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Arch structure and injury patterns in runners

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Abstract

Objective. The purpose of this study was to determine if high-arched and low-arched runners exhibit different injury patterns.

Design. Non-randomized, two-group injury survey.

Background. Running-related injuries are thought to be related, in part, to lower extremity structure. High-arched and low-arched runners with their different bony architecture may exhibit very different lower extremity mechanics and, consequently, different injury patterns. It was hypothesized that high-arched runners will exhibit a greater incidence of lateral injuries, skeletal injuries and knee injuries while low-arched runners will show a greater incidence of medial injuries, soft tissue injuries and foot injuries.

Methods. Twenty high-arched and 20 low-arched runners were included in this study. Running-related injuries were recorded and divided into injury patterns of medial/lateral, bony/soft tissue and knee/foot and ankle for both high-arched and low-arched runners. A χ^2 analysis was then employed in an attempt to associate injury patterns with arch structure.

Results. High-arched runners reported a greater incidence of ankle injuries, bony injuries and lateral injuries. Low-arched runners exhibited more knee injuries, soft tissue injuries and medial injuries.

Conclusions. Based on these results, high and low arch structure is associated with different injury patterns in runners.

Relevance

Different injury patterns are present in individuals with extreme high arches when compared to those with extremely low arches. These relationships may lead to improved treatment and intervention strategies for runners based on their predisposing foot structure.

Keywords: Lower extremity; Foot; Injury survey; Running

1. Introduction

It is believed that many factors play a role in the development of injuries in the lower extremities of runners. Injuries are often reported to be due to overuse [1,2]. In addition, lower extremity mechanics are thought to play a role [3,4]. However, abnormal structure has also been implicated as a factor that increases risk for injury [5–9]. Although there are a number of studies regarding injuries in runners, specific relationships between structural deviations and injury patterns have not been well established.

Foot structure is commonly associated with lower extremity problems. Giladi et al. [10] demonstrated that high-arched (HA) or normal subjects were more likely to develop stress fractures than low-arched (LA) people. Similarly, Cowan et al. [11] reported that HA individuals had the greatest propensity toward injuries of the lower extremities when compared to runners with normal and LA structures. Additionally, HA individuals are reported to have an increased number of tibial and femoral stress fractures while LA subjects demonstrate a greater number of metatarsal injuries [12]. It was found that both HA and LA patients had greater incidences of knee injuries than patients with a normal arch structure [13]. Conversely, it has been reported that a high arch was protective against all injuries in runners [14]. The same study found no relationship between low arch and injuries. Finally, a recent prospective study of Navy Seals suggests the static characteristics of pes planus, pes cavus and rearfoot range of motion are risk factors for

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development of lower extremity overuse injuries in general [15]. Some investigators have found no relationship to the structure [3,16].

Based on these studies, there does not appear to be a clear relationship between arch structure and injury pattern. Differences in the results of all of these studies may be related to the method of defining and categorizing arch structure. Some were based on visual observation [13], which has been shown to be unreliable [17]. Others used footprint measures [18], which may not characterize the bony architecture well. Finally, the criteria for placing subjects into HA and LA groups is often arbitrary resulting in HA and LA groups that include subjects with only mild deviations. For example, if arch height is normally distributed, then dividing the range of arch values into thirds (HA, normal, LA) may result in a significant number of normal individuals falling within the HA and LA categories.

Arch height may effect the distribution of injury in the lower extremity through its influence on the mechanical coupling between the subtalar joint and the knee. This coupling is related to the orientation of the subtalar joint axis. It has been reported that the subtalar joint axis is oriented 42° in the sagittal plane [19], which would be approximately equal motion of the subtalar joint in the frontal (inversion/eversion) and transverse (abduction/adduction) planes. Abduction and adduction at the subtalar joint translates to external and internal rotation, respectively, of the tibia. A low arch with a relatively low angle of inclination at the subtalar joint is thought to result in a higher component of eversion at the subtalar joint and a lower component of tibial internal rotation.

Nigg et al. [20] found that arch height did not influence the individual measures of eversion (EV) excursion or tibial internal rotation (TIR) excursion during the stance phase of running. However, he determined that 27% of the variance present in the ratio between these motions (EV/TIR) was explained by arch height. Additionally, Nawoczenski et al. [21] found that LA individuals had a higher EV/TIR ratio while HA individuals had greater relative internal rotation resulting in a lower EV/TIR ratio than LA runners. Both authors suggest that a higher EV/TIR with relatively higher EV present in LA individuals might place a greater strain on the foot and ankle. Conversely, a low EV/TIR ratio seen in HA individuals may place more stress on the knee secondary to a relative increase in transverse plane motion of the tibia.

It has been suggested that a pronated or planus foot loads the medial foot while a HA runner tends to load the lateral structures more [22]. This suggests that runners with planus or LA feet may develop more medial foot and lower extremity problems and those with cavus or HA feet, more lateral problems. These medial and lateral loads may also be transferred more proximally up the entire lower extremity. For example, genu valgum is often seen in individuals with pronated feet and may stress the medial structures of the knee.

LA individuals are typically thought to have mobile feet while HA individuals exhibit more rigid feet [22]. A HA rigid foot is likely to be less able to attenuate shock resulting in greater forces experienced by the foot and transferred proximally in the lower extremity. Conversely, LA runners with more mobile feet may require more control of the structures of the foot. Increased demand may be placed on the soft tissue structures such as ligaments and tendons necessary for providing this control and result in more injuries in these structures.

Although, many authors have speculated that abnormal structure results in associated injuries, few definitive correlations have been found. It has been difficult to establish a relationship between a single structural deviation and a specific injury as the etiology of injuries is multifactorial in nature. However, a single structural deviation, if large enough, may have a stronger correlation to an injury or group of injuries. Based on the previous literature, few studies utilized subjects with large structural deviations. Subjects with greater deviations in structure may be more limited in their compensatory strategies and more likely to present with specific patterns of injury.

Therefore, the purpose of this study was to determine if foot types could be associated with injury patterns. It was hypothesized that HA runners would exhibit a greater incidence of lateral injuries, skeletal injuries and knee injuries while LA runners would show a greater incidence of medial injuries, soft tissue injuries and foot injuries. This was an attempt to demonstrate different injury patterns were present in individuals with different foot structures.

2. Methods

A preliminary power analysis for the χ^2-test using a 5% level of significance was conducted in order to determine the number of subjects required in each group. The study included 20 HA (10 females; 10 males) and 20 LA (12 females; 8 males) runners between the ages of 18 and 50 (mean 27.8 yrs; SD 8.1) with no neurological abnormality or history of foot surgery. Subjects were excluded if they were currently injured, ACL deficient or had a recent lower extremity surgery within the past 12 months. All subjects had a history of running-related lower extremity injury that kept them from running for at least one week. Subjects ran at least six miles per week at a minimal eight minute per mile pace.

Runners with HA and LA were recruited through the local community by word of mouth, physicians, podiatrists, running clubs and track teams. All subjects were then screened with the use of an arch ratio for inclusion in the HA or LA group [23]. The arch ratio was defined as the height to the dorsum of the foot from the floor (at 50% of the foot length) divided by the individual's truncated foot length (DORS/TFL). TFL was the length of the foot from the most posterior portion of the calcaneus to the medial joint space of the first metatarsal phalangeal joint. Subjects with an arch ratio of at least 0.356 were considered HA and those with an arch ratio of at most 0.275 were considered LA. These values fell at or outside 1.5 SD above or below the mean arch ratio measurement of 0.316 (SD 0.027) based on a previously examined sample population of 102 feet [23]. Those values would place individuals in the highest and lowest 7% and 8% respectively of the previously measured sample. These strict inclusion criteria were employed in order to evaluate individuals whose capacity for compensation may be more limited in scope. This arch ratio was found to be a reliable and valid method of categorizing feet in both 10% weight bearing and 90% weight bearing. ICC values were above 0.939 for intratester reliability, above 0.811 for intertester reliability, and above 0.844 for concurrent validity [23].

All subjects signed informed consent forms prior to the experiment. Subjects completed an injury history questionnaire in which they independently reported all running-related lower extremity injuries. All injuries had been previously diagnosed by a medical professional. These injury data are part of a larger study, which included analyses of kinematic and kinetic data in these subjects.

Subjects were instructed to be as specific as possible about the location and nature of the injuries sustained. Specific diagnoses were reported when appropriate. Injuries with no specific diagnosis (i.e., anterior knee pain) were recorded as 'other'. However, a diagnosis such as anterior knee pain would be recorded as a knee injury. All injuries were then categorized into three groups: (1) medial or lateral (2) bony or soft tissue (3) foot/ankle or knee. This grouping of injuries was done to increase the power of the design and was based upon proposed mechanisms of injuries suggested in the literature. An injury could fall into more than one category. For instance, a lateral ankle sprain would be considered lateral, soft tissue and ankle. All injuries were reported to and categorized by a licensed physical therapist. Injuries that did not clearly fall into a category were not classified. For example, a mid-belly hamstring strain would be classified as soft tissue but neither medial-lateral nor ankle/foot-knee. A χ^2 analysis was performed on the incidence of injury patterns within the groups.

3. Results

HA and LA subjects' characteristics are displayed in Table 1. There were no differences between subjects in height, weight or age. Injuries are reported in Table 2 and grouped by location. There were a total of 70 injuries in the HA group and 64 in the LA group. The χ^2 analysis showed significant differences between the groups in injury patterns (Fig. 1). HA runners showed more lateral injuries and LA runners had more medial injuries ($\chi^2 = 9.22, P = 0.002$). HA runners reported more bony injuries while LA runners had more soft tissue injuries ($\chi^2 = 3.94, P = 0.047$). Finally, LA runners demonstrated more knee injuries and HA runners showed more foot and ankle injuries ($\chi^2 = 4.03$, $P = 0.045$).

The most common injuries in the HA group were plantar fasciitis, lateral ankle sprains and iliotibial band (ITB) friction syndrome. All metatarsal stress fractures in the HA runners were at the fifth metatarsal. LA runners reported general knee pain, patellar tendinitis and plantar fasciitis as the most frequent injuries. Metatarsal stress fractures and syndromes were distributed on the second and third metatarsals in the LA runners. The center of pressure of the foot remained more lateral in the HA runners when compared to the LA runners with a peak difference of 0.6 cm (Fig. 2). LA runners also exhibited greater knee flexion and external rotation than the HA runners (Table 3).

4. Discussion

The distribution of injuries was consistent with previous studies of running injuries as summarized by van Mechelen [24]. The majority of the overall injuries in the

Table 1
Subject Demographics

	High arch	Low arch	*P*-value
Number of subjects	20	20	
Sex	12 F, 8 M	10 F, 10 M	
Height (m)	1.72 (0.09)	1.74 (0.10)	0.510
Mass (kg)	66.45 (9.49)	72.73 (17.89)	0.174
Age (yr)	28.0 (8.1)	27.7 (7.5)	0.904
Miles/week	30.0 (16.9)	27.5 (19.3)	0.336
Arch ratio	0.368 (0.012)	0.264 (0.013)	0.000*

* Statistically significant using Student's *t*-test.

Table 2
Injury profiles by location

Location	Injury	Total #	HA #	LA #	(B)one or (S)oft	(M)edial or (L)ateral
Back	Vertebral stress fracture	1		1	B	
	Strain	2		2	S	
	Other	5	2	3	B, S	
	Total	8	2	6		
Hip/Groin	Groin strain	2	2		S	M
	Greater trochanteritis	1		1	S	L
	Other	4	2	2	B, S	M, L
	Total	7	4	3		
Thigh	Hamstring strain	3	2	1	S	M, L
	Adductor Strain	2	2		S	M
	Total	5	4	1		
Knee	Patellofemoral pain	3	1	2	B, S	M, L
	Patellar tendinitis	9	3	6	S	M, L
	IT band friction	8	5	3	S	L
	Medial collateral strain	2	1	1	S	M
	Quadriceps tendinitis	1	1		S	M, L
	Other	8		8	B, S	M, L
	Total	31	11	20		
Lower Leg	Tibial stress syndrome	5	3	2	B	M, L
	Tibial stress fracture	6	4	2	B	M, L
	Anterior compartment syndrome	3	1	2	S	L
	Posterior compartment syndrome	1	1		S	M, L
	Gastroc/soleus strain	2	2		S	M, L
	Anterior tibialis strain	1		1	S	L
	Peroneal strain	1	1		S	L
	Other	7	4	3	B, S	M, L
	Total	26	16	10		
Ankle	Medial ankle sprain	4	1	3	S	M
	Lateral ankle sprain	9	8	1	S	L
	Achilles tendinitis	3	1	2	S	M, L
	Tibialis posterior tendinitis	4	1	3	S	M
	Other	7	2	5	B, S	M, L
	Total	27	13	14		
Foot	Plantar fasciitis	13	8	5	S	M, L
	Metatarsal stress fracture	5	3	2	B	M, L
	Sesmoiditis	2		2	B, S	M
	First MTP joint pain	1	1		B, S	M
	Neuroma	3	3		S	M, L
	Other	6	3	3	B, S	M, L
	Total	30	20	10		
Grand total		134	70	64		

current study were at the knee (23%), foot (22.2%), ankle (20%) and lower leg (19.4%). This places 84.6% of the total injuries at the knee and distally.

Injury laterality was found to differ significantly between the two groups with HA runners reporting more lateral injuries and LA runners showing more medial

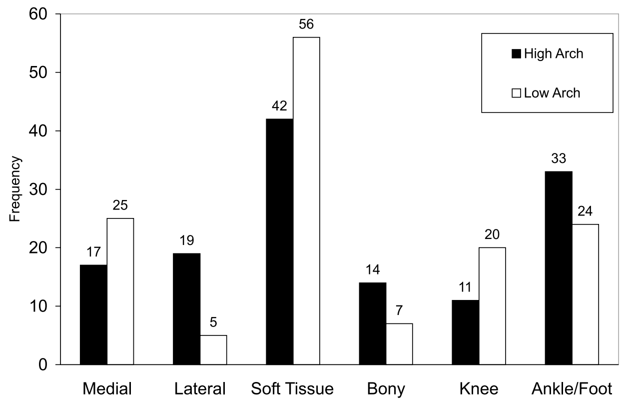

Fig. 1. Injury profiles by category.

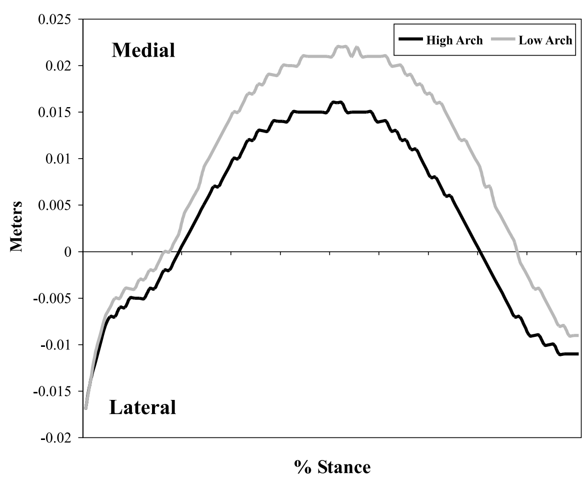

Fig. 2. Center of pressure values during stance. Note the center of pressure remains more lateral in the HA group throughout stance.

injuries. It appears that the pronated position of the foot often associated with a planus foot places increased stress on the medial structures of the lower extremity. In the associated biomechanical analysis, LA runners in this study were also found to have increased eversion excursion and eversion velocity at the rearfoot, which may have required more active and passive control by the medial structures of the foot and ankle. LA runners reported three times (three vs. one) as many incidences of posterior tibialis tendinitis as HA runners, although the number of incidences are too small to draw specific conclusions. The posterior tibialis has been shown to be a major decelerator of pronation during stance [25]. Future evaluation of HA and LA individuals with posterior tibialis tendinitis may further clarify this relationship. The increased number of lateral injuries in the HA subjects may be partially related to increased lateral loading of the foot as the center of pressure remained more lateral throughout stance in the HA runners (Fig. 2).

HA runners reported twice as many bony injuries as LA runners, although both groups demonstrated relatively high rates of stress fractures. 35% of HA subjects had stress fractures while 25% of LA subjects reported stress fractures. The incidence of stress fractures is consistent with the 39.6% has been previously reported in HA runners [10]. The values for the LA runners are greater than the values reported by Giladi et al. [10], who cited 10% in their LA group. The higher values seen in the present study may be due to the rigorous inclusion criteria, which only included injured runners with very high and low arches. HA runners reported more tibial stress fractures and stress syndromes than LA runners did which is consistent with the findings of Simkin [12]. Interestingly, all three metatarsal stress fractures reported by the HA runners were at the fifth metatarsal while the LA runners reported two metatarsal stress syndromes at the second metatarsal and two metatarsal stress fractures on the second and third metatarsals. This suggests there may be greater lateral loading of the HA foot and medial loading in the LA foot.

Both groups of runners reported a large number of soft tissue injuries. In fact the three most common injuries in both groups were all related to soft tissue (Table 4). This is consistent with James et al. [3] who report five of the six most common injuries as being related to soft tissue. A category of general knee pain was provided for those who did not have a specific diagnosis for their knee pain. All of these injuries were described to the tester as soft tissue in nature or of unknown origin.

There were almost twice as many knee injuries in the LA group (20 vs. 11). Two of the most common injuries were patellar tendinitis and medial knee pain, comprising the majority of these injuries (55%). Of the knee

Table 3
Selected biomechanical variables (mean (SD))

	High arch	Low arch	*P*
Peak COP position (cm)[a]	1.61 (0.57)	2.23 (0.87)	0.006
Peak knee external rotation (°)	11.65 (4.02)	14.96 (5.14)	0.033
Peak knee flexion (°)	46.48 (4.08)	49.19 (5.45)	0.040

[a] COP = center of pressure.

Table 4
Selected injuries

	High arch	Low arch
Plantar fasciitis	8	5
Fifth metatarsal stress fracture	3	0
Lateral ankle sprain	8	0
Posterior tibialis tendinitis	1	3
General knee pain	0	8
Patellar tendinitis	3	6

injuries, HA runners only reported a 27% incidence of patellar tendinitis and medial knee pain while 45% of their injuries were ITB friction syndrome. The LA runners exhibited more knee external rotation during the first part of stance, likely resulting in an increased *Q*-angle. This increase in the *Q*-angle likely results in a malalignment of the patellofemoral joint. In addition, an increased peak knee flexion angle was seen in the LA runners when compared to the HA runners [26]. This likely results in an increase in the patellofemoral joint contact forces. A subsequent increase in quadriceps muscle force would be necessary to prevent further knee flexion and would therefore increase the patellofemoral joint contact force. This increased force coupled with the malaligned patella, may have contributed to the knee injuries in the LA group.

A greater number of lateral ankle sprains were seen in the HA group. Lateral ankle sprains are typically due to an acute perturbation rather than overuse. However, the structure of the HA foot may have led to a decrease in the available eversion range of motion (as was found in two subjects in a post-hoc assessment). This decrease in available eversion range of motion places an inversion bias at the ankle, which in combination with a perturbation, may have led to the increased number of ankle sprains. Further evaluation of the mechanism of lateral ankle sprains in individuals with different arch structures may elucidate this relationship.

One possible limitation of this study was the number of subjects in both groups who wore foot orthoses on a regular basis (8 in the LA group; 7 in the HA group). It is possible that the use of foot orthoses may have had an effect on the injury patterns seen in these individuals. Although orthoses are usually prescribed to decrease lower extremity symptoms related to structure, it is possible that their use could create new problems. However, all of the subjects who wore orthoses in this study had a decrease in the symptoms for which their orthoses were prescribed. Even with the differences in orthotic use, the two groups demonstrated statistically different injury patterns. This suggests that each group's structure was anomalous enough to relate similar structure to similar injury patterns.

HA and LA individuals have been found to have a higher risk of injury in the past when compared to individuals with average arch structure [13,10]. However, relationships between arch type and injuries have been inconsistent in these studies. Another possible limitation of this study, as an epidemiological study, is the low number of subjects included. However, the subjects included in this study were above 1.9 SD and below 1.7 SD for HA and LA structure respectively. While the results apply specifically to runners with very high and very low arches, the relationship between arch structure and injury may exist in some subjects with less severe cavus or planus, especially in the presence of other risk factors such as high mileage and other structural deviations (i.e., genu valgum). However, those with extreme deviations will be less able to compensate for their structure and will exhibit a stronger relationship between arch structure and injury.

In summary, it appears that HA runners are more likely to develop bony injuries, injuries on lateral portion of the lower extremity and injuries at the foot. Common injuries in this group include tibial stress fractures and lateral ankle sprains. LA runners are more likely to develop soft tissue injuries on the medial side of the lower extremity, and at the knee such as patellar tendinitis and general knee pain. Although caution should be exercised when applying these results to more moderate arch deviations, similar injuries may be present by the same mechanisms described in this study. Examination into mechanisms associated with these injuries may help to strengthen the relationship between arch structure and specific lower extremity injuries. Future studies may also include a large-scale prospective study to further clarify the relationship between arch structure and lower extremity injury patterns.

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