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Research Article

Regional Differences and Age Related Changes in the Thickness of the Plantar Aponeurosis

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Abstract

Background: Decrease in the foot's biomechanical efficiency occurs with age possibly due to age-related alterations in the Medial Longitudinal Arch (MLA) and Plantar Aponeurosis (PA). Even though this relationship has been inferred, it has not been described. Thus, study aimed to determine the same.

Materials and Methods: Sixty feet were sourced, following which, the dorsum height and truncated foot length were measured and divided to derive the AHI (Arch Height Index). The PA was then exposed by dissection and the thickness of its enthuses and three bands were measured. Data was coded into SPSS where means were calculated. Age related differences in the truncated foot length, dorsum height, AHI and the PA' enthesis and 3 bands was determined using ANOVA. *P*-value≤0.05 was considered significant at 95% confidence interval.

Results: The mean truncated foot length, dorsum height, AHI and PA enthesis thickness were 20.57mm, 7.9mm, 0.392 and 3.34mm respectively. There was no statistical significant difference among the age groups on the dorsum height, truncated foot length. Statistical significant difference was however noted on the AHI and enthesus. As for the bands, the central, lateral and medial sections had mean values 2.65, 2.08 and 1.2mm respectively. Moreover, statistical significant differences based on age grouping was, only, in the thickness of the central band and the medial band. There was no linear association between the AHI and the thickness of the PA.

Conclusion: The aging differences in the observed parameters may be due to adaptability to the configuration of the MLA.

Keywords: Enthesis; Plantar aponeurosis; Arch height index; Truncated foot length

Introduction

The Plantar Aponeurosis (PA), the deep fascia of the foot [1], is the main stability factor for maintenance of the Medial Longitudinal Arch (MLA) of the foot [2]. Together with the MLA, the PA aids in efficient propulsion of thrust from the hindfoot to the forefoot in locomotion via the "windlass" mechanism [3]. In this role, the biomechanical properties of the PA are dependent on its viscoelasticity, partly a function of its thickness [4]. Pertinent to this, the structure of the PA is responsive to biomechanical stresses which are determined by the conformation of the medial longitudinal arch [5]. Further, as the main stability factor for the MLA, the PA influences the configuration of the MLA [6].

This configuration of the MLA can be represented by the Arch Height Index (AHI), which is defined as the ratio of dorsum height to truncated length of the foot. The dorsum height is the height of the foot at 50% of the length of the foot while truncated length of the foot is the distance from the tip of the heel to the first metatarsophalangeal joint [7]. A high AHI results in a stiffer MLA [3] which in turn leads to a reduction of the ability of the PA to act as a mechanical truss in the "windlass" mechanism [8]. On the other hand, a low AHI leads to an increase in the movement of the foot in the sagittal plane which is associated with thickening of the PA [9]. The change in the thickness of the PA in response to the configuration of the MLA is due to its adaptability to the varied biomechanical strains precipitated by these different conformations of the MLA [5]. On the other hand, the thickness of the PA influences the configuration of the MLA [6]. A relationship between the AHI and the thickness of the PA is therefore inferred though it has not been described. Moreover, there is scarcity of information on the age-related changes in the AHI that may lead to changes in the thickness of the PA.

The biomechanical efficiency of the foot reduces with age [10] due to changes in the configuration of the MLA and implies consequent modifications of the structure of the PA [11]. These modifications include changes in its thickness (Craig et al., 2001). Such changes in the thickness of the PA are seen in diabetes [6] and Plantar Fasciitis (PF) [12] and they result in altered foot biomechanics [11,5]. It is however not known whether similar changes in the thickness of the PA contribute to the age-related decrease in the foot's biomechanical efficiency. This study therefore also sought to describe the changes in the thickness of the PA that occur with age. Our null hypothesis was that the thickness of the plantar aponeurosis neither has regional differences nor age related changes.

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Table 1: Table showing the mean values of the truncated foot length, dorsum height and arch height indices with age.

Age group (years)	Dorsum height (mm)	Truncated foot length (mm)	Arch Height Index
20-29	8.214±1.03	20.28±1.99	0.404±0.015
30-39	8.18±0.52	20.82±1.15	0.394±0.029
40-49	8.00±0.20	20.50±0.58	0.390±0.011
50-59	7.33±0.52	20.67±1.37	0.358±0.050
p value	0.088	0.803	0.016

Materials and Methods

A total of fresh 120 feet of 60 subjects aged between 20 and 56 years were used in this cadaveric study. These were obtained from Chiromo Funeral Parlour in the Department of Human Anatomy, University of Nairobi. Ethical approval was granted by the Kenyatta National Hospital/University of Nairobi Ethics and Research Committee and the Kenyan constitution. Further, consent was sought from each family members and benefits of the study explicitly explained to them prior to any dissections. All procedures were carried out in accordance with the principles laid out in the Declaration of Helsinki 1964. Subjects who had feet that had suffered trauma, had been operated on or had deformities were excluded from the study.

With the foot resting on the table, the truncated length of the foot (the length without the phalanges) was measured to the nearest millimeter using a measuring ruler (Haco® Industries Kenya Limited, Nairobi). A wooden block was placed against the sole of the foot vertically and the dorsum height measured, using the same ruler, to the nearest millimeter Figure 1. To minimize intra-observer errors, three measurements of the same dimension were taken and an average of these recorded. The AHI was calculated as the ratio of the dorsum height to the truncated foot length [7].

The plantar aponeurosis was then accessed by an incision on the dorsolateral aspect of the foot extending from the calcaneus to the fifth metatarsophalangeal joint. This incision created a fasciocutaneous flap comprising skin and superficial fascia that was reflected to expose the plantar aponeurosis Figure 2. The aponeurosis was then incised at its distal end and reflected. It was then cleaned and the thickness of the Plantar Enthesis (PE) was measured at the anteroinferior aspect of the calcaneal attachment of the PA. Measurements of the thickness of each of the three bands of the PA were taken at 50% of foot length. These measurements were taken using a digital pair of vernier calipers (Sealey Professional Tools™, United Kingdom). To minimize intra-observer errors, three measurements of the thickness of the PA at these regions were taken and an average of these recorded.

Data was coded into SPSS from where means and standard deviations were calculated. Age related differences in the thickness of the aponeurosis, as well as truncated foot length, dorsum height, enthesis and arch height indices was then determined using one-way ANOVA where *p*-value<0.05 was considered significant at 95% confidence interval. Linear correlation (Pearson's) test was then done to assess for the association between the AHI and the thickness of the PA. Data are presented using photographs and tables.

Results

The ages of the subjects ranged from 20-56 years (with a mean value of 35.75±10.8 years. The mean truncated foot length, dorsum height and AHI were 20.57, 7.9 and 0.392mm respectively. While the truncated foot length did not reduce with aging, the dorsum height reduced gradually. There was however no significant difference among the age groups on both dorsum height and truncated foot length (p values=0.088 and 0.803 respectively). There was an observed gradual reduction in the AHI with age with statically significant differences based on age being noted (p value=0.016). Summary mean values of the truncated foot length, dorsum height and arch height indices with age have been summarized Table 1.

The thickness of the PE (Plantar enthuses) ranged from 2.43 to 4.30 mm with the mean thickness of 3.34±0.40 mm. The thickness of the central, lateral and medial bands of the aponeurosis was 2.57±0.36 mm (range 1.86-3.27 mm), 2.03±0.32 mm (range 1.21-2.62 mm) and 1.18±0.20 mm (range 0.84-1.59 mm) respectively. Summary findings for the thickness of the aponeurosis with age has been summarized Table 2. While the thickness of the plantar enthesis increased gradually with aging, the thickness of the PA in other regions did not show any changes with aging.

One way ANOVA revealed a statistical significant difference based on age on the PE (p value=0.003). *Post hoc* analysis using Scheffe's test revealed this difference to be solely between the 20-29 and 40-49 age groups (p value=0.025). The test also revealed a statistically significant difference in the thicknesses of the central and medial bands amongst the age groups p values, 0.005 and 0.028 respectively Table 2. Further *post hoc* analysis using Scheffés test, revealed the difference in the mean thickness of the central band to be between the age groups 20-29 and 40-49 years. In the medial band, the difference was noted between the age groups 30-39 and 40-49 years.

There was no linear association between the AHI and the

Table 2: Table showing the mean thickness of the different bands of the plantar aponeurosis with age.

Age group (years)	Mean thickness of the plantar enthesis (mm)	Mean thickness of the central band (mm)	Mean thickness of the lateral band (mm)	Mean thickness of the medial band (mm)
20-29	3.17±0.33	2.66±0.36	2.05±0.05	1.27±0.15
30-39	3.28±0.39	2.36±0.30	1.93±0.43	1.07±0.16
40-49	3.37±0.16	2.99±0.28	2.22±0.26	1.28±0.21
50-59	3.86±0.34	2.60±0.36	2.10±0.18	1.18±0.27
p value	0.003	0.005	0.369	0.028

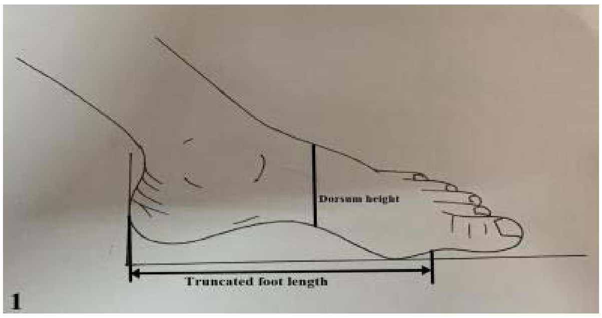

Figure 1: Diagrammatic representation showing the foot placed vertically and measurements of the truncated foot length and dorsum height.

Figure 2: Diagrammatic representation of the plantar aponeurosis following exposure. Note its 3 bands, and the dark lines on each band (representing where the measurements for thickness were done).

thickness of the PA.

Discussion and Conclusion

The gross morphology of the PA seen in the current study is concordant with previous descriptions of its anatomy [1,2,11]. The PA was noted to have three bands: medial, central and lateral in all cases. These results differ from the report of absence of the lateral band in 12% of individuals in the Czech population [13]. This difference could be due to populational differences in the morphology of the PA as the present study was on indigenous Kenyans while Dylevsky studied the Czech population [13]. Absence of the lateral band of the PA has been attributed to defects in ontogenesis and could suggest a reduction in the efficiency of dissipation of tensile strain by the PA [13].

Studies published in literature that have recorded the thickness of the PA have employed ultrasonography in measurement of this thickness [14,15]. Nevertheless, the measurements of the thickness of the PA obtained in the current study are comparable to those obtained by these workers. In the current study the mean thickness of the PE was 3.34±0.40 mm. Huerta and Garcia obtained a mean PE thickness of 3.33±0.69mm while Udoh and co-workers obtained a mean thickness of 3.15±0.11mm. Results of the current study indicate that the PE thickens with age. Huerta and Garcia and Udoh et al., also observed this thickening of the PE. A similar age-related thickening has been reported in Achilles tendon [16] where it has been attributed to the increase in turnover of collagen that occurs with age [17]. It is likely that the same mechanism underlies the age-related thickening of the PA. On the other hand, thickening of the aponeurosis could be an adaptation to the increase in vertical compression forces [18], which is a consequence of the loss of elasticity in the heel pad that occurs with age [19]. Thickening of the PA reduces its ability to aid in resupination of the foot in the gait cycle as it becomes stiffer due to a reduction of its viscoelasticity [6]. The altered mechanical properties of the PA predispose it to Plantar Fasciitis (PF) [20,21]. The thickening of the PA seen in the current study therefore suggests a preponderance of older individuals to this condition.

Concordant with previous reports [14], the thickening of the PA with age shows regional differences. The significant increase in the thickness of the PE compared to other regions of the PA could be due to the differences between the PE and the three bands in strain dissipation. The PE is subjected to both vertical compression and longitudinal traction forces for the whole duration of the stance phase of gait in comparison to the longitudinal traction forces dissipated to each of the three bands of the PA during mid-stance and push-off [21]. The thickening of these bands therefore reflects the forces they are subjected to.

The arch height index and its relationship with the thickness of the plantar aponeurosis

The mean AHI of 0.392±0.031 obtained in the current study was higher than the mean AHI of 0.316±0.027 reported by Williams and McCLay. This disparity may be as a result of the different methodology employed in the current study as these investigators took the measurements of dorsum height and truncated length of the foot in live patients who were seated a position in which the foot bears 10% of body weight hence the lowered MLA [22]. Despite this disparity, the AHI obtained in the current study can be used for comparison of the configuration of the MLA in different individuals since AHI is a ratio.

In the present study, 90% of the feet had an intermediate arch and 10%, all from individuals aged between 50 and 59 years, were low arched. Though no high arched feet were observed, these results are comparable to the results obtained by Williams et al., who studied a sample population of 102 feet and reported 8% low arched feet and 6% high arched feet. The difference in the proportions could be because the subjects studied by these workers were less than 43 years of age. It is possible that these younger subjects, in keeping with the trend observed in the current study, had higher arches.

The reduction in dorsum height with age may explain the age-related gradual reduction of the AHI. This reduction of the AHI with age has previously been reported [23] and is attributed to age-related changes in temporo-spatial gait parameters like speed, strength and cadence [23]. Arch lowering is also due the laxity of capsular ligaments of the joints of the foot [24]. This lowering is accompanied by calcaneal eversion, which in turn lowers the inclination of the subtalar joint's axis of rotation [8]. Secondary to this, there is increased forefoot dorsiflexion, abduction and eversion [25]. This results in the reduction of the ability of the foot to form a rigid lever at push off due to altered kinematic coupling between the hindfoot and the forefoot [25]; a consequence of the increase in sagittal plane motion and decrease in transverse plane motion. The reduction of the AHI with age as seen in the current study therefore suggests a gradual, age-related reduction in the efficiency of the "windlass" mechanism. Since the plantar aponeurosis is the main passive stabilizer of the MLA [9], one would expect that the aponeurosis would thicken in adaptation to this altered configuration of the MLA [4,5]. However, the results of the present study have shown that there is no association between the AHI and the thickness of the PA.

This therefore precludes the conclusion that the differences in the thickness of the PA are purely because of adaptability to the configuration of the MLA. It is therefore plausible to posit that the changes in the thickness of PA observed in the current study were because of the aging process and not necessarily, an effect of the variant foot architecture observed.

Limitations of the Study: In our study, we used donated cadaveric specimen and as such, deriving their medical information to confirm prior presence foot related anomalies was difficult.

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