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Relationship between the mobility of medial longitudinal arch and postural control

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ABSTRACT

Objective: The aim of this study was to analyze the relationship between the medial longitudinal arch mobility and static and dynamic balance.
Methods: A total of 50 subjects (25 female, and 25 male; Mean age: 22.2 ± 1.3 years; BMI: 22.8 ± 3.8 kg/m^2) were included in this study. The relative arch deformity (RAD) was calculated with both 10% and 90% weight bearing (WB). Static balance was evaluated with Single Leg Stance Test and dynamic balance with TechnoBody PK 200WL computerized balance device. Subjects were evaluated for goniometric measurements of lower extremity joints, leg dominance and leg-length discrepancy.
Results: Bipedal dynamic balance was correlated with both feet length at 10% WB and 90% WB. There was a correlation between the dynamic balance on dominant foot and RAD value on the aspect of Medium Speed ($r = -0.32$, $p = 0.02$), Perimeter Length ($r = -0.32$, $p = 0.02$) and Anterior–Posterior Sway ($r = 0.36$, $p = 0.01$). Static balance was unaffected by RAD value when the visual system was eliminated.
Conclusion: Our results suggest that decrease of arch mobility on the dominant foot is associated with posterior sway by causing knee or hip strategy and preventing ankle strategy even in small perturbations. The rate of deviation from the equilibrium point and the degree of total swaying increase when arch mobility decreases.

The foot and ankle is the most distal segment of the human body. It has complex structure and plays an important role in interacting body with the ground in upright posture.[1] The multiple bones of the foot form arches to serve the functions of both stability and flexibility; to contribute to the propulsive mechanism of gait; to support the body weight distribution; to generate energy and to protect the articular surfaces of the feet, ankles and knees. Medial Longitudinal Arch (MLA), consisted by the first metatarsal, the medial cuneiform, the navicular, the calcaneus and the talus, is arguably the most important arch of the foot.[2,3] Height of the MLA is measured with several methods to categorize the foot structure as planus (low arch), rectus (normal arch) and cavus (high arch). Most of these methods try to quantify the arch but some methods are based on observation.[4–6]

The MLA mobility is assessed with using dorsal arch height to calculate relative arch deformation while weight bearing and non-weight bearing stance conditions.[7,8] Such measurements, particularly arch height, have also been associated with the development of lower extremity overuse injuries.[9–11] Actually, quantifying the MLA height is a part of the arch mobility assessment. However, arch mobility has received less attention in the literature. Assuming that an individual with a high arch foot posture would have decreased foot mobility is intuitive and the opposite may not be true for an individual with a low arch foot posture. For example, the individual with a low arch foot posture could indeed exhibit increased foot mobility or have actually decreased mobility as in the case of a rigid pes planus foot deformity.[12]

Considering the fact that the foot is primary shock absorbing structure and provides base of support for muscles and joints of lower extremity chain, biomechanical alterations of the foot may influence postural control strategies. Joint coupling or coordination

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is influenced by arch mobility. Changes in intersegment coordination can result in the need for compensation.[13] Further, there is some evidence confirming an association between altered postural stability and structure of MLA. Chang et al[14] indicated that alterations of the foot arch impact on both static standing and dynamic athletic activities, in contrast, Cote and associates[15] suggested that foot type has effect on static balance minimally but, its structural abnormalities alter stability limits during dynamic activities. Although the arch structure has received much attention, there has been little focus on the relationship between mobility of the medial longitudinal arch and postural control. Therefore, two purposes of this study were: (1) to identify whether altered dynamic and static balance are related to the mobility of the MLA (2) to examine how MLA mobility changes with gender and anthropometric features. It was hypothesized that the mobility of the MLA has impact on both dynamic and static balance and also women would have flexible arches as compared to men.

Patients and methods

This study was conducted in Yeditepe University during November 2014–January 2015. Fifty subjects were participated in this study after all of them were asked to read and sign an informed consent form, which had been approved by the ethical committee at Istanbul Medipol University Non-interventional Clinical Researches Ethics Committee (Approval Number: 249). Subjects with any musculoskeletal injury of lower extremity history or falling history in the six months before the study, cold or flu at the time of the study, using any drug which affects balance at the time of the study, wearing prescribed foot orthotics, any neurological or specific orthopedic problem, limited range of motion in the lower extremity joints or Body Mass Index (BMI) higher than 30 kg/cm^2 were excluded from the study. Subjects included in the study were aged between 18 and 35 years and without any communication problem. A questionnaire was used to assess socio-demographic information (age, weight, height, chronic diseases, injury of the lower extremities, regular medication).

Subjects were evaluated bilaterally for goniometric measurements of the hip, knee and ankle by using basic goniometer to exclude if there is any limited motion in the lower extremity joints.[16] The leg used to kick a ball was accepted as the dominant side.[17] Leg length measurements included direct measurement of each limb, measuring from the top of the anterior superior iliac spine to the medial malleolus on standing position.[18]

Foot measurements were taken in 2 stance conditions: 10% of weight bearing (WB) and 90% of WB. Subjects were weighed on a standard scale to calculate 10% of their total weight. The foot, which will be measured, was placed on the scale and the other foot was placed on an adjoining surface. Subjects stood with their hands resting on a cane to lower their amount of weight by not leaning to either side until 10% of WB had been achieved. Bony landmarks were used to measure Foot Length (FL), Navicular Height (NH), Dorsum Height (DH), and Truncated Foot Length (TFL) with a ruler (Fig. 1). As reported in the William and McClay's study,[7] FL was measured from the most posterior portion of the calcaneus to the end of the longest toe; NH was measured from the floor to the most anterior-inferior portion of the navicular; DH was measured from the floor to the top of the foot at 50% of foot length; TFL was measured from the most posterior portion of the calcaneus to the center of the first metatarsophalangeal joint. The process was repeated for 90% of WB condition. Arch mobility was assessed with using an equation for calculating relative arch deformity (RAD) modified from that described by Nigg et al[8]

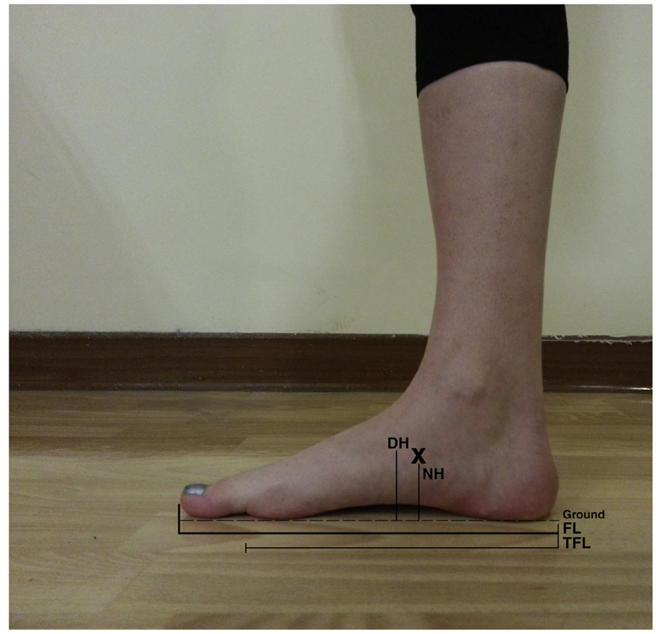

Fig. 1. Bony landmarks of foot measurements (FL; Foot Length, NH; Navicular Height, DH; Dorsum Height and TFL; Truncated Foot Length).

$$RAD = \left(\frac{AHU - AH}{AHU}\right)\frac{10^4}{BW}$$

AHU represents dorsum height at 10% of WB,
AH represents dorsum height at 90% of WB,
Body weight(BW)is expressed in Newton.

Static balance was evaluated with Single Leg Stance Test (SLST). The results with minimum error while eyes opened and eyes closed were recorded out of a total of 3 trials.[19] TechnoBody PK200WL computerized balance device was used for dynamic balance assessment.[20] The subject's barefoot was placed on the balance platform in a standardized position (the maximum point of the medial longitudinal arch was projected on the x-axis and the distance between feet was 8 cm). The test compromises trying to move in a reference circle seen on the computer screen which provides continuous visual feedback to understand the difference between what he/she was feeling on a kinaesthetic level and what is actually happening at motor level.[21] (Fig. 2). Dynamic balance on the right foot, on the left foot and on bipedal stance were tested separately for 30-s and easy mode was used. Test results included 5 parameters; Perimeter length; The total degrees came about during the test time; Area gap percentage; The percentage of the area involved in the drawn with respect to the reference circle; Medium speed; The mean number of covered degrees for a second; Medium equilibrium center-AP; The mean between the values achieved on backward–forward axis; Medium equilibrium center-ML; The mean between the values achieved on medium–lateral axis.[22] All measurements were performed by the same physiotherapist.

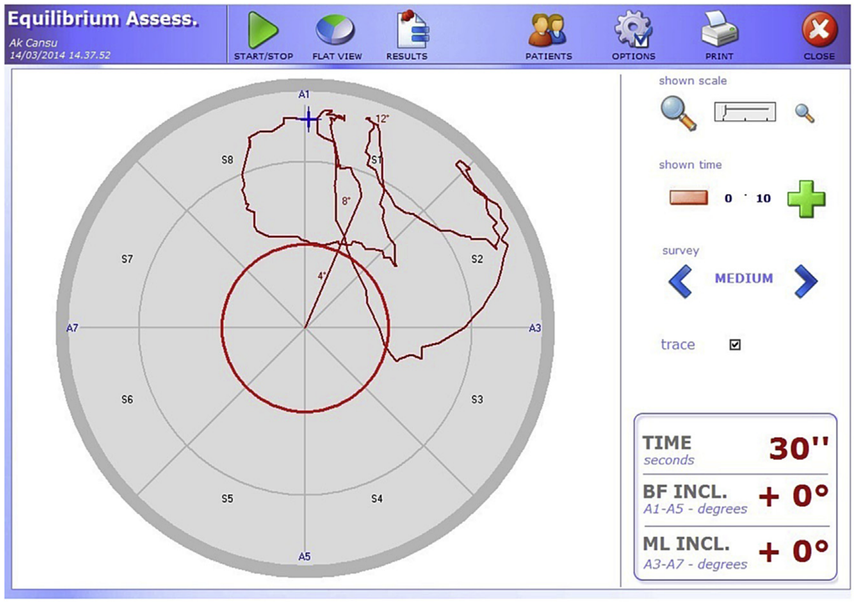

Fig. 2. Dynamic balance assessment (reference circle seen on the computer screen which provides continuous visual feedback to understand the difference between what he/she was feeling on a kinaesthetic level and what is actually happening at motor level).

Statistical analysis

The independent samples t-test was used to detect between-gender differences when normal distribution was satisfied. Pearson correlation coefficient(r) was used to explore the relationship between foot characteristics and the linear combination of all outcome variables (static balance, dynamic balance, BMI) (specifically, $r = 0.5–1.0$ was large; 0.30–0.49 was moderate and 0.1–0.29 was small).[23] To analyze the differences in RAD value and in leg-length discrepancy across the direction of swaying in dynamic balance test results, a one-way ANOVA was performed. The level of significance was set at $p \leq 0.05$.

Results

Subject characteristics are presented in Table 1. There were significant differences in weight, height, RAD and BMI values between males and females. Mean RAD value was significantly higher in females than males in both feet (Table 1). BMI and RAD value were negatively correlated in right and left foot respectively, Pearson's r (50) = −0.45, p = 0.001, Pearson's r (50) = −0.42, p = 0.002. These correlations were moderate.

Single leg stance test results on right or left foot did not differ significantly between males and females under eyes closed and open conditions ($p > 0.05$). No significant relationship was observed between SLST results and NH, FL and RAD value on both feet ($p > 0.05$). In contrast, bipedal dynamic balance test results had moderate positive correlation with FL in both feet (Table 2). Significant moderate correlation was only found between single leg dynamic balance test and RAD value on dominant foot (Table 3).

Discussion

The average values of foot characteristics measurement in our study were found to be in good agreement with values reported previously.[7,8] The first aim of this study was to examine the differences in the mobility of MLA across genders. As we hypothesized, the females showed higher RAD value as compared to men. Based on these differences, it could be concluded that women tend to have more pliable arch because RAD value is reported in literature as 1.0–2.0/N for healthy subjects[8] and values closer to 1.0/N represent unflexible arch.[24] These findings were in good agreement with studies suggested that arch stiffness is higher in men than women.[25,26] There might be two possible explanation for this

Table 1
Subject characteristics.

Parameters	Total (n = 50)	Female (n = 25)	Male (n = 25)	p
Age (year)	22.20 (1.32)[a]	22.04 (1.39)	22.09 (0.97)	0.20
BMI (kg^2/cm)	22.78 (3.84)	20.21 (1.82)	25.35 (3.61)	0.001**
Height (cm)	171.28 (8.49)	165.32 (6.82)	177.24 (5.16)	0.001**
Mass (kg)	67.59 (16.00)	55.40 (8.41)	79.78 (1.19)	0.001**
Leg dominance (R/L)	47/3	24/1	23/2	0.55
RAD				
Right foot	1.35 (0.47)	1.58 (0.44)	1.12 (0.39)	0.001**
Left foot	1.35 (0.52)	1.63 (0.55)	1.08 (0.33)	0.001**
Dominant Foot	1.32 (0.46)	1.56 (0.43)	1.10 (0.38)	0.001**
Non-dominant foot	1.31 (0.49)	1.55 (0.50)	1.05 (0.33)	0.001**
Leg-length discrepancy(cm)	0.16 (0.32)	0.16 (0.28)	0.16 (0.37)	0.73

Abbreviation: BMI, Body Mass Index; RAD, Relative Arch Deformity Value.
**Between-group difference using an independent t test, is significant at the $p \leq 0.05$ level.
[a] Mean (SD).

Table 2
Pearson's correlation coefficients between dynamic balance on bipedal stance and FL & NH.

	Right foot				Left foot			
	FL		NH		FL		NH	
	10% WB	90% WB	10% WB	90% WB	10% WB	90% WB	10% WB	90% WB
P.L. (°)	0.34 (0.01)[a,*]	0.36 (0.01)[*]	−0.06 (0.66)	−0.07 (0.60)	0.38 (0.007)[*]	0.37 (0.009)[*]	0.06 (0.65)	0.12 (0.39)
A.G.P. (%)	0.22 (0.13)	0.24 (0.10)	−0,03 (0.98)	0.03 (0.82)	0.27 (0.06)	0.25 (0.08)	0.17 (0.25)	0.24 (0.10)
M.S. (°/sec)	0.36 (0.01)[*]	0.37 (0.009)[*]	−0.59 (0.69)	−0.07 (0.64)	0.39 (0.005)[*]	0.38 (0.007)[*]	0.08 (0.57)	0.14 (0.33)
M.E.C(AP) (°)	−0.04 (0.76)	−0.02 (0.88)	−0.10 (0.46)	−0.11 (0.43)	−0.05 (0.73)	−0.04 (0.75)	0.08 (0.58)	0.07 (0.63)
M.E.C(ML) (°)	0.11 (0.42)	0.13 (0.35)	−0.12 (0.40)	−0.15 (0.30)	0.10 (0.47)	0.10 (0.46)	0.06 (0.68)	0.05 (0.69)

Abbreviation: PL, Perimeter Length. AGP, Area Gap Percentage (estimation). MS, Medium Speed. MEC(A–P), Medium Equilibrium Center-(Anterior–Posterior). MEC(M–L), Medium Equilibrium Center-(Medial–Lateral). FL, Foot Length, NH, Navicular Height, WB, Weight Bearing.
[*]Correlation is significant at the $p \leq 0.05$ level. (2-tailed).
[a] r(p).

Table 3
Pearson's correlation coefficients between single leg dynamic balance and RAD value according to foot dominance.

	Dominant foot RAD	Non-dominant foot RAD
P.L. (°)	−0.32 (0.02)[a,*]	−0.19 (0.17)
A.G.P. (%)	−0.09 (0.53)	−0.10 (0.47)
M.S. (°/sec)	−0.32 (0.02)[*]	−0.14 (0.31)
M.E.C.(AP) (°)	0.36 (0.01)[*]	0.18 (0.20)
M.E.C (ML) (°)	0.13 (0.36)	0.02 (0.86)

Abbreviation: PL, Perimeter Length, AGP, Area Gap Percentage (estimation), MS, Medium Speed, MEC(A–P), Medium Equilibrium Center-(Anterior–Posterior), MEC(M–L), Medium Equilibrium Center-(Medial–Lateral), RAD, Relative Arch Deformity Value.
[*]Correlation is significant at the $p \leq 0.05$ level. (2-tailed).
[a] r(p).

finding. First is that joint laxity is generally greater in females.[27,28] and another explanation is that males had higher BMI than females in our sample due to the fact that increased flattening of the arch of foot have a causal link.[29] An increment of dynamic plantar loading can cause the ligaments of the foot to become more elongated and result in deterioration of the medial longitudinal arch as BMI increases.

Secondly, neither SLST nor dynamic balance test results had any association between NH which is considered as the keystone of the arch.[1] Williams and McClay[7] suggested that the absolute NH may not accurately reflect the structure of the arch and also may cause misclassification of arch structure so the measurement of NH alone is not sufficient to identify the effect of MLA height on postural stability. On the other hand, bipedal dynamic balance test had relationship with FL of both feet. Perimeter length, is the number of total degrees done during the test, and medium speed, is the average number of covered degrees for second, had moderate positive correlation with FL. This study was based on a cross-sectional data collection. Hence we cannot draw conclusions about causal effects but these findings can refer that foot length might be associated with agility of restoring disturbed balance on bipedal stance because procedures of dynamic balance assessment with Prokin-Line require maintaining equilibrium without changing his or her base of support.

There were also moderate negative correlation between dynamic balance test results and RAD values, only on the dominant foot, according to the perimeter length, the medium speed and moderate positive correlation between the medium equilibrium center-anterior/posterior. Subjects with increased posterior sway had less RAD value of the dominant foot than the other subjects ($p = 0.02$). However, there was not any significant difference in postural sway with respect to the arch mobility on non-dominant foot. Ericksen et al[27] indicated that anterior-posterior ankle laxity was greater on the dominant side than on the non-dominant side but we postulated that this might be related to difference in role of preferred and non-preferred foot. The non-dominant foot has an important role in balancing and supporting the actions of the body whereas dominant foot or mobilizing foot tends to perform fine motor tasks.[30] Two major postural strategies are defined; (1) hip strategy used for strong control and (2) ankle strategy related to delicate postural control.[31] During dynamic balance assessment with prokin-line, the ankle strategy could be used mainly for maintenance of a stable posture. Due to dominant foot is related to mobilization, decreasing arch mobility on dominant foot may result in preventing ankle strategy and causing knee or hip strategy even in small perturbations. Besides, the rate of deviation from the equilibrium point and the degree of total swaying increase when the mobility of MLA decreases.

The relationship between SLST results and RAD value was not found with vision or without vision. However, the fact that supposing that RAD value does not affect postural control in static stance is not precise because simple static stance might not meet the demands of the postural control subsystem in order to detect altered feedbacks.

Finally, there was conflicting results about the effect of limb length discrepancy on postural control. Mahar et al[32] suggested that a leg-length discrepancy of as little as 1-cm cause postural sway in a mediolateral direction whereas Murrell et al[33] indicated that there is no difference in postural sway between those with and without a leg-length discrepancy as we found. Leg-length discrepancy has a greater effect on pelvic position than spine position and a significant increase in pelvic tilt and pelvic torsion resulting from a leg-length inequality of 1-cm increments.[34] Nevertheless, we cannot conclude that the leg-length discrepancy has no impact on postural sways because there are only 3 subjects having a discrepancy of 1-cm. Majority of our sample (36 of the subjects) is without leg-length discrepancy and 11 of the subjects had a discrepancy less than 1-cm.

The relationship between the height of MLA and the lower extremity injuries was investigated in several aspects such as types and regions of injuries. Increasing or decreasing in arch height was found as a risk factor for lower extremity injury.[9,10] Although measuring the arch height is a part of identifying arch mobility, assessing the arch mobility is not common to characterize the MLA. The subjects with medial tibial stress syndrome have increased navicular drop and MLA deformation during quiet standing and increased MLA during gait compared to healthy subjects.[11] In our results demonstrated that decreasing in arch mobility causes altered postural control. Therefore, in our opinion, assessment of the arch mobility can help the clinician by either preventing injury or if there is an injured segment it can avoid reinjury. The assessment monitors the need for support or the stabilization of the arch, so that clinician can take the precautions for the injury.

Further research should consider our limitations. Firstly, a relatively small sample of subjects having an evident leg-length discrepancy becomes a barrier to interpret whether postural sways were affected by leg-length discrepancy or not. Besides, a control group could be beneficial to interpret data. Secondly, using a computerized system for assessing static balance could be more useful because single leg stance test cannot totally meet demands. To exclude inter-observer error, a single researcher took all measurements. However, a second observer could prevent potential bias.

To sum up, our results indicate that mobility of MLA is related to gender and BMI. It has also a relationship with single dynamic balance on dominant foot in healthy subjects. Decreasing of arch mobility on dominant foot can lead to posterior sway by causing knee or hip strategy and preventing ankle strategy even in small perturbations. Nonetheless, navicular height was not associated with dynamic and static balance but foot length had impact on dynamic balance on bipedal stance.

In the clinical setting, mobility of the MLA, leg dominance and gender should be taken into account when evaluating the postural control in healthy subjects.

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