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The relationship between arch height and foot length: Implications for size grading

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A B S T R A C T

Objective: Medial longitudinal Arch Height is synonymous with classifying foot type and conversely foot function. Detailed knowledge of foot anthropometry is essential in the development of ergonomically sound footwear. Current Footwear design incorporates a direct proportionate scaling of instep dimensions with those of foot length. The objective of this paper is to investigate if a direct proportional relationship exists between human arch height parameters and foot length in subjects with normal foot posture.
Method: A healthy convenience sample of 62 volunteers was recruited to participate in this observational study. All subjects were screened for normal foot health and posture. Each subject's foot dimensions were scanned and measured using a 3D Foot Scanner. From this foot length and arch height parameters were obtained. Normalised ratios of arch height with respect to foot length were also calculated. The arch height parameters and the normalised arch ratios were used interchangeably as the dependent variables with the foot length parameters used as the independent variable for Simple Linear Regression and Correlation.
Results: Analysis of foot length measures demonstrated poor correlation with all arch height parameters.
Conclusion: No significant relationships between arch height and foot length were found. The predictive value of the relationship was found to be poor. This holds significant implications for the current method of proportionate scaling of footwear in terms of fit and function to the midfoot region for a normative population.

1. Introduction

The study of the medial longitudinal arch (MLA) has been the primary anthropometric measure to determine foot type and function throughout the history of anthropology ranging from antiquity (Xarchas and Tsolakidis, 2004) to modern day research (Xiong et al., 2010; Pohl and Farr, 2010; Murley et al., 2009a; Razeghi and Batt, 2002; Williams and McClay, 2000). The anatomy of the MLA enables it to function as a truss resolving the loads applied to it into compressive and tensile stresses exploiting the mechanical resistant properties of bone and fascia (Kogler et al., 1999). The Arch shows a high degree of resilience, providing shock attenuation via lengthening in initial loading and recoiling to form a relatively rigid lever during propulsive activities (Nielson et al., 2009; Vinicombe et al., 2001; Xiong et al., 2010).

The shape of MLA is widely variable with demographics such as: race (Igbigbi and Msamati, 2002), sex (Krauss et al., 2008; Wunderlich and Cavanagh, 2001), body type (Dowling et al., 2001; Morrison et al., 2007), age (Gilmour and Burns, 2001; Scott et al., 2007), and even geographical location (Mauch et al., 2008) displaying notable structural variation in a healthy population, ranging from highly arched to flat (Redmond et al., 2008). Variations in MLA dimensions have been shown to influence the activity of lower limb muscle groups in gait (Murley et al., 2009a) and predispose to injury, high arched dimensions tending towards: skeletal, ankle and lateral lower extremity injury, with those of low arched dimensions predisposing to: soft tissue, knee and medial lower extremity injury (Cowan et al., 1993; Cain et al., 2007; Burns et al., 2005).

Abbreviations: MLA, Medial Longitudinal Arch; FPI, Foot posture Index; FL_TOT, Foot Length Total; INS_L, Instep Length; INS_H, Instep Height; N_H, Navicular Height; NNH_Ins, Normalised Navicular Height to Instep Length; AHI_Ins, Arch Height Index to Instep Length; NNH_TOT, Normalised Navicular Height to Total Foot Length; AHI_TOT, Arch Height Index to Total Foot Length).

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Numerous methods have been developed to quantify the medial longitudinal arch with considerable debate still on going as to the validity of these various measures (Xiong et al., 2010; Razeghi and Batt, 2002). The existing measures reported in the literature are based on morphological parameters of the MLA. Methods for classification of the MLA can be placed into one of the following general categories

1) Visual non-quantitative Clinical Subjective Ranking 2) Footprint Indices either Ratio related (Area index, Length Index, Width index) or Angle related 3) Anthropometric Dimension Indices Direct measured values of skeletal landmarks. 4) Anthropometric Angular Indices Measures of skeletal angulation. 5) Foot Mobility Indices Measures of Change in MLA dimension between two stated static positions.

The techniques used to determine the indices are various and include, inked foot printing, pressure mapping, calliper based measurements, radiographic imaging, digital photography, simple visual observation, and most recently three dimensional laser scanning (Xiong et al 2008, 2010; Pohl and Farr, 2010; Murley et al., 2009b; McPoil et al., 2009, 2008, Williams and McClay, 2000; Chu et al., 1995; Shiang et al., 1998; Menz, 1998; Cavanagh and Rodgers, 1987).

Navicular height defined as the distance from the medial tuberosity of the navicular to the supporting surface is considered to be the best approximation of plantar MLA height, representing the peak of the calcaneal inclination angle (CAI) (Fig. 1) (Murley et al., 2009b; Razeghi and Batt, 2002; Saltzman et al., 1995). Instep height at 50% total foot length is considered the best approximation of dorsal MLA height (Williams and McClay, 2000) representing the dorsal aspect of the medial cuneiform (McPoil et al., 2009) which lies along the inclination angle of the first metatarsal (Fig. 1) (Xiong et al., 2010). Both measures have previously been captured with calliper-based techniques and have demonstrated face validity compared with lateral radiographs of the MLA, (Menz and Munteanu, 2005; Williams and McClay, 2000; Saltzman et al., 1995 Pohl and Farr, 2010; Murley et al., 2009b). Three dimensional laser scanning has the advantage of capturing data more rapidly than calliper based techniques, and has increasingly been used in ergonomic and clinical studies (Xiong et al., 2008; Krauss et al., 2008; Mickle et al., 2010; Witana et al., 2006; Pfeiffer et al., 2006; Telfer and Woodburn, 2010; De Mits et al., 2010, 2011).

Scanners such as the USB standard INFOOT 3-D digitizer model IFU-S-01 (I-Ware Laboratory Co Ltd) have shown substantial to near perfect inter and intra rater reliability, and has established validity in comparison to clinical calliper data and radiographic measurements (De Mits et al., 2010, 2011).

Even with valid and reliable measures there has been a lack of clarity as to what constitutes abnormal arch height (Murley et al., 2009b). Navicular height and dorsal arch height cannot be used alone since the shape of the arch (Fig. 1). is roughly a triangular shape that indicates a relationship between arch length and arch height (Fig. 1) i.e. a 30 mm navicular height would represent a different calcaneal inclination angle in an individual with a standard EU size 43 to that of an individual with EU size 36, dividing the height measures by foot length provide gradient indices to account for this. The normalised navicular height measure (NNH) divides navicular height by foot length and the arch height index (AHI) is the ratio of the instep height at 50% foot length and the foot length (Williams and McClay, 2000).

The foot length is defined as either the total foot length (the distance between the most posterior aspect of the heel and the tip of the longest toe measured along the foot axis), or truncated foot length/instep length (defined as the perpendicular distance from the first metatarso-phalangeal joint to the most posterior aspect of the heel (Fig. 1). These height to length gradients are representative of the calcaneal inclination and calcaneal first metatarsal angles (Fig. 1) enabling comparison of arch height throughout the range of foot lengths (Williams and McClay, 2000). These normalised measures can only accommodate for the differences if there is a linear relationship between the arch height and foot length measures. However it is not readily apparent in the literature if a linear relationship exists between arch height and foot length (Xiong et al., 2008).

Xiong and co-workers (2008) noted this paucity in the literature and concluded that the lack of the true relationship between foot height and foot length dimensions could lead to poor generalised footwear models. While dimensions such as overall stature and foot length have shown a significant proportional relationship (Krishan, 2008), it is well documented that no linear relationship exist between the width based foot dimensions and total foot length (Xiong et al., 2008). This indicates that various characteristic dimensional foot types are not distributed homogeneously throughout foot length with shorter feet being wider in proportion to those of longer length (Mauch et al., 2007, 2009; Bataller et al., 2001,Krauss et al., 2007, 2008).

To investigate the relationship between arch height and length Xiong et al. (2008) and Li et al. (2005) studied the relationship of midfoot height and overall foot length dimensions in a healthy sample of a mixed gender using 3 dimensional laser scanning technique. While both studies reported total foot length to be a

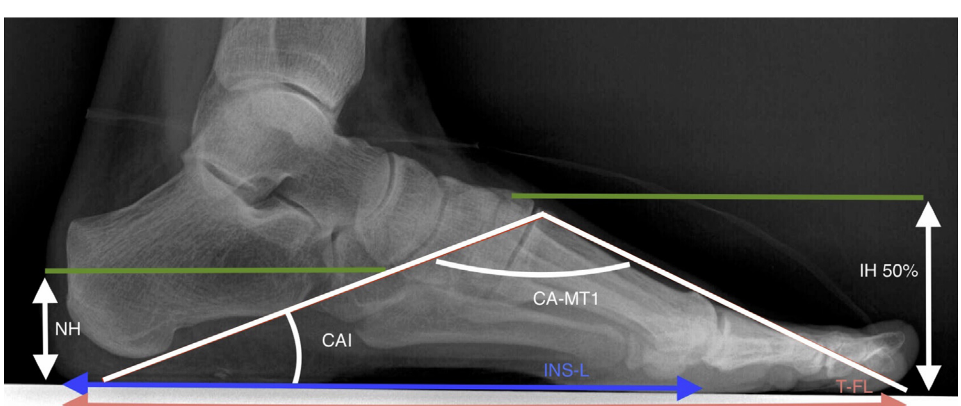

Fig. 1. Skeletal arrangement of the medial longitudinal arch. Calcaneal Inclination Angle (Defined as the angle between the tangent to the inferior surface of the calcaneus and the horizontal plane.) (CAI), Calcaneal First Metatarsal Angle (Defined as the angle subtended by tangent to the inferior surface of the calcaneus and the tangent to the dorsal surface of the 1st metatarsal.) (CA-MT1) Instep/Truncated Foot Length (INS-L) Total Foot Length (TF-L) Navicular Height (NH) Instep Height at 50% total foot length (IH 50%).