plantar aponeurosis thickness, Plantar fasciitis, structural correlation

Egwu Ogugua A.

Department of Anatomy,
Federal University, Ndufu-Alike Ikwo,
Ebonyi State, Southeast Nigeria

Address for Correspondence:
Dr. Egwu Ogugua A,
Department of Anatomy,
Federal University, Ndufu-Alike Ikwo,
Ebonyi, Nigeria.
E-mail: egwuoc@gmail.com

INTRODUCTION

In Biomechanics, the foot is no longer viewed as the triangle at the bottom of the leg rather the "foot" suggests that some single functional entity exists, when in fact the 26 bones, hundreds of ligaments and muscles demand that we adopt a far more complex conceptual model of the foot.[1] Structurally, the foot is a vital connection between the human body and the ground and plays a highly important role in human locomotion.[2] Therefore, knowledge of the structural dynamics between its components will definitely be fundamental in understanding their functions and better comprehension of common and uncommon disorders associated with them.

Stresses within the foot structure are dependent on the three-dimensional geometry of its components (hard and soft tissues), including anatomical areas through which muscular and skeletal forces are transferred. The directions and magnitudes of these forces in the three-dimensional space, which are functions of the activity performed (e.g, gait, running, jumping, etc.) are also basic factors that determine the stress state of the foot.[2] These vectored forces are transferred via the soft tissues of the foot to the ground. As such, stress states of the foot can also manifest on the structural inclinations and activity-related dynamics of the soft tissues there-in.

Access this article online	
Quick Response Code:	Website: www.bioanthrojournal.org
	DOI: 10.4103/2315-7992.143402

The plantar fascia or aponeurosis is composed of densely compacted collagen fibres oriented mainly longitudinally but also transversely. Its central part is the strongest and thickest.[3] Aldridge[4] described the plantar fascia as being multilayered with three (3) portions- medial, lateral and central and the fascia attaches to the main weight bearing layers of the foot (Calcaneus, first and fifth metatarsal heads). The fascia is contributive in sustaining the arch of the foot[5,6] and protecting the subjacent vascular and neural bundles. It is mainly affected by Plantar Fascitis.[7]

The diagnosis and treatment of heel pain from plantar fasciitis results in one (1) million patient visits per year in the United States[8] but in Nigeria, such data hasn't been recorded although there could be so many undiagnosed cases of heel pain among peasants and middle class individuals because a lifetime prevalence of this condition has been estimated to be 10-15% in runners and in similar proportion in the general population.[4,9] Hence, study of the plantar fascia could help as a guide to describe its structural relationships and establish possible predisposing factors in the occurrence of heel pain in our environment. Also, adequate knowledge of the foot soft tissue structure of which the plantar fascia is componential, could also serve as a guide in the examination of victims of Falanga torture and subsequent recommendations for medico-legal implications.[10] This is a type of torture on individuals where their soles are badly damaged/disfigured and there's loss of structural uniformity in the foot. It is usually practiced among dare devil security agents in most parts of the world.

The plantar fascia has long been considered to have a significant purpose in the weight bearing foot, both in static stance and in dynamic function. Various functional and structural roles have been indicated by virtue of its anatomical attachments.[11] Hicks[5] described the function of the plantar aponeurosis as being analogous to the windlass mechanism in which the arch of the foot elevates by winding of the plantar aponeurosis around the heads of the metatarsals during toe extension. Various cadaveric studies have revealed that release of plantar aponeurosis decreases arch height, confirming the arch supporting function of the plantar aponeurosis.[12-14]

Ker *et al*.[15] identified the plantar aponeurosis as a mechanism of energy storage in the foot in an *in vitro* experiment. Kim and Voloshin[16] in their study of the role of plantar aponeurosis on the load bearing capacity of the foot using computer models also opined that it is the energy storage mechanism of the foot. Another function of the aponeurosis was to provide better cushioning against the high ground reactions forces occurring in the late stance phase by tightening of the soft tissue framework beneath the metatarsal heads.[17]

Plantar aponeurosis thickness (PAT) has been used to access the mechanical properties of the plantar fascia. Berkowitz *et al*.[18] using magnetic resonance imaging stated that PAT for normal adults is 3.00 mm. Bolton *et al*.[19] using computed tomography discovered that PAT was 3.6 mm. Udoh[20] in a Nigerian population stated that the range of PAT was 2.88- 3.75 mm for males and 2.00-3.25 mm for females with mean thickness of 3.25 mm for males and 2.36 for females. Recently, Huang *et al*.[21] in their ultrasonographic study stated that PAT was 5.5 mm; a value higher than others. These thickness values for plantar fascia may affect the relative occurrence of individual foot prints considering its imposing effect on the foot arch morphology where Hicks[5] described a windlass mechanism to initiate a mechanical pull between the Calcaneus and the proximal phalanges. As a result, the plantar aponeurosis is highly involved in the kinetics and kinematics of gait and human locomotion[22]

This study will try to establish the relationship between the PAT and the foot anthropometric parameters of which arch index is a composite part, without ignoring the impact of the individual's environmental slope on these foot parameters.

The anthropometric orientation of the foot in all studies carried out in the past receives relative contributions from the structural inclinations of the foot morphological components. And as such, we believe there could be a relationship between the anthropometric outcome and the foot components within, especially, the weight cushioning parts. While some studies have established statistical relationships between the PAT and other known anthropometric variables like height, weight, BSA, BMI,[22,23] others studies have tried to establish an indirect link with some foot parameters. Considering the windlass mechanism proposed by Hicks[5] where the plantar fascia contributes a great deal in sustaining the arch of the foot, it is hypothetical to state that since the arch is a principal part of the foot print and morphology, there could be a significantly statistical structural relationship between the arch and print and the plantar fascia.

This study will try to establish a systematic relationship between the thickness of the plantar fascia (PAT) and foot anthropometric parameters with emphasis on the arch index. It is believed that this study will empirically elucidate the morphological relationships in the foot and create a more vivid understanding of the functional aspects of the central strut of human bipedalism- the foot.

MATERIALS AND METHODS

The methodology for carrying out the research was structured in two parts- Sonographic study and Anthropometric study.

Part 1 (sonographic study)

Design

This is an experimental research which was carried out within Abakaliki metropolis, Ebonyi State, southeast, Nigeria.

Study area

Abakaliki is the capital city of Ebonyi state, which is a mainland south-eastern state of Nigeria, inhabited and populated primarily by Igbos of the south eastern, Nigeria. It lies approximately within longitude $7^{O}30^{1}$ and $7^{O}30^{1}$E and latitude $5^{O}40^{1}$ and $6^{O}45^{1}$N. it has a landmass of about 5,935 square kilometers. The population of Ebonyi state according to National Population Commission held on 21st march, 2006 is 2,176,947 peoples with 1,064,156 males and 1,112,791 females. Agriculture in the major economic base of the state with about 80% of the population actively engaged. Abakaliki is the leading producer of rice, yams, potatoes, maize, beans, cassava, etc., while those living in the riverine areas are actively engaged in fish farming.

Study centre

The study was conducted in a private ultrasound scanning centre – Veramax imaging centre, Abakaliki, Ebonyi State. This ultrasound and Imaging centre receives patients from within Abakaliki metropolis and beyond. Their patients are mostly obstetric patients and individuals with soft tissue pathology including all forms of intra-abdominal pathologies. It is well staffed with a total of twelve (12) resident Medical Imaging Scientists. The center receives patients from all the private hospitals in Abakaliki Metropolis and beyond as well as those not accommodated in the Federal Teaching Hospital, Abakaliki, Ebonyi State, southeast Nigeria.

Study population

The study population comprise of a convenient purposive sample of 120 subjects who gave their written consent to participate in the study. They were all Igbos by tribe and were of Ebonyi State Origin in Southeast Nigeria. The subjects were apparently healthy; did not have any history of a systemic disease like diabetes, familial hypercholesterolemia etc., or foot deformity or had not undergone any form of foot surgery and were not pregnant. This is to avoid any possible effect of pregnancy and these ailments.

Scanning protocols

A 7.5 linear-array transducer (Siemens sonoline 940- 2000 model) with a diameter of 39 mm was used for the assessment of the thickness of plantar fascia. During measurement of PAT, each subject lay in a prone position on the couch with knees flexed with the ultrasound gel applied generously on the plantar aspect of the foot. Scanning was then carried out when the probe was placed longitudinally over the centre of the foot at about 3 cm from the calcaneal insertion of the aponeurosis. The PAT was measured from its anterior wall to the posterior wall.[20]

Part 2: Measurement of the foot anthropometric parameters

The foot dimensions were measured with foot prints obtained on plain white paper. After the feet of the subjects were cleaned, cyclostyling ink was applied to the cleaned soles and the subjects were asked to step on to the white plain paper on a flat surface during which the left and right footprints were recorded one by one.[24,25] Before the feet were lifted off from the paper, the following anatomical landmarks of the feet were noted and marked on the paper:

- Mid-rear heel point (pternion): This was determined as the most posterior part of the foot and heel
- Medial metatarsal point: This was determined as the most medial point of the ball of the foot
- Lateral metatarsal point: This was determined as the most lateral point on the ball of the foot
- Medial Calcaneal concavity: This was determined as the most medial point of the heel
- Lateral calcaneal tubercle: This was determined as the most lateral point of the heel.

A total of nine (9) measurements were taken on the right and left footprints of each subject. For a definite axial orientation for measurements, a designated longitudinal axis and a base line were drawn.[25,26] The measurements include:

- T1 (PT to tip of big toe)
- T2 (PT to tip of Second toe)
- T3 (PT to tip of Third toe)
- T4 (PT to tip of Fourth toe)
- T5 (Pternion to tip of Fifth toe)
- Breadth at ball (medial metatarsal point to lateral metatarsal point)
- Breadth at heel (medial calcaneal concavity to lateral calcaneal tubercle)
- Big toe pad length
- Big toe pad breadth

All the measurements as seen in Figure 1 were taken by one individual to avoid interobserver variability

The arch index of the subjects was determined using the method adopted by Huang *et al*.[27] as shown in the Figure 2.

Statistical analysis

All measurements obtained were expressed as means ± standard deviation. The data obtained in both part 1 and 2 were both analyzed using Statistical Package

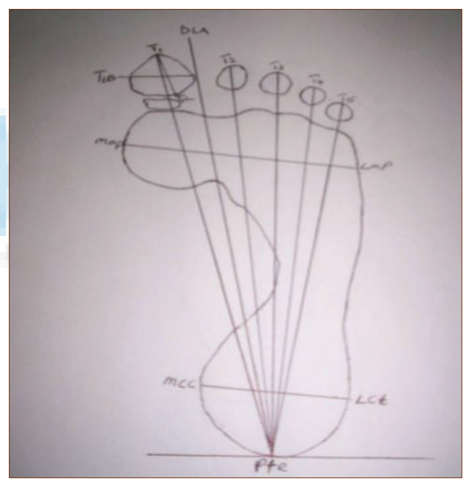

Figure 1: The measurements taken from the foot prints

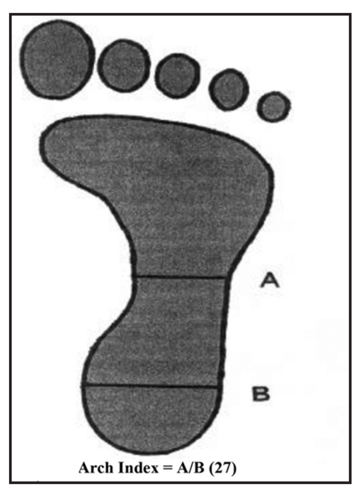

Figure 2: Measurement of arch index

for Social Sciences (SPSS Inc. Chicago, Illinois, USA) in Microsoft windows.

Ethical approval

In line with Belmont report of 1979 where respect for persons, beneficence and justice are recommended in every research involving human subjects, ethical approval was obtained from the Ethics and Research committee of the College of Health Sciences, Abia State University, Uturu.

RESULTS

The table above shows the descriptive statistics for PAT and some foot anthropometric variables. PAT values were 3.41 ± 0.74 mm and 3.40 ± 0.75 mm for the right and left foot respectively. The T1-RT length was 25.70 ± 1.54 cm while T5-RT length was 21.06 ± 1.26 cm. These figures are the length of the foot from the most posterior part of the foot- the ptenion (Pt) to the tip of each digit.

The table above shows other anthropometric parameters of the foot. The values for the arch index of RT and LT feet were 0.723 (100) and 0.729 (100) respectively. The breadth at ball (RT and LT) read 9.49 ± 0.82 and 9.48 ± 0.79 cm respectively. The fat pad of the big toe was also recorded as Big Toe pad length (RT and LT) and breadth (RT and LT). The values obtained were 3.50 ± 0.51, 3.48 ± 0.24, 2.78 ± 0.26 and 2.80 ± 0.24 cm respectively.

The PAT in the table above correlates with arch index and negatively correlates with breadth at heel.

Based on the positive relationship between the PAT and the arch index of the foot, a simple regression equation was derived as follows: PAT = 3.250 + 0.214 Arch Index; where PAT is the dependent variable.

DISCUSSION

Knowledge of functional and structural inclinations of foot components is highly important in the understanding of the biomechanics of the foot and clinical manifestations of pathologies and occupation related activities that induce highly elevated stresses in the foot.

Numerous foot anthropometric variables were assessed ranging from the length of the foot from the most posterior point of the foot (Pternion) to the tip of the five digits (T1-T5 length) to the arch index. These parameters are not just necessary in the forensic examination of the foot but in the estimation of individuals' stature and possibly in the determination of the structure of internal soft tissues of the foot.

The T5 length to T1 length of foot print ranged from 21.06-25.70 cm [Table 1]. These values are in conformity with studies by Krishan[28] though his values were slightly lower (20.09-24.15). This indicates that the values of foot print parameters in our environment are almost the same with those of Gujjars Indians. No such parameters have been assessed previously in our environment using foot prints making our findings novel. The Breadth at ball and Heel for the population was 9.49 and 6.173 cm respectively [Table 2]. Krishan[28] recorded slightly lower values (8.69 and 4.92 cm respectively), which could be as a result of environmental and genetic diversity.[29] The arch index for the general population was 0.76. Staheli *et al*.[30] reported slightly lower values of 0.71 for males and 0.66 for females in an American population and these results are very important factor in

Table 1: Descriptive statistics of PAT and some foot anthropometric parameters

Variables	No of subjects	Min	Max	Mean	Std error	Std dev.
T1-RT	120	23.5	28.2	25.70	0.28	1.54
T1-LT	120	23.5	28.1	25.67	0.28	1.51
T2-RT	120	22.4	28.0	25.00	0.29	1.57
T2-LT	120	22.5	28.0	25.01	0.29	1.57
T3-RT	120	21.7	27.3	24.07	0.28	1.52
T3-LT	120	21.7	27.2	24.08	0.27	1.50
T4-RT	120	20.5	25.6	22.77	0.24	1.32
T4-LT	120	20.4	25.6	22.74	0.24	1.34
T5-RT	120	19.2	23.6	21.06	0.23	1.26
T5-LT	120	19.4	23.5	21.12	0.22	1.22
PAT (RT)	120	1.90	5.90	3.41	0.25	0.74
PAT (LT)	120	2.00	5.80	3.40	0.23	0.75

PAT: Plantar aponeurosis thickness

Table 2: Descriptive statistics of other foot anthropometric parameters

Variables	No of subjects	Min	Max	Mean	Std error	Std dev.
BRDT at ball RT	120	7.7	10.4	9.490	0.1494	0.8181
BRDT at ball LT	120	7.8	10.4	9.477	0.1449	0.7938
BRDT at heel RT	120	5.3	7.0	6.187	0.1020	0.5588
BRDT at heel LT	120	5.3	7.0	6.173	0.1023	0.5601
Arch index RT A	120	2.6	7.6	4.487	0.2615	1.4323
Arch index RT B	120	5.3	7.0	6.187	0.1020	0.5588
Arch index RT A/B	120	0.5	1.3	0.723	0.0421	0.2306
Arch index LT A	120	2.7	7.5	4.513	0.2522	1.3813
Arch index LT B	120	5.3	7.0	6.173	0.1023	0.5601
Arch index LT A/B	120	0.5	1.3	0.729	0.0403	0.2208
Big toe pad lenght RT	120	2.8	4.4	3.500	0.0935	0.5119
Big toe pad lenght LT	120	2.7	4.3	3.477	0.0922	0.5049
Big toe pad breadth RT	120	2.3	3.2	2.780	0.0466	0.2552
Big toe pad breadth LT	120	2.3	3.1	2.797	0.0446	0.2442

LT: Left Toe, RT: Right Toe, BRDT: Breadth

Table 3: Correlations between the PAT and other anthropometric parameters

	T1	T2	T3	T4	T5	BR at ball	BR at heel	Arch index	Big toe pad lenght	Big toe pad breadth
PAT										
Pearsons correlation	0.005	0.077	0.105	0.190	0.206	0.093	−0.610**	0.417*	−0.037	0.025
P value	0.978	0.684	0.580	0.316	0.274	0.623	0.000	0.022	0.846	0.895

PAT: Plantar aponeurosis thickness, BR: Breadth

the assessment of foot prints and arch height. Arch index provides a simple quantitative means of assessing the height of the medial longitudinal arch with the limitation that only half of the variance in arch height can be explained.[31]

From the results, PAT correlated with the Arch Index [Table 3]. This implies that there is an obvious statistical relationship between the plantar fascia and the arch index. This may be an exact explanation to the illustrations of Hicks[5] in describing the relationship between the plantar aponeurosis and the arch index. It is possible that in the process of sustaining the arch in the windlass theory[5] and to ensure stability within the arch system, there is a fascial adaptive thickening and thinning that perhaps, tends to depend on the structural disposition of the foot during the stance and dynamic phases of propulsion. Therefore, an adaptive thickening of the plantar fascia will indicate an accompanying increase in arch height and a reduction in thickness will indicate a reduction in arch height- an outcome of arch index.

This relationship that has been illustratively theorized by studies in the past is based on the anatomical inclinations of the plantar fascia and foot arches. No study in the past has attempted to establish a statisticostructural link between these two important components of the human bipedalic system of locomotion. This relationship could be used in the planned surgical adjustment of the plantar fascia and in the understanding of possible predisposing factors in the occurrence of plantar fasciitis.

The non-correlation of PAT with the lengths of the foot across the five digits that is T1-T5 [Table 3] indicates that the possible length of the foot could be associated with the orientation of the plantar fascia but is not a structural determinant of its thickness. The negative correlation with the breadth at heel may be indicative of an inverse relationship that is adaptively designed to sustain the functional dynamics of the foot.

In conclusion, this study has established that the thickness of the plantar fascia has direct statistical and structural relationship which can be validated and used in the understanding of predisposing factors in plantar fasciitis and in the possible maintenance of an efficient arch height for optimum performance during human propulsion.

REFERENCES

1. Nester CJ. Lessons from dynamic cadaver and invasive bone pin studies: Do we know how the foot really moves during gait. J Foot Ankle Res 2009;2:18.
2. Gefen A, Megido-Ravid M, Itzchak Y, Arman A. Biomechanical analysis of three dimensional foot structure during gait: A basic tool for clinical application. J Biomech Eng 2000;122:630-9.
3. In: Standring S, Ellis H, Healy J, Johnson D, Williams A, editors. Gray's Anatomy. 39th ed. London: Churchill Livingstone; 2005. p. 807-8.
4. Aldridge T. Diagnosing heel pain in adults. Am Fam Physician 2004;70:332-8.
5. Hicks JH. The mechanics of the foot. II. The plantar aponeurosis and the arch. J Anat 1954;88:25-30.
6. Erdemir A, Hamel AJ, Fauth AR, Piazza SJ, Sharkey NA. Dynamic loading of the plantar aponeurosis in walking. J Bone Joint Surg Am 2004;86-A:546-52.
7. Stupar M, Tibbles A Heel pain and HIV-associated lipodystrophy: A report of two cases. J Can Chiropr Assoc 2008;52:103-9.
8. Riddle DL, Schappert SM. Volume of ambulatory care visits and patterns of care for patients diagnosed with plantar fascitis: A national study of medical doctors. Foot Ankle Int 2004;25:303-10.
9. DeMaio M, Paine R, Mangine RE, Drez D Jr. Plantar fascitis. Orthopadics 1993;16:1153-63.
10. Amris K, Rasmussen OV, Baykal T, Lok V. The diagnostic value of clinical examination after falanga. Torture 2009;19:5-11.
11. Aquino A, Payne C. Function of the plantar fascia. Foot 1999;9:73-8.
12. Kitaoka HB, Ahn TK, Luo ZP, An KN. Stability of the arch of the foot. Foot Ankle Int 1997;18:644-8.
13. Thordarson DB, Schmotzer H, Chon J, Peters J. Dynamic support of the human longitudinal arch: A biomechanical evaluation. Clin Orthop Relat Res 1995;316:165-72.
14. Sharkey NA, Hamel AJ. A dynamic cadaver model of the stance phase of gait: Performance characteristics and kinetic validation. Clin Biomech (Bristol, Avon) 1998;13:420-33.
15. Ker RF, Bennet MB, Bibby SR, Kester RC, Alexander RM. The spring in the arch of the human foot. Nature 1987;325:147-9.
16. Kim W, Voloshin AS. Role of Plantar fascia in the load bearing capacity of the human foot. J Biomech 1995;28:1025-33.
17. Bojsen-Møller F, Lamoreux L. Significance of free-dorsiflexion of the toes in walking. Acta Orthop Scand 1979;50:471-9.
18. Berkowitz I, Kier R, Rudical S. Plantar fascitis: MR imaging. Radiology 1991;179:665-7.
19. Bolton NR, Smith KE, Pilgram TK, Mueller MJ, Bae KT. Computed tomography to visualize and quantify the plantar aponeurosis and flexor hallusis longus tendon in the diabetic foot. Clin Biomech (Bristol, Avon) 2005;20:540-6.
20. Udoh BE. Effects of type 2 Diabeties mellitus on the plantar aponeurosis and heel pad in an adult Nigerian population. MSc thesis, University of Nigeria, Enugu Campus, 2006.
21. Huang YC, Wei SH, Wang HK, Lieu FK. Ultrasonographic guided

botulinum toxin type A for plantar fasciitis: An outcome based investigation for treating pain and gait changes. J Rehabil Med 2010;42:136-40.

22. Egwu OA, Anibeze CI, Akpuaka FC. Estimating plantar aponeurosis (PAT) using known anthropometric variables: An ultrasound based study. J Exp Clin Anat 2011;10:21-6.
23. Paschal Huerta J, Garcia JM, Matamoros EC, Matamoros JC, Martinez TD. Relationship of body mass index, ankle dorsiflexion, and foot pronation on plantar fascia thickness in healthy, asymptomatic subjects. J Am Podiatr Med Assoc 2008;98:379-85.
24. Cummins H, Midlo C. Fingerprinta palms and soles: An introduction to dermatoglyphics. New York: Dover Publications; 1961.
25. Krishan K. Establishing correlation of footprints with body weight – forensic aspects. Forensic Sci Int 2007;179:63-9.
26. Robbins LM. Footprints - Collection, Analysis and Interpretation. Charles C. Thomas, Springfield IL, USA; 1985.
27. Huang YC, Wang LY, Wang HC, Chang KL, Leong CP. The relationship between the flexible flatfoot and plantar fasciitis: Ultrasonographic evaluation. Chang Gung Med J 2004;27:443-8.
28. Krishan K. Determination of stature from foot and its segments in a north Indian Population. Am J Forensic Med Pathol 2008;29:297-303.
29. Tanner JM. In: The physique of the Olympic athlete. London: George Allen and Unwin; 1964.
30. Staheli LT, Chew DE, Corbett M. The longitudinal arch: A survey of eight hundred and eighty-two feet in normal children and adults. J Bone Joint Surg Am 1987;69:426-8.
31. McCrory JL, Young MJ, Boulton AJM, Cavanagh PR. Arch index as a predictor of arch height. Foot 2007;7:79-81.

How to cite this article: Ogugua EA. Plantar aponeurosis thickness and foot arch index: Any significant structural relationship?. Ann Bioanthropol 2014;2:17-22.

Source of Support: Nil, **Conflict of Interest:** Nil.