A Study on the relation between height of medial longitudinal arch and sport injuries in lower limb of professional runners by using Navicular Drop and Arch Index clinical tests

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Abstract: Understanding foot-to-ground contact is not simple due to sophistication of its structure. Plantar pressure measurement devices may be a proper device for determining foot structural situation. The results of the present paper reveal that change in the foot structure, particularly the medial longitudinal arch, may increase probability of injury. Association of pathologic biomechanical changes of foot with an activity such as running that increases the ground reaction force up to 5 times more than the body weight is still among the most important discussed issues. This paper is aimed at studying the effect of longitudinal arch of foot on the sport injuries in professional runners and studying the relation between navicular drop clinical test and plantar pressure measurements (pedobarography). 47 professional runners were selected from Sabzevar City and divided into three groups namely, normal, low arched, and high arched runners by using navicular drop test. Also by using emed-x system, maximum force, peak pressure, and contact area parameters in two static and dynamic postures were measured and recorded. 2x test showed no relation between running injuries and arch height (P=0.58). Correlation between navicular drop clinical test and modified arch index calculated from pedobarography measurements in two static and dynamic postures was between 0.32 and 0.57. Due to multi factorial nature of running injuries, changes in the arch height may not increase risk of injury. Although there was not a very high correlation between navicular drop test and plantar measurements, the obtained correlation is a good correlation since this test is clinical. Despite prior studies differentiate static posture (standing on both feet) from dynamic situation, but it seems that plantar pressure distribution in the static posture of single limb support may have a great similarity with functional situation of walking.
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Key words: medial longitudinal arch, sport injury, navicular drop clinical test, arch index test

Introduction

Foot skeleton has been made up of three parts: tarsus, metatarsus, and toes. Tarsus includes seven bones namely, talus, calcaneus, navicular, internal, medial, and external caniform, cuboid. These seven bones are joined together and are in contact with five metatarsus bones. And finally each of these five bones is joined to one of the toes. Each toe has three phalanges, except for big toe that has two phalanges (Kapandji, 1987).

The bottom of the foot includes longitudinal and latitudinal arcs. The longitudinal arch has two internal and external parts that join together in calcaneus but get apart on the forefoot. The external part of longitudinal arch has been comprised of calcaneus, cuboid, and fifth metatarsus and it is flat enough to allow the external side of foot to be placed on the ground. The internal part of longitudinal arch that is the highest part of the arch passes through calcaneus, talus, navicular, internal caniform, and first metatarsus bone and is supported by tendons of anterior tibialis muscles, posterior tibialis, and flexor hallucis longus (Nordin and Frandke, 2001). The plantar arch is an architectural construct which integrates all components of the leg, i.e. joints, ligaments, and muscles. With regard to the change in the curvature and elasticity, the plantar arch adapts itself to the roughness of the ground surface and can transfer the resultant forces of the body and its movements to the ground. This is obtained in different situations and by enjoying the best mechanical advantage. The plantar arch takes the impacts and is necessary for flexibility of walking. Any kind of pathologic states that smooth or worsen its curves may have a negative effect on walking (Kapandji, 1987).

Running is one of the most important activities that may cause overuse injuries in the lower limb. The main reason of these injuries is not clear; but one can claim that it is multi factorial. These factors can be divided into three general groups: variables related to the body structure, biomechanical variables, and variables related to training (Hreljac et al., 2000). Different factors such as age, gender, race, shoes and the age shoes wearing begin may affect formation and function of the arch (Williams et al., 2004 ؛Razeghi & Batt, 2002).

Since foot has contact with the ground in a closed cycle, difference in the foot structure particularly medial longitudinal arch may lead to difference in the whole mechanics of the lower limb (Williams et al., 2004). Regardless of these matters, it can be stated that the smallest changes in the body supporter (foot) may influence body situation control; particularly when foot is in the pronation or supination situation excessively, it may influence body stability through changing movement in the joints, changing contact surface, or changing muscle strategies (Cote et al., 2005). So, importance of the medial longitudinal arch form is one of the controversial issues in many foot- related sciences.

For an ideal function, foot must play two different roles simultaneously: first, absorbing force while accepting weight at the beginning of stance; second, conversion into a rigid lever to propel the body while pushing off. Quality of playing these two roles has a direct relation with anatomical structure of foot. During walking, anatomical structure of foot bears and distributes the force caused by foot-to-ground contact. So, different parts of foot are subject to different rates of pressure at any moment. On the other hand, foot structure is raised as one of the effective factors on the plantar pressure (Ledoux & Hillstrom, 2002). Increase in the plantar pressure may increase risk of injuries and may be the pain origin. As the speed of walking increases, the plantar pressure increases as well (Burnfield et al., 2004).

Structural differences of body with the normal status are called risk factors. Among them, importance of the medial longitudinal arch form is one of the controversial issues of Orthopedics (Kanatli et al., 2001). To maintain stability, anatomical structure of the foot is able to have pronation and supination whenever necessary. Moreover, pathological changes of the arch height may influence biomechanics of the whole organ (Williams et al., 2004). This disorder influences body control strategies (Cote et al., 2005). However, its intensity highlights the role of structural disorders as a risk factor. During slow walking, the force caused by foot-to-ground contact is only a bit more than body weight; while during running, it varies from 1.5 to 5 times more than body weight with regard to the speed of runner and ground surface. Hence, running may have a great effect on heavy injuries (Hreljac, 2004).

Studying plantar pressure may provide the researcher with important information about contact of foot different structures with the ground. So,

difficult to compare studies that have used similar techniques. So, attempts to provided normal data and standardize measurement techniques may lead to more efficient diagnosis and treatment of recent studies have sought to cope with "foot-to-ground contact"; because it seems that unrolling mechanism of foot during running stance phase may clarify etiology of overuse sport injuries (De Cock et al., 2005).

Glimour & Bums (2001) studied medial longitudinal arch in 272 children aged 5 to 11 years. This research used A.I and navicular height (NH) parameters as a non-aggressive method for objective measurement of medial longitudinal arch. Bennett and colleagues (2001) carried out a research on 125 high school runners aiming at determining risk factors of medial tibial stress syndrome. One of the factors they selected and studied was medial longitudinal arch height and they used navicular drop test for this purpose. T test showed a significant difference between the injured and healthy runners. Williams and colleagues (2001) tried to study overuse injuries model in persons with low arches and high arches. People who have high arches show more injuries in ankle and exterior side of foot; while persons with low arches show more injuries in knee, soft tissues, and interior part of foot. According to these results, arch structure had relation with different injury patterns. Hreljac and colleagues (2000) studied overuse injuries of the lower limb in the runners. The findings revealed that height of longitudinal arch and footprint index were not different among groups. Hogan and Staheli (2002) carried out a retrospective observational – analytic research on 48 women and 51 men to study the relation between arch height and pain in the lower limb. The statistical non-parametric tests showed no relation between arch index and pain degree. BMI, disease, and working hours per week showed no significant relation with pain degree. Lun and colleagues (2004) studied the relation between running injuries and static alignment of the lower limb in 153 runners in a prospective research. In this research, no evidence was observed for prevalence of the abnormal situation and more pronation in the injured group compared to the healthy group. To clarify the role of medial longitudinal arch as a risk factor in ankle sprains, Mei-Dan and colleagues (2005) conducted a retrospective and prospective research on 83 persons. Chippaux – Smirak index was used in this research. The results of retrospective data obtained by questionnaire showed that in persons with low arches, ankle sprains was more prevalent particularly in the right foot compared to normal people. Lack of normal information for many quantitative measurement techniques may make it lower limb injuries. Prior studies reported contradictory results (Hreljac et al., 2000 ؛Bennett et al., 2001 ؛Burns et al., 2005 ؛Michelson et al., 2003). Therefore, with regard to the importance of this issue, it seems necessary to study the relation of foot structure with overuse sport injuries and its correlation with plantar pressure. This paper seeks to study the relation between height of medial longitudinal arch and sport injuries and also correlation between two "navicular drop" and "modified arch index" clinical tests.

Materials and Methods

This paper selected randomly 47 professional runners (Members of Sabzevar track and field team) with the average age 21.4±3 years and height 180.3±7 cm and weight 69±8 kg with at least 3 years running experience (3 sessions per week and each session 2 hours at least). To calculate sample volume and ensure system reliability, a pilot study was carried out on 10 runners. Some items were considered as exclusion criteria including use of medical insoles, any spinal defect, any instability in knee or ankle or any kind of pain at the test time.

To calculate minimum sample volume, below formula was used:

$N = Z^2 S^2 / d^2$

Where Z equals 1.96 with 95% confidence (α=5%).

S denotes standard deviation of the sample that was estimated 2.71 mm in the pilot study.

D is the rate of acceptable error in estimating the mean decrease in navicular that was considered 1 mm (Cote et al., 2005). The minimum sample volume for this research was estimated 28; to ensure reliability of the obtained results, 47 persons were examined. Before test, the participants completed the questionnaire related to injuries happened for them during running. To determine the person foot type, "navicular drop" test was used. So, first the most prominent part of navicular bone was touched and marked. The examinee sat on a seat to not bear the weight. Knee and ankle of the dominant foot were placed in the flexion 90 ° and the center of two heels became apart as much as shoulder width. Thumb and point finger of the examiner were placed on both sides of tibiotalar joint, and normal situation of sabtalar joint was determined by inversion and eversion of hindfoot and ankle. The normal situation of this joint is when the examiner feels that depth of two sides beneath his thumb and point finger has got equal. This situation was used for measurement and vertical height of navicular bone was marked on a card that had already been cut in dimensions 15x10 cm. vertical height of navicular was registered again on the same card after standing and weight-bearing upon the lower limb. The difference between initial height and secondary height in this bone was considered as "navicular drop".

To calculate modified arch index, emed – x system pedobarograph device was used. This system acts through calibrated capacitive sensors and is directly connected to the computer via USB cable. Calibration of the device was carried out by the manufacturing company (Novel Electronics, Munich, Germany). The system transparency was 4 sensors per square centimeter and frequency was 100 Hz. This part of the test was conducted in two static and dynamic stages. Each person was given ten minutes to become familiar with the testing process and exercises walking on the platform. In the static stage, the examinee was asked to stand on one foot on the platform imitating mid stance situation and rest one hand on the device wall to prevent fluctuation. Then after 5 seconds that his fluctuations decreased, static data was recorded. This was repeated six times. Then mean of six trials was calculated and stored for analysis. In the dynamic stage, free gait method was used. Therefore, the person is asked to stand 4 meters away from platform and, looking at the front, walk on the platform in a way that first the dominant foot is placed on the sensitive plate (figure 1).

Similar to static stage, this is repeated again until six acceptable trials are recorded. The trial is accepted when the person walks on the platform by a normal speed and no considerable change is observed in the manner of walking. Again, mean of six accepted trials is stored for analysis. To reduce error, the ground surface was made equal to the height of platform by foam. To evaluate foot function better, the participants walked on the platform barefoot. Before test, the examinee was asked to walk in the corridor freely and by a normal rhythm. He was asked to have a comfortable posture during test and walk by normal fluctuations of arms and do not look down.

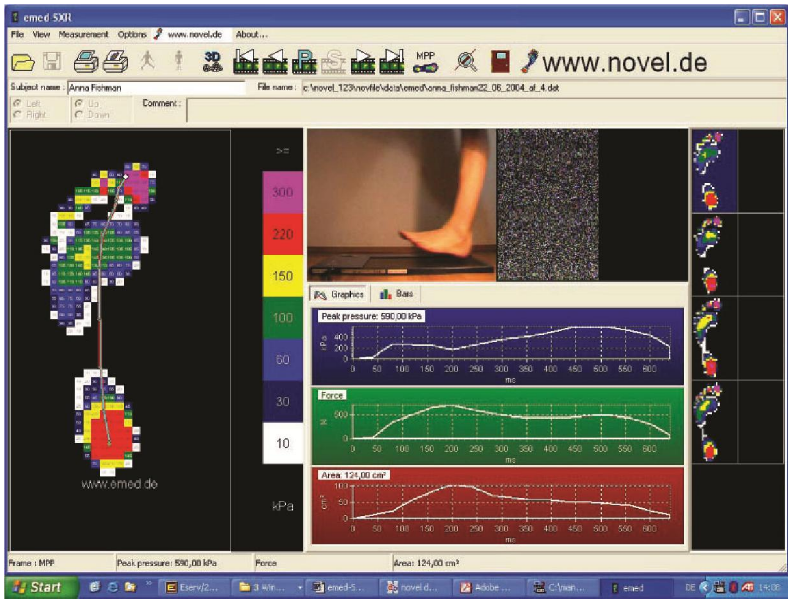

Figure 1- dynamic stage: the examinee stands 4 meters away from platform and while looking at the front, walk on the platform without placing the second step on the platform.

Data was processed by using Novel – Diabetes software. Auto Mask application of this software divides the bottom of foot into 10 areas corresponding to anatomical areas of foot and measures time – space parameters and pressure for each area including Contact Time (ms^2), Contact Area (cm^2), PeakPressure (KPa), Max Force (N), Pressure-Time Integral (KPa S), Force-Time Integral (NS).

Research Findings

In the pilot study, 10 runners were tested. The mean of navicular drop in this population was 6.7 mm and standard deviation was 2.71 mm. tables 1 presents the results of device reliability used for each variable.

Table 1- reliability coefficient of data obtained from emed-x platform

N= 10	Peak Pressure Arch Index	Max Force Arch Index	Contact Area Arch Index
ICC	0.85	0.89	0.91

Prevalence of injury

According to navicular drop test, 28 persons (59%) were considered among normal group, 14 persons (29%) among high arch group and 5 persons (1%) among low arch group. In 17 persons (36%), injury has been reported. The reported injuries constituted 60% of low arch group, 39.3% of normal group, and 21.4% of high arch group. Ankle sprain and knee joint injuries constituted respectively 47% and 23% of the observed injuries. The other injuries including tendonitis and shin area pains and muscle strains constitute 30% of the observed injuries. The rate of sport injuries in professional runners was estimated between 0.06 and 0.27 in the ankle and between 0.01 and 0.16 in the knee with 95% confidence. Also the rate of sport injuries in ankle and knee was estimated between 0.12 and 0.37 with 95% confidence.

Table 2- distribution of the injured and healthy runners in three groups based on "navicular drop" test

Arch height	Healthy	Injured	Sum
Normal	17	11	28
Low arch	2	3	5
High arch	11	3	14
Sum	30	17	47

Relation between longitudinal arch situation and injury

The participants have no significant difference in terms of age, height, and weight ($P<0.05$). comparison of navicular drop variable means in two groups show a significant difference in two healthy and injured groups by using independent t-test ($P=0.002$). $\chi 2$ test showed no significant difference between sport injury and medial longitudinal arch situation ($P=0.58$). Table 3 shows specifications of two injured and healthy groups participating in the main study.

Table 3- distribution of "navicular drop" test mean in two injured and healthy groups

Group	Number	Navicular Drop Mean	Age	Height	Weight
Healthy	30	5.3±2	21.33	180.46	69.08
Injured	17	7.4±2.5	21.20	181.47	69.27
P value	0.002		0.902	0.684	0.949

Correlation of "Modified Arch Index" in two dynamic and static postures

In this paper, the modified arch indexes (M.A.I) obtained in two dynamic and static postures were compared via pedobarograph device. Correlation between dynamic peak pressure A.I and static peak pressure A.I was estimated 0.71 (diagram 1). Correlation of maximum force A.I for two situations was 0.78 (diagram 2). Correlation of contact area A.I for two static and dynamic postures was 0.87 (diagram 3).

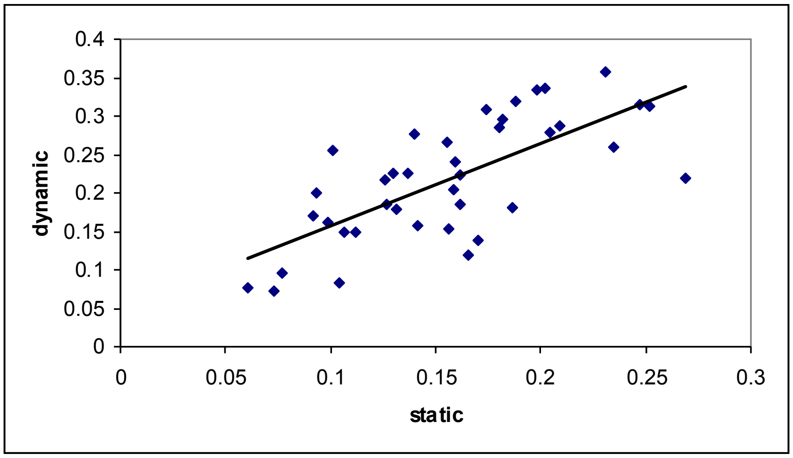

Diagram 1- correlation between dynamic peak pressure A.I and static peak pressure A.I data (r= 0.71)

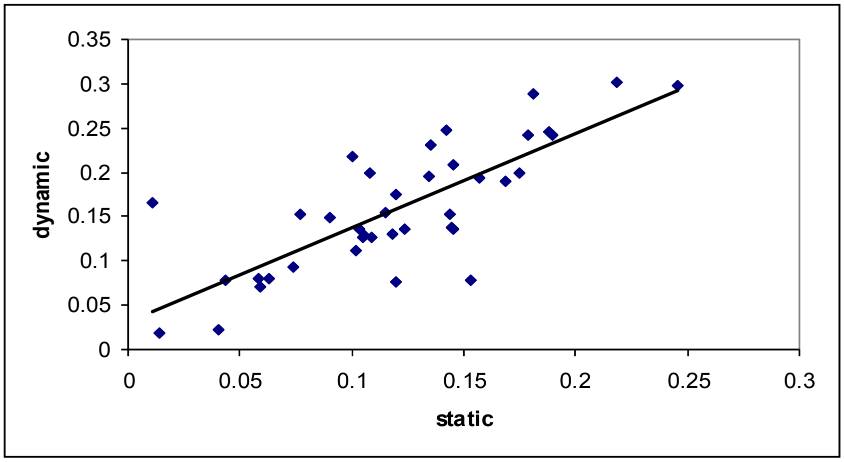

Diagram 2- correlation between Dynamic Maximum Force A.I and Static Maximum Force A.I data (r= 0.78)

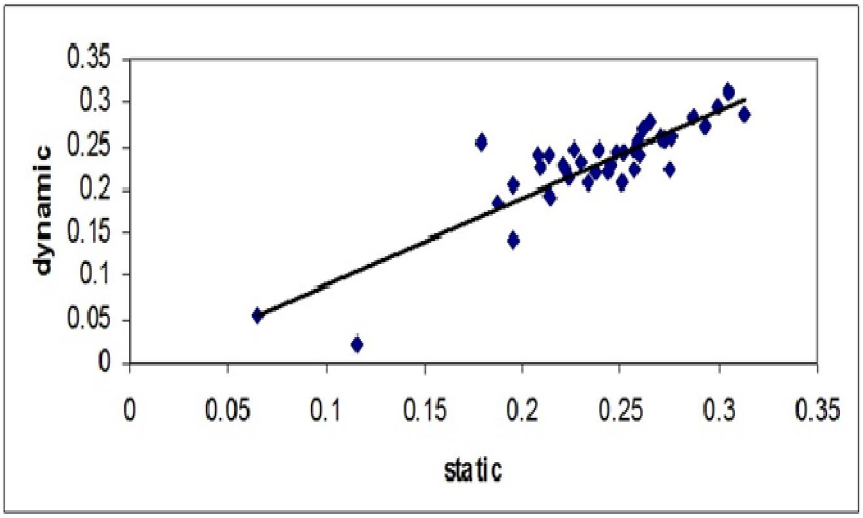

Diagram 3- correlation between Dynamic Contact Area A.I and Static Contact Area A.I data (r= 0.87)

Correlation between "navicular drop" and "Modified Arch Index" in two dynamic and static postures

As shown in table 4, correlation between navicular drop and modified arch index in two static and dynamic postures varies from 0.32 to 0.57.

Table 4- correlation coefficient between two navicular drop and modified arch index variables

N=39	Dynamic Peak Pressure A.I	Static Peak Pressure A.I	Dynamic Maximum Force A.I	Static Maximum Force A.I	Dynamic Contact Area A.I	Static Contact Area A.I
Navicular Drop	0.32	0.49	0.51	0.57	0.57	0.44

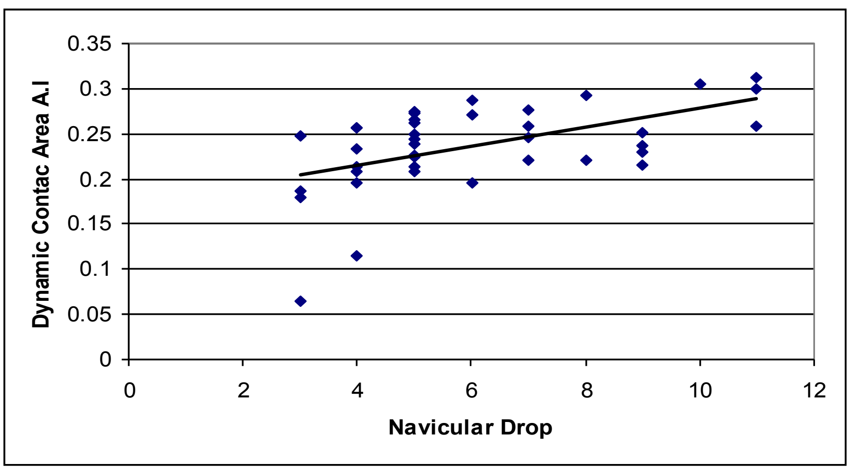

Diagram 4- correlation between navicular drop clinical test and Dynamic Contact Area A.I data (r=0.52)

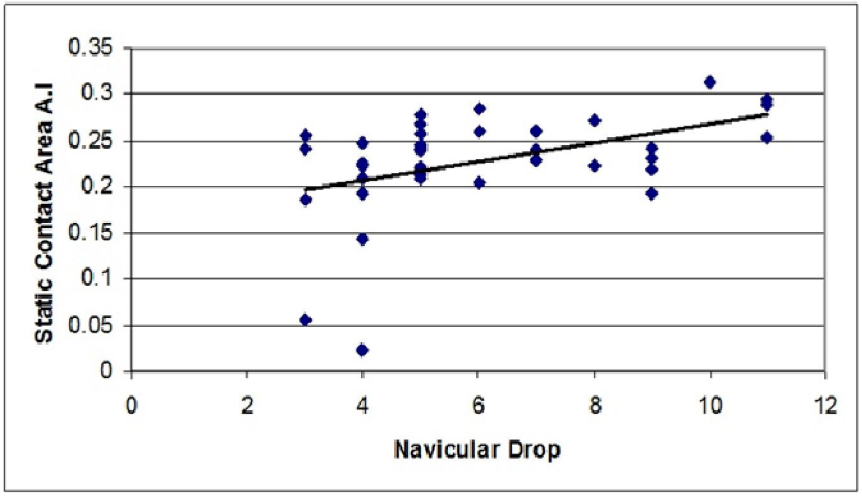

Diagram 5- correlation between navicular drop clinical test and Static Contact Area A.I data (r=0.44)

In the prior studies, correlation between radiography measurements and A.I has been reported significant (Kanatli et al., 2001). So, A.I may be a valid index for measuring height of medial longitudinal arch indirectly. In the clinical tests including navicular drop test, since measurement is carried out in a non-aggressive manner and through marking bony landmarks on the skin, the error rate is different depending upon the examiner skill.

Although there was no high correlation between navicular drop test and plantar measurements, this test is still one of the best tests for evaluating foot static posture. This relatively good correlation shows the importance of the above clinical test in determining foot posture as a non-aggressive and reliable measurement.

Glimmour and Bronze reported correlation between navicular height and AI as -0.46 (Williams et al., 2001). Findings of the present paper are similar to those of Morag and Cavanagh research (1999). Their findings indicated that the structure of the foot that has less arch and so more contact surface shows more Dynamic Peak Pressure A.I. this had a good correlation with calcaneus slope in radiography pictures (r=0.64). They considered such factors as dynamic variables like rearfoot movements at the beginning of the stance phase, first metatarsophalangeal joint motions at the end of stance phase and structural variables including form of medial longitudinal arch to be involved in determining plantar pressure patterns (Morag & Cavanagh, 1999).

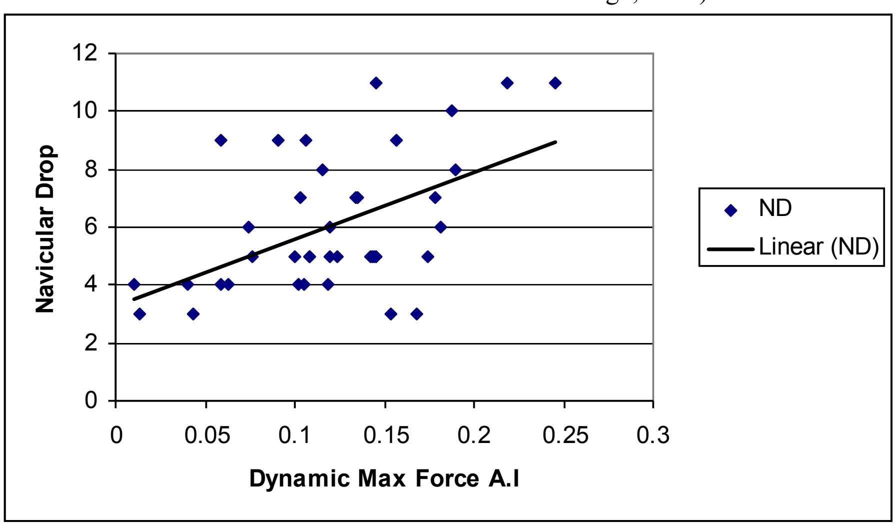

Diagram 6- correlation between navicular drop clinical test and Dynamic Max Force A.I data (r= 0.51)

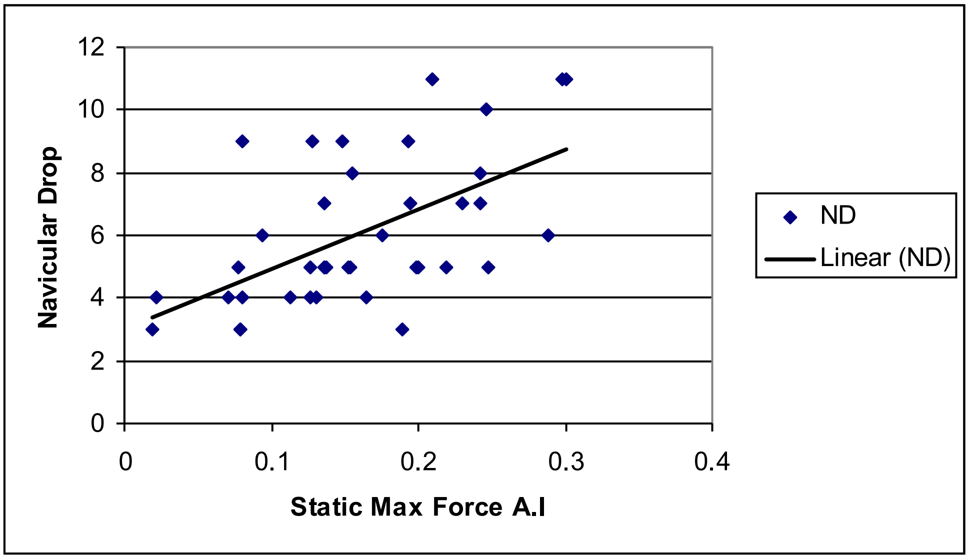

Diagram 7- correlation between navicular drop clinical test and Static Max Force A.I data (r= 0.57)

Calcaneus eversion is among variables that are frequently used as a general pronation index for subtalar joint in the static measurements. Rosenbaum and colleagues (1994) studied the relation between plantar pressure pattern and calcaneus eversion static angle. This research showed that when calcaneus eversion was more in the static posture, the exerted pressure in the midfoot inner side was more in the dynamic situation (Rosenbaum et al., 1994). Cavanagh and colleagues (1997) regarded medial longitudinal arch situation as one of the most important factors of foot static structure which may have a major effect on plantar pressure while walking (Cavanagh et al., 1997).

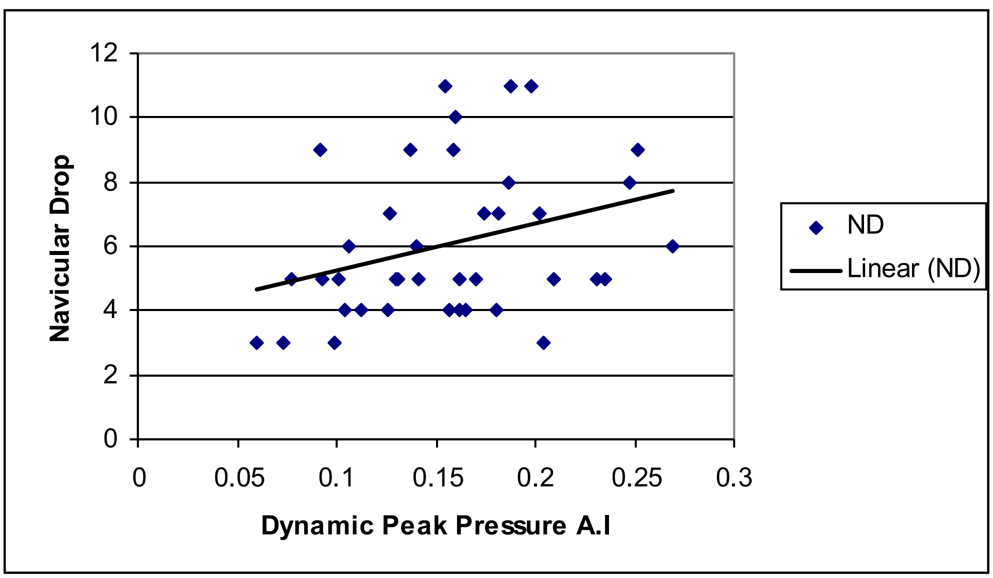

Diagram 8- correlation between navicular drop clinical test and Dynamic Peak Pressure A.I data (r= 0.32)

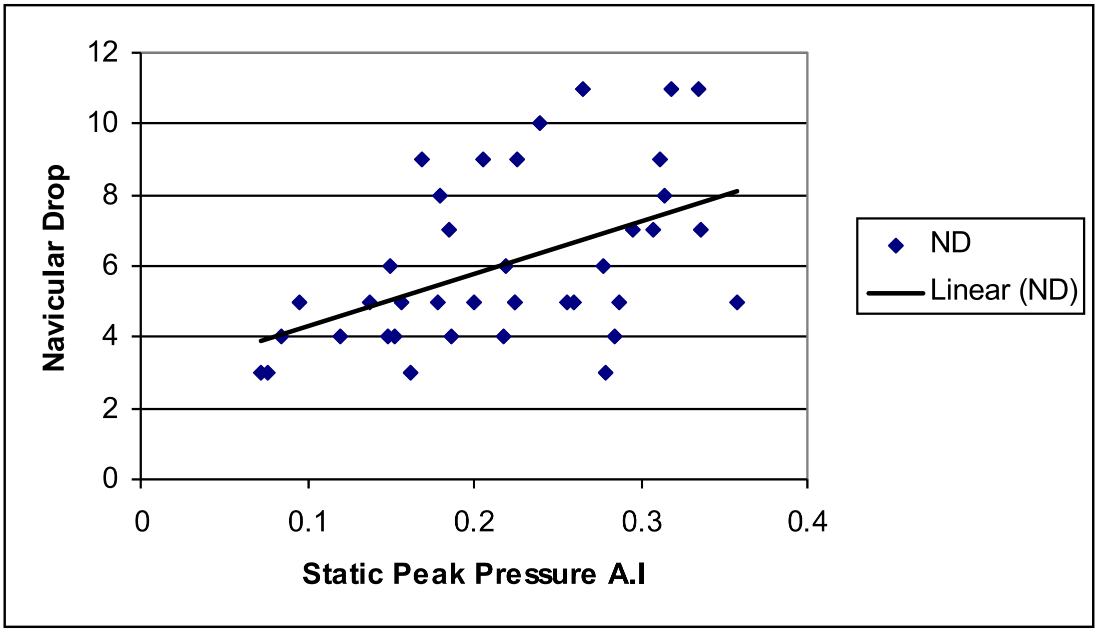

Diagram 9- correlation between navicular drop clinical test and Static Peak Pressure A.I data (r= 0.49)

Strong correlation of MAI in two static and dynamic postures in the present paper may be due to similarity of single limb support situation and functional situation of walking. To achieve a correct judgment, correlation of MAI in static and dynamic situations must be studied by other tests including arc three-dimensional kinematics. Since high reproducibility of this index and its strong correlation with direct height of arch have been proved in the prior studies (Chu et al., 1995), it can be expected to predict foot dynamic function by using situation of single limb support to high extent. Studies carried out on the effect of structural deviation on kinematics, the ground reaction force, and plantar pressure report different findings due to using different devices and methods; but if one can predict foot dynamic function by using pressure and force static measurements, a new perspective is opened in the field of early evaluation and estimation of sport injuries.

Comparison of "Modified Arch Index" means in three groups in two dynamic and static postures

By using one-sided variance analysis, modified arch index means in two static and dynamic states in three groups (high arch, low arch, normal) were compared. The results showed that Peak Pressure A.I means of three groups had no significant difference in dynamic situation and were different in static situation ($P<0.05$). Max Force A.I means of three groups were different in both static and dynamic postures ($P<0.05$). Contact Area A.I means of three groups were different in both static and dynamic postures ($P<0.05$).

Table 5- results of comparing Peak Pressure A.I means in three groups

Dynamic Peak Pressure A.I			Static Peak Pressure A.I			
Normal	Low Arch	High Arch	Normal	Low Arch	High Arch	Group
0.26±0.01	0.28±0.06	0.21±0.08	0.41±0.16	0.52±0.2	0.28±0.15	Mean
0.09-0.56	0.28-0.29	0.09-0.34	0.11-0.79	0.15-0.69	0.1-0.61	Range

Table 6- results of comparing Maximum Force A.I means in three groups

Dynamic Maximum Force A.I			Static Maximum Force A.I			
Normal	Low Arch	High Arch	Normal	Low Arch	High Arch	**Group**
0.20±0.13	0.31±0.06	0.16±0.19	0.15±0.05	0.24±0.05	0.1±0.05	**Mean**
0.02-0.76	0.22-0.38	0.10-0.71	0.26-0.60	0.18-0.29	0.01-0.21	**Range**

By comparing MAI means of three groups in two static and dynamic postures, it was observed that only Dynamic Peak Pressure A.I was not different among three groups. Max Force A.I means of three groups were different in two situations. This may be due to less sensitivity of pressure – i.e. vertical force on the surface – to force compared to effective items including foot structure and arch height. In Static Peak Pressure A.I and Contact Area A.I, the difference observed among normal, high arch, and low arch groups in two static and dynamic postures was significant.

Despite significant difference between high arch and low arch groups, no significant difference was observed between low arch and normal groups. Difference between normal and low arch groups may involve exertion of a force more than body weight so as to specify this difference through kinematics changes in dynamic conditions by exerting more force (replacing ordinary walking with running). Prior studies have shown that pressure distribution in two rearfoot and forefoot areas is more which may be related to lack of weight bearing in the midfoot area (Cavanagh et al., 1997).

Table 7- results of comparing contact area A.I means in three groups

Dynamic Contact Area A.I			Static Contact Area A.I			
Normal	Low Arch	High Arch	Normal	Low Arch	High Arch	**Group**
0.2±0.02	0.25±0.02	0.15±0.05	0.21±0.01	0.26±0.05	0.15±0.06	**Mean**

By examining ground reaction force (GRF) in normal and low arch groups, one can state that since foot is the means of body interaction with the ground and bears and distributes ground reaction force, its structure may influence foot function and distribution of pressures caused by foot-to-ground contact. So, measurement of plantar pressure may provide direct information about interaction between different foot structures and ground. Analysis of foot-to-ground contact during movement and stance phase is difficult due to sophistication of foot structure. Recent studies have used foot multi-segment models so as to provide information about kinematics and kinetics of rearfoot, midfoot, and forefoot areas and their interaction (MacWilliams et al., 2003; Leardini et al., 1999). And many models of foot situation evaluation have tried to predict foot dynamic function by using its structure static measurement.

In this paper, the rate of ankle injuries and knee injuries in the professional runners were respectively estimated between 0.06 and 0.27 and between 0.01 and 0.16 with 95% confidence; while Taunton and colleagues (2003) estimated prevalence of knee injuries 42% (Taunton et al., 2003). They introduced knee as the most prevalent area of injury and "Patellofemoral Syndrome" constituted maximum percentage of injuries in this joint. Studies carried out in the recent years including Pinshaw et al. (1994) and Clement et al. (1981) reported similar results (Pinshaw et al., 1984; Clement et al., 1981). The mentioned studies were epidemiologic. So, volume of the sample studied in this paper was less considerably.

Conclusions

Despite significant difference of navicular drop variable means in two injured and healthy groups, hypothesis of this paper was not approved and findings showed that there is no relation between sport injuries and medial longitudinal arch height. Studying navicular drop and modified arch index (MAI) showed that there is a relatively good correlation between these two variables. Furthermore, a very good correlation was observed between MAI data in two dynamic and static postures. The rate of ankle and knee injuries in the professional runners was estimated between 0.12 and 0.37. Since this paper was focused on studying ankle and knee injuries, other injuries in the hip joints, Sacroiliac and other organs were not studied. So, the results of above mentioned studies and findings of the present paper must be compared cautiously. Reduction of injury probability in this paper compared to other studies may be due to three reasons: first, not reporting injury in other organs; second, difference in injury definition used by the researcher; third, difference in the type of exercise and anthropometric structure of body. The main hypothesis of this paper indicating the relation between sport injuries and changes in the medial longitudinal arch height was not approved, though there was a significant difference between navicular drop changes means in two injured and healthy groups. Bennett and colleagues (2001) studied the rate of navicular drop in two injured and healthy groups and found out that mean of navicular drop variable in the injured runners was more than healthy runners (Bennett et al., 2001). Besides different method, it must be noted that structural deviation is only one of the reasons causing sport injuries and the nature of most of them is multi factorial. So with regard to the results of this paper, the mind is focused on the role of such factors as type of shoes, type of flooring, previous injuries, intensity and type of exercise.

In sum, this paper does not regard ankle and knee sport injuries in the professional runners to be influenced by medial longitudinal arch structure. So, use of medical shoes in athletes whose plantar arch is different from normal state cannot be justified by these results, and multiple factors such as type of shoes, type of flooring, previous injuries, intensity and distance and type of exercise may be effective on injury occurrence. The findings support this hypothesis that maximum force exerted on the foot structure and plantar pressure may indicate type of foot to high extent. Therefore, future research must take this matter into consideration. Although prior studies regard static posture (single limb support) different from dynamic situation, it seems that distribution of plantar pressure in the static state of single limb support may have a great similarity with the functional situation of walking. So, many results of this paper can be generalized to the dynamic situation.

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