EFFECTS OF SHOD AND BAREFOOT CONDITIONS ON MEDIAL LONGITUDINAL ARCH ANGLE DURING RUNNING

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The structure of the medial longitudinal arch (MLA) affects the spring-like function of the foot and is crucial to running performance. The purpose of this study was to investigate the differences in the MLA angle between barefoot and shod conditions by using a high-speed dual fluoroscopic imaging system (DFIS). Computed tomography was taken of each participant's right foot for the construction of 3D models and local coordinate systems. Fifteen participants ran with or without running shoes at 3 m/s$\pm$5% speed. We recorded foot kinematics using DFIS. After the process of 3D-2D registration, MLA angles were calculated. Compared to barefoot, wearing shoes 1) decreased the initial landing MLA angle, maximum MLA angle and range of motion of the MLA angle ($p < 0.05$); 2) decreased the MLA angles during 0%-70% of the stance phase ($p < 0.05$). It suggests that shoes limit the MLA compression and recoil and its spring-like function.

KEYWORDS: Medial longitudinal arch, DFIS, Running, Barefoot, Shod.

INTRODUCTION: During running, the foot is an important structure connecting the ground to the body, adapting to the running surface, affecting energy absorption and transfer, (Welte et al., 2018). The medial longitudinal arch (MLA) is crucial in energy transmission (Lynn et al., 2012) This arch structure connecting the human body and the ground plays an important role in human bipedal locomotion and allows the human foot to act as a shock attenuator during landing (Kelly et al., 2016). Footwear has provided mechanical protection for human feet when running. Despite the fast development of running shoes, running injury rates remains at a relatively high level of 7.7%-17.85, leading some to question the efficacy of modern running shoes in preventing injuries (Videbaek et al., 2015). Some scholars even suggested that modern running shoes may hinder our running performance. Due to the complex structure of the MLA, it is impossible to accurately measure the motion of the MLA using traditional motion capture systems based on reflective markers. Consequently, there is no unified conclusion on the effect of footwear on the MLA. The dual fluoroscopic imaging system (DFIS) has enabled the accurate and non-invasive measurements of the dynamic activities in the joints of the human body which can effectively make up for the defects of traditional measurement and has been applied in measuring MLA (Balsdon et al., 2016). Therefore, this study aimed to determine the effect of wearing shoes and barefoot in in-vivo MLA kinematics while running using the high-speed DFIS to clarify the potential relationships between footwear and injuries and provide scientific reference for runners to choose running footwear reasonably.

METHODS: Fifteen recreational healthy male runners (training volume: 38.8 ± 16.6 km/week, age: 29.1 ± 6.9 yrs., height: 173.0 ± 4.5 cm, mass: 71.7 ± 7.3 kg) underwent the foot CT scan for the construction of 3D models and local coordinate system.
All subjects were provided with a pair of running shoes (traditional footwear, heel-to-toe drop: 6 mm, midsole material: TPU and EVA; without any arch support) before the running experiment. During running data collection, each participant ran at 3 ± 5%m/s speed on the runway under barefoot and shod conditions with a rearfoot strike pattern and landed their right heel within the marked area on the runway. To reduce the total ionizing radiation, valid data were collected once under barefoot and shod conditions.
Similar to the MLA measurement used by Tome et al. (2006), landmarks including the medial process of the calcaneus (MP), the navicular tuberosity (NT), and the most distal point on the first metatarsal head (MH) were digitized to quantify the angle representing the MLA. After the process of 3D–2D registration, a custom algorithm was used to calculate the spatial vector

angles which represented the MLA angles using vectors from NT to the MP and the NT to the first MH in the three-dimensional space.
A larger MLA angle represents a lower (flattened) arch height, and vice versa.

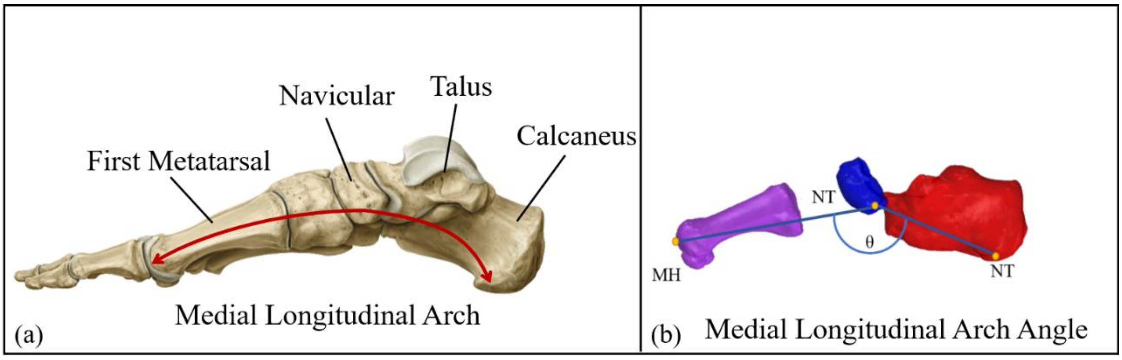

Figure 1: (a) MLA of the foot. (b) Bones and landmarks defining the MLA angle (θ).

A paired sample t-test was used to compare the MLA angle under barefoot and shod conditions. Statistical significance was set at $p < 0.05$.

RESULTS: The MLA angle during rearfoot initial landing, maximum/minimum MLA angle, and MLA range of motion (ROM) under barefoot and shod conditions are shown in Table 1. The MLA angle during initial landing, maximum angle, and MLA ROM under shod condition was significantly smaller than barefoot. And the MLA angle during 0%-70% of the stance phase when wearing shoes were significantly smaller than the barefoot condition ($p < 0.05$) (Figure 1)

Table 1: MLA angle of initial landing, maximum, minimum and range of motion.

The MLA angle	Barefoot (°)	Shod (°)	Sig
Initial landing	129.63 ± 8.43	126.13 ± 7.67	0.004
Maximum angle	143.71 ± 7.36	138.36 ± 8.04	0.002
Minimum angle	123.39 ± 8.15	123.35 ± 7.76	0.973
Range of motion (ROM)	20.32 ± 4.20	15.01 ± 3.98	0.000

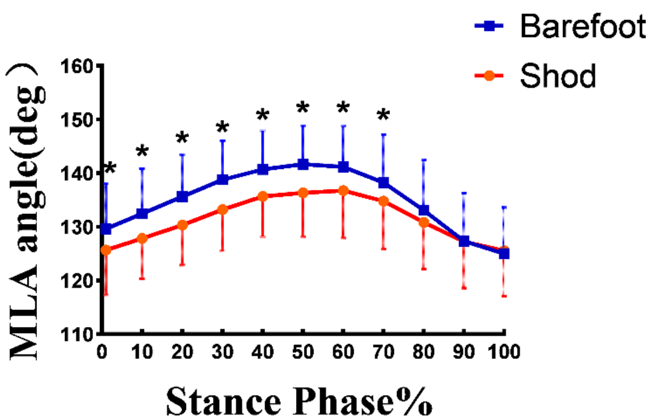

Figure 2: MLA angle of the stance phase under barefoot and shod conditions.
*: compared to barefoot, there are significant differences in shod condition, $p < 0.05$.

DISCUSSION: Our study found that wearing shoes limited the compression and recoil of the MLA, including the initial landing MLA angle, the maximum MLA angle, and the MLA angle

ROM. MLA angle in shoe-wearing is significantly smaller than under barefoot conditions during 0%-70% of the stance phase.
Specifically, MLA angles in shoe-wearing were significantly smaller, which was consistent with previous studies (Balsdon et al.,2019; Kelly et al.,2016). Due to a comparatively high modulus of elasticity of the midsole in most running shoes, the springlike action of the foot was limited thus led to a reduction in the magnitude of MLA compression and recoil, suggesting that running shoes impede foot-spring function. Meanwhile, during 0%-70% of the stance phase, MLA angles in shod condition were significantly smaller than barefoot. And there were no differences in MLA angle were apparent between barefoot and shod conditions during 80%-100% of the stance phase. These findings suggest that running shoes provide support for the MLA and reduce the strain on the MLA which was in line with previous studies (Hoffman et al.,2015; Peltz et al.,2014). However, these characteristics of running shoes are likely consequence of reduced activation of the MLA muscles and weaken MLA function. Due to the decreased of MLA activation and function, plantar fascia has to perform too much work when running which potentially accelerate the risk of muscle injuries in the foot such as plantar fasciitis.

CONCLUSION: Running with shoes resulted in a significantly smaller MLA angle compared to barefoot condition, suggesting that running shoes limited the MLA compression and recoil. And during the early and middle of the stance phase, MLA angles in shoe-wearing were significantly smaller than barefoot indicating that running shoes helped to absorb the shock but a reduce of MLA compression and recoil may hinder the foot-spring function.

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