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Original Article

Forefoot transverse arch height asymmetry is associated with foot injuries in athletes participating in college track events

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Abstract. [Purpose] The association between foot injuries and foot alignment, including the transverse arch height (TAH) and asymmetry, was examined in athletes participating in college track events. [Participants and Methods] This study included 55 male athletes participating in a college track and field club. Data including demographic information and the incidence of foot injuries within a year prior to participation in this study were obtained via questionnaires. TAH and the medial longitudinal arch height during 10 and 90% loading, leg-heel alignment, and the heel angle were measured before calculating the asymmetry of each alignment parameter measured. Participants were categorized into an injury or a normal group. Unpaired t-tests were used to perform between-group comparisons for each alignment parameter measured and asymmetry. Additionally, logistic regression analysis was performed to identify factors associated with foot injuries after adjustment for demographic data. [Results] TAH asymmetry during 10 and 90% loading was significantly greater in the injury group. Further logistic regression analysis performed showed that only TAH asymmetry during 90% loading was significantly associated with foot injuries after adjustment for demographic data. [Conclusion] With regard to track events, a greater asymmetry of forefoot TAH in a weight-bearing position was observed to be associated with foot injuries.

Key words: Transverse arch, Foot injury, Asymmetry

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INTRODUCTION

Track and field is one of the most popular sports and comprises various events such as running, jumping, and throwing. Of these, running events such as sprinting and long-distance running are undertaken by the largest number of athletes. Track and field athletes who partake in such events are required to repeatedly perform running movements when practicing and racing. These repeated cyclic movements place stress on specific body parts, mainly the lower extremities and feet, leading to injury. The foot is especially prone to injury; as it is the only body part that is in contact with the ground, it directly experiences shock from ground impact. It is therefore unsurprising that Liong SY and Whitehouse RW[1)] have reported that stress fractures of the metatarsals occur more commonly in track and field athletes than in other athletes. In addition to this injury of the foot, plantar fasciitis also often occurs in track and field athletes[2–4)]. These injuries are particularly challenging due to their associated slow recovery times, and as such, are considered to be a serious problem for track and field athletes. To treat and prevent injuries, much research on the association between injuries and various factors such as running form, muscle strength, flexibility and foot alignment has been conducted[4–10)]. Among these factors, we focused on foot alignments.

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The foot is divided into 3 parts: the rearfoot, midfoot, and forefoot. There are many studies on rearfoot and midfoot alignments, such as leg heel alignment (LHA) and medial longitudinal arch height (MLAH). However, fewer studies on forefoot alignment have conducted. In the current study, we focused on forefoot alignment in terms of transverse arch height (TAH). It is generally known that as with the medial longitudinal arch, the transverse arch has functions including shock absorption and the generation of propulsive force. As such, deformity of the transverse arch has been associated with medial tibial stress syndrome, a common overuse injury in track and field athletes[11]. TAH can relate to foot injuries. Furthermore, asymmetry of alignment is also thought to induce some injuries, with an association between asymmetry of the Q-angle and lower extremity injuries having been reported[12]. Thus, in addition to unilateral data, we also deemed it necessary to consider asymmetry.

Considering the above points, the purpose of this study was therefore to investigate by means of ultrasonography whether there is an association between foot alignment (in terms of forefoot TAH and each alignment asymmetry) and foot injuries in college track event athletes. We hypothesized that athletes who have experienced foot injuries would have lower TAH or greater foot asymmetry than those who have not.

PARTICIPANTS AND METHODS

A total of 55 male athletes from a college track and field club participated in the current study (mean age=22 ± 1.4 years, age range=18–25 years, body mass index [BMI]=20.2 ± 1.4 kg/m^2). Participants were included if they belonged to a college track and field club and had running as their main event. Participants were excluded if they were injured and were not able to assume the position required for alignment measurements. The participants received sufficient verbal and written explanation of the purpose and methods of this study, and all signed a consent form. The study was approved by the Kyoto University Graduate School and the Faculty of Medicine Kyoto University Hospital Ethics Committee (Approval No. R0645-1).

Data including demographic information and history of foot injury were collected by questionnaire. Demographic data included age, body height, body weight, and competition history. BMI was calculated from collected body weight and height. Foot injuries were defined as the pain at the foot distal to ankle joint which occurred in training and race of track and field within one year, excluding accidental injuries such as sprain and bruise. Foot injuries prevented participants from participating track and field at least one day.

As athletes apply repeated loads to their feet during running, it is important to measure foot alignment under weight-bearing conditions. Weight-bearing images are able to be obtained by an ultrasound imaging device originally designed by Matsubara who was our laboratory member. We call the device weight-bearing plantar ultrasound imaging device (WPUID). Matsubara et al.[13] reported that the reliability of ultrasonography is sufficient and comparable to computed tomography for evaluating forefoot structure in the coronal plane. Therefore, TAH was evaluated using a Noblus machine (Hitachi Aloka Medical, Mitaka, Japan) that had been adapted for use with the WPUID. A 92 mm-wide linear probe set to 5–10 MHz (EUP-L53L, Hitachi Aloka Medical) and a digital weight scale were attached to the foot surface. Echo jelly (GEL-SCAN-KA, Hitachi Aloka Medical) was also applied to a solid gel plate (SONAGEL®S; TAKIRON, Osaka, Japan), which was set on the ultrasound probe. Participants placed 1 foot on the gel and their other foot on the scale for loading rate adjustment. We then took plantar ultrasound images with participants in the static bilateral standing position under conditions of 10% and 90% weight loading on the measured foot. For the imaging itself, we adjusted the position of participants' feet by watching the screen of ultrasound machine to obtain images where the medial and lateral sesamoid bones and the 2nd and 5th metatarsal heads were visible. We analyzed the plantar ultrasound images using Image J (National Institutes of Health, Maryland, USA). TAH was calculated as the perpendicular distance of the 2nd metatarsal bony head from the line connecting the medial sesamoid bone and 5th metatarsal bony head (Figs. 1, 2)[13].

MLAH is commonly assessed by measuring navicular bone height[14–16]. In the current study, MLAH was evaluated by measuring the height of the navicular bone from the floor with participants in the static bilateral stance under 10% and 90% weight loading conditions. Participants had 1 foot placed on the digital weight scale for loading rate adjustment, and the other on a board placed at the same height as the scale.

LHA and HA were measured with participants in a relaxed standing position. Prior to imaging, we marked 3 points on each participant: point 1, the bisection point of the lower one third of the leg; point 2, the tuber calcanei; and point 3, bottom of the tuber calcanei. We then photographed the back of participants' legs and analyzed the images using Image J. Specifically, LHA was calculated as the angle between the line connecting point 1 to point 2 and the line connecting point 2 to point 3 [17–19]. HA was calculated as the angle between the line connecting point 2 to point 3 and the flat surface on which participants' feet were placed[20, 21].

The asymmetry of all alignment measures (TAH, MLAH, LHA, and HA) was calculated as deviation of left from right values[22].

Participants were allocated into either the injury or normal group depending on their questionnaire responses. Unpaired t-tests were then performed to compare alignments and asymmetry (for each of TAH, MLAH, LHA, and HA) between the 2 groups. Factors that were found to significantly differ between groups then underwent logistic regression analysis (stepwise method), with these factors as independent variables. Finally, logistic regression analysis (forced entry method) was conducted to examine whether factors that had been selected by the stepwise procedure were independently associated with foot injury when adjusted for demographic data (i.e., BMI and competition history). The statistical significance level

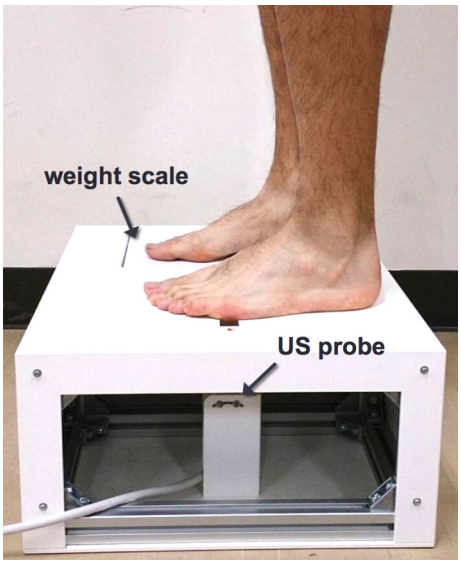

Fig. 1. Weight-bearing plantar ultrasound imaging device (WPUID).
This is the measurement of left transverse arch height (TAH). When measuring the TAH at 90% loading of a participant with a body weight of 60 kg, take an ultrasound image at the time the weight scale shows 6 kg.
US probe: ultrasound probe.

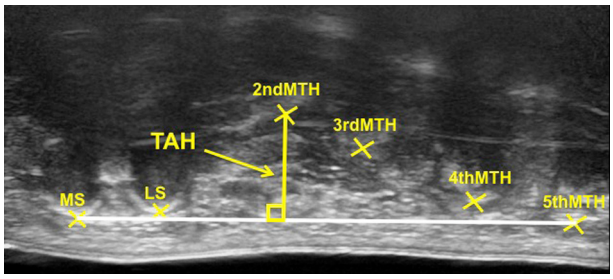

Fig. 2. Ultrasound image of transverse arch height (TAH) using the weight-bearing plantar ultrasound imaging device (WPUID).
MS: medial sesamoid bone; LS: lateral sesamoid bone; MTH: metatarsal head.

was set at $p<0.05$ for all tests.

RESULTS

As there was no missing data, data from all 55 enrolled participants were included in statistical analysis. Of these 55 participants, 16 (29%) were in the injury group and 39 (71%) were in the normal group. In injury group, one injured both feet, five injured the right foot and ten injured the left foot. Participant demographics, which did not significantly differ between the two groups, are summarized in Table 1.

The results of between-group comparisons using unpaired t-tests are presented in Tables 2 and 3. Key results included significantly greater TAH asymmetry in the injury than normal group during 10% loading (injury: 1.8 ± 2.8 mm, normal: 0.1 ± 2.8 mm) and 90% loading (injury: 2.9 ± 3.8 mm, normal: 0.0 ± 3.2 mm) conditions. Within the injury group, right TAH was significantly greater than left TAH.

The results of the logistic regression analyses are shown in Table 4. TAH asymmetry during 90% loading was selected by the stepwise method (odds ratio [OR]=1.27, 95% confidence interval [CI]=1.05–1.54), and was significantly associated with foot injuries regardless of BMI and competition history (OR=1.26, 95% CI=1.03–1.54).

DISCUSSION

To our knowledge, this is the first study to investigate in track event athletes the association between foot injuries and foot alignment in terms of forefoot TAH and asymmetry. Our main finding was that athletes who had suffered foot injuries had greater TAH asymmetry under 90% loading conditions than those who had not. There are 3 discussion points regarding this result.

First, asymmetry of TAH during 90% loading was more strongly associated with foot injuries than during 10% loading. A load is repeatedly applied to the feet when running, which is considered by many researchers to be associated with some injuries[23–25]. In addition, there are some studies suggesting that foot alignment is related to plantar load[23, 26], with reports of foot alignments being different between weight- and non-weight-bearing positions[27, 28]. As such, foot alignment during running may have been better reflected by the 90% than 10% loading position, which would account for an association between foot injuries and the former but not the latter.

Second, only forefoot alignment, and not rearfoot or midfoot alignment, was found to be associated with foot injuries. This is likely due to the manner in which the foot strikes the ground when running. Forrester SE & Townend J[29] reported that at

Table 1. Participants' demographic data

	Injury (N=16)	Normal (N=39)
Age (years)	20.4 ± 1.3	20.2 ± 1.6
Body height (cm)	173.2 ± 6.2	173.2 ± 4.8
Body weight (kg)	59.3 ± 5.3	61.0 ± 5.7
Body Mass Index (kg/m^2)	19.8 ± 1.3	20.3 ± 1.5
Competition history (years)	8.3 ± 2.0	7.3 ± 2.7

Mean ± SD.

Table 2. Unpaired t-test results for between-group comparisons of foot alignment measures

		Injury (N=16)	Normal (N=39)
TAH (10%) (mm)	Right	8.2 ± 3.1	6.8 ± 3.5
	Left	6.4 ± 3.4	6.8 ± 3.2
TAH (90%) (mm)	Right	7.9 ± 3.9	6.4 ± 3.6
	Left	5.0 ± 3.7	6.3 ± 3.1
MLAH (10%) (cm)	Right	3.9 ± 0.6	4.2 ± 0.6
	Left	3.8 ± 0.6	4.0 ± 0.5
MLAH (90%) (cm)	Right	3.4 ± 0.6	3.4 ± 0.6
	Left	3.1 ± 0.4	3.3 ± 0.6
LHA (°)	Right	6.3 ± 3.0	5.8 ± 2.3
	Left	6.0 ± 2.8	5.8 ± 2.1
HA (°)	Right	1.6 ± 1.7	1.4 ± 2.1
	Left	3.1 ± 1.9	2.1 ± 1.6

Mean ± SD.

Table 3. Unpaired t-test results for between-group comparisons of foot alignment asymmetry

Asymmetry (Right-Left)	Injury (N=16)	Normal (N=39)
TAH (10%) (mm)	1.8 ± 2.8*	0.1 ± 2.8
TAH (90%) (mm)	2.9 ± 3.8**	0.0 ± 3.2
MLAH (10%) (cm)	0.1 ± 0.4	0.1 ± 0.4
MLAH (90%) (cm)	0.1 ± 0.3	0.1 ± 0.3
LHA (°)	0.3 ± 2.7	0.0 ± 2.5
HA (°)	−1.5 ± 2.5	−0.7 ± 2.2

Mean ± SD, *p<0.05,**p<0.01.

Table 4. Logistic regression analysis

		OR (95%CI)
Stepwise method	Asymmetry of TAH (90%)	1.27 (1.05–1.54)*
	Asymmetry of TAH (10%)	-
Forced entry method†	Asymmetry of TAH (90%)	1.26 (1.03–1.54)*

OR: Odds Ratio; CI: Confidence Interval. †adjusted for BMI, competition history.
*p<0.05.

running velocities above 5 m/s, runners tend to move away from rearfoot strike towards midfoot and forefoot strike. Among our college track event athletes, both sprinters and long distance runners run at speeds above 5 m/s. Thus, it is to be expected that only forefoot alignment asymmetry was found to be related to foot injuries in our study.

Finally, though there were no significant differences in unilateral data, asymmetry of TAH was associated with foot injuries. Our result is in agreement with other studies that have found a relationship between injuries and asymmetry of strength and alignment[12, 30]. In the current study, TAH in the injury group tended to be lower in the left than right foot. It has been reported that bend running causes different forces to be applied to the lower limbs[31]. Since track event athletes always run in the counterclockwise direction, the left (inside of curve) foot has a longer ground contact time and suffers from more rotational stress than the right (outside of the curve) foot[31]. This can then cause asymmetry of TAH, as seen in the injury group. However, it must also be considered why TAH asymmetry, and subsequently injury, occur in some athletes but not others. As with other foot arches, the transverse arch functions to absorb shock, which is important for avoiding sports injuries. Indeed, several studies have shown an association between high medial arches and injuries[32, 33], while others have associated flat feet with injuries[34, 35]. Taken together, these studies suggest that there is an ideal height at which the foot arch functions properly. Therefore, it is possible that athletes with greater TAH asymmetry have non-ideal arch heights of one or both feet, leading to inadequate shock absorption and a higher risk of injury.

Despite the insights provided by this study, there are 3 main limitations to be considered. First, foot injury histories were collected by questionnaire and were not restrictedly defined. Second, the number of participants was insufficient for further

statistical analysis. Finally, the causal relationship between foot injuries and TAH asymmetry is unclear because this study design was cross-sectional. Nevertheless, this study is useful for the prevention and treatment of foot injuries because it is the first to implicate TAH asymmetry under weight-bearing conditions in the occurrence of foot injuries.

In track event athletes, we found that TAH asymmetry under weight-bearing conditions was associated with foot injuries regardless of demographic factors such as BMI and competition history. This result implies that for the prevention and treatment of foot injuries, it is necessary to evaluate forefoot alignment in weight-loading positions and to consider TAH asymmetry. This may enable better treatment or prevention approaches for athletes with foot injuries to be developed. In the future, it is necessary to research on the effective treatment for TAH, such as taping and foot pad.

Conflict of interest

None.

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