Does Plantar Pressure Distribution Influence the Lumbar Multifidus Muscle Thickness in Asymptomatic Individuals? A Preliminary Study

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ABSTRACT

Background: Atrophy can occur in the lumbar multifidus (LM) muscle quickly as a result of various musculoskeletal problems. Knowing factors influencing muscle thickness of the LM will provide important clues about lumbopelvic stability.

Objectives: Although there are several studies in the literature investigating the adverse effects of foot−ankle postural disorders on the lumbopelvic region, to our knowledge there has been no investigation of plantar pressure distribution (PPD) as a factor influencing muscle thickness of the LM. The aim of this study was to determine whether PPD could affect LM muscle thickness.

Methods: This observational study consisted of 25 asymptomatic individuals. Ultrasonographic imaging was used to determine the thickness of the LM. All participants were subjected to PPD analysis using the Digital Biometry Scanning System and Milletrix software in 9 different plantar pressure zones. The Pearson product-moment correlation coefficients were used to examine the correlations between the LM muscle thickness and other variables. Stepwise multiple linear regression analysis was used to determine the variables with the greatest influence on LM muscle thickness.

Results: Peak pressures of medial and lateral zones of the heel were the significant and independent factors influencing static LM thickness, with 39.5% of the variance; moreover, the peak pressures of heel medial and fourth metatarsal bone were the significant and independent factors influencing dynamic LM thickness, with 38.7% of the variance.

Conclusions: Plantar pressure distribution could be an important factor influencing LM thickness, although further research is required. Examining foot−ankle biomechanics may provide information about the stability of the LM. (J Manipulative Physiol Ther 2020;43;909-921)

Key Indexing Terms: *Lumbosacral Region; Low Back Pain; Foot*

INTRODUCTION

The relationship between central nerve system and synergistic co-contraction of local muscles is an effective factor in ensuring lumbopelvic stability.[1,2] Among the local muscles, the lumbar multifidus (LM) muscle has a distinctive prominence for lumbopelvic stability. Among all erector spinae muscles, the LM is different in terms of vertical orientation of its superficial fibers, excessive muscle fibril lengths, absence of tendon structures, and total strength created.[1-3] The morphological structure of the deep LM contains 63% of type-1 fibers. This structure increases capillarization, which in return increases oxidation.[4] Histochemical properties and excessive amount of type-1 fibers in the LM indicate that its contraction type is mostly tonic, and this muscle is specialized for lumbopelvic stabilization.[5] It is known that the LM rapidly undergoes atrophy owing to reflex inhibition, in cases such as long-term bed rest, sway-back posture, lumbar surgeries, lumbar disc herniation, facet joint problems, and lower extremity problems.[6-8] As a result of reflex inhibition, muscle fibrils and total muscle mass of LM decrease within the first 3 days; and at the end of a 1-week period, there is 37% or more loss in muscle volume.[6-8]

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The foot has various tasks, such as maintaining balance by forming a supporting surface, absorbing the shocks exposed to the body, providing mobile adaptation during movement, and when necessary, stabilizing the lower limb to reduce the negative effects of hypermobility on the body.[13] For biomechanical alignment, it is essential that the pressures accumulated on the plantar surface of the foot are distributed correctly so that the foot−ankle complex can fulfill both stabilization and mobilization tasks.[13] The physiologic function of the subtalar joint plays an effective role in distributing plantar pressure properly.[14,15] It is important for healthy walking that pronation and supination movements of the joint occur timely and within normal ranges. Therefore, increased and prolonged pronation of the foot causes an increase in the contact and pressure in the medial line of the foot.[14,15] This, based on kinetic chain principles, affects the proximal segments, especially the lumbopelvic region, and makes stabilization difficult during both static and dynamic activities.[14,15]

Several studies have shown that foot−ankle postural disorders and dysfunctions adversely affect the alignment of the lower extremity.[9,10] These disorders can affect lumbopelvic region muscles and biomechanics, leading to excessive stress accumulation in the lumbopelvic joints, which can lead to atrophy in the lumbopelvic muscles, indirectly.[9-12] However, there is no study in the literature investigating whether the LM, which has a distinctive prominence for lumbopelvic stability, is affected by plantar pressure distribution (PPD). Therefore, the aim of this study was to determine whether different plantar pressure zones could be factors influencing LM muscle thickness. As the hypothesis of the study, it was predicted that PPD would affect the LM muscle thickness. In this way, by recording deviations from the normative data, training on lumbopelvic stabilization can begin quickly if necessary.

METHODS

Study Design

This is observational study consisted of 25 individuals (based on Koppenhaver et al's[27] findings [$R^2 = 0.27$; $P < .05$]) aged 18 to 65 years. All participants (10 women and 15 men) were evaluated by the same investigators.

Participants

Asymptomatic individuals can apply directly to physiotherapists for exercise program in our country. Physical therapists can plan exercise programs for healthy individuals. Participants applied to our clinic for a healthier life. Individuals who referred to the Department of Physical Therapy and Rehabilitation of Ahi Evran University and accepted to participate in the study were directed to Ahi Evran University Training and Research Hospital Radiology Clinic in case they met the inclusion criteria.

The inclusion criteria for this study were: being asymptomatic, volunteering to participate in the study, being in the age range of 18 to 65 years based on World Health Organization age criteria, and having a normal weight with body mass index between 18.5 and 24.9 kg/m^2. The exclusion criteria were: pregnancy, presence of a diagnosed systemic problem (eg, neurologic, psychological, geriatric, musculoskeletal, endocrinologic, rheumatologic), the presence of a pathology involving lower extremity and spine (eg, back pain, scoliosis, previous surgeries), sensory loss, and diabetic neuropathy (Fig 1).[1,19,20]

Ethics Committee

This study was approved by Kırşehir Ahi Evran University Medical Faculty Clinical Research Ethics Committee (14.11.2017 GO 2017-17/200). Before initiation of the study, written and verbal consent was obtained from all individuals, and the study was conducted in accordance with the Declaration of Helsinki.

Evaluation Methods

Ultrasonographic Imaging. Ultrasonographic imaging was conducted by a radiologist (experience >15 years) to determine muscle thickness of the LM.[21] Images in the parasagittal plane of a linear probe (Aplio 500; Toshiba, Nasu, Japan) set at 4 to 11 MHz was used for ultrasonographic imaging of the muscle thickness. The device was tested before the assessment of individuals, and test−retest reliability for the LM was substantial (intraclass correlation coefficients > .81). All participants were evaluated by the same radiologist.

One week before the tests, the “abdominal hollowing” maneuver was taught to all participants by a physiotherapist. For a total of 5 sessions, the participants practiced the maneuver, which involves inward and upward pulling of the abdomen without any excessive movement on the superficial abdominal muscles. This maneuver activates the transversus abdominus muscle and provides co-contraction of muscles responsible for stabilization, in particular co-contraction of the LM via the fascia thoracolumbalis.[22] For the maneuver to be done correctly, it is necessary to develop the perception of achievement in individuals. For this purpose, the basic anatomy of the muscles was illustrated and explained to the participants. They were also assisted with the biofeedback pressure unit (Stabilizer Pressure Biofeedback-Chattanooga Stabilizer) to eliminate excessive movement in the superficial muscles. This made it easier to understand the difference between an individual’s trunk movement and the abdominal hollowing movement.[16-18] To teach this maneuver, participants were asked to place the index fingers of both hands 1 cm anteromedially above the anterior superior iliac spine and apply deep pressure. The participants were told that if they did

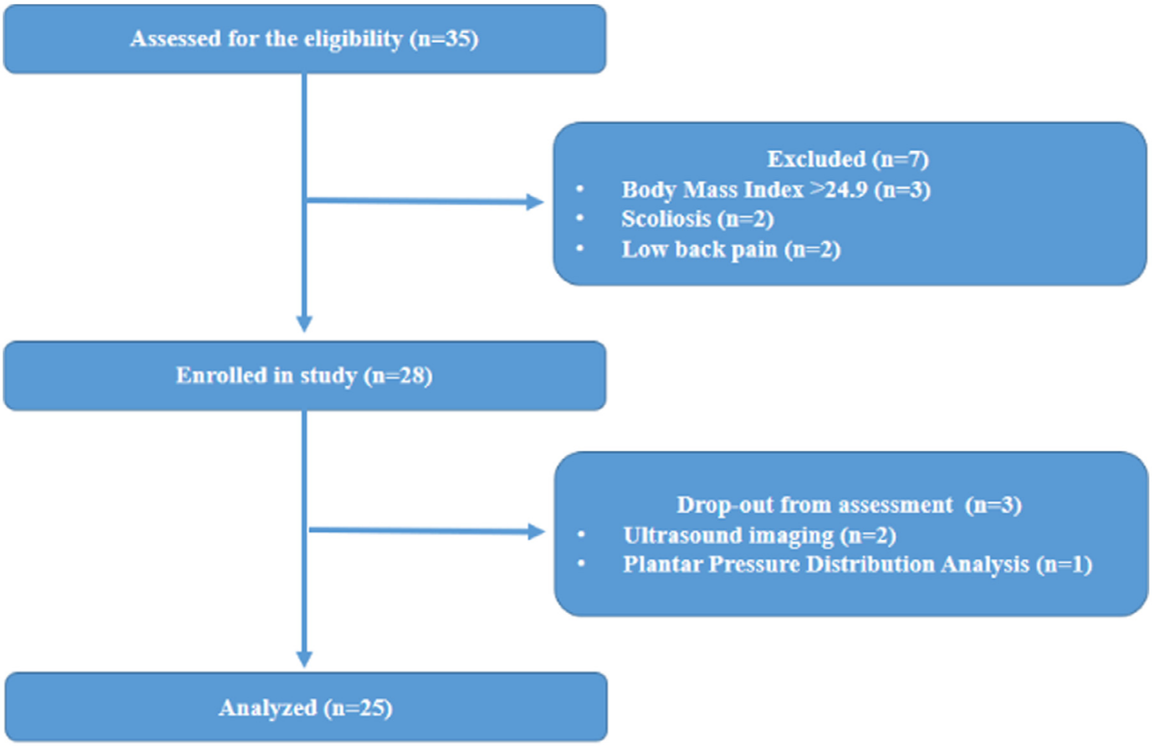

Fig 1. *Flow chart of the study.*

the maneuver correctly, they would feel the increase of tonus under their index fingers. The physiotherapist confirmed that all participants were doing the maneuver correctly. For full performance during contraction, the participants were requested to concentrate on their lower abdominal part. Ultrasonographic measurements were taken once the individuals could correctly perform the maneuver (Fig 2).[22] The measurements of all participants were done by the same radiologist.

Prone position was used to test the LM statically (Fig 3). For each individual, a height-adjustable pillow was placed under the abdomen to prevent formation of lordosis >10 degrees during measurement.[27] To determine the thickness of the LM, ultrasonic probe was placed on level of the fourth and fifth lumbar vertebrae. Muscle thickness was recorded during the abdominal hollowing maneuver.[22,23]

To test the LM dynamically, the prone position was again used as in the static measurement. A height-adjustable pillow was placed under the abdomen so that no more than 10 degrees of lordosis was allowed during the measurement. First, dumbbell weights corresponding to the 30% of maximal voluntary isometric LM muscle contraction of participants was detected using ultrasonographic imaging.[27] The participants were asked to hold the dumbbell contralaterally in their hands and then lift it 5 cm above the bed level with 135° of shoulder abduction and 90° of

Fig 2. *Abdominal hollowing maneuver.*

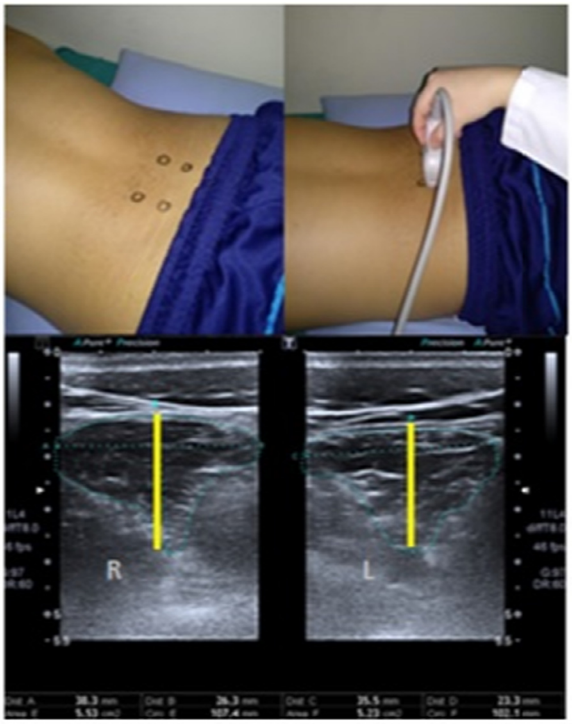

Fig 3. *Prone position.*

elbow flexion. In this position, ultrasonographic imaging measured submaximal contraction of the LM while the participant was performing the abdominal hollowing maneuver.[27] Muscle thickness was recorded by placing the ultrasonic probe on the level of the fourth and fifth lumbar vertebrae.[23,24]

In both static and dynamic measurements, the longitudinal diameter, anteroposterior diameter, and cross-sectional area of the LM were measured. To determine muscle thickness, the anteroposterior diameter of the LM (in millimeters) was used.[25] Because the measurement of LM muscle thickness can be affected by misplacement of the ultrasonic probe, and to minimize the errors that might arise from the device, each participant's measurement was repeated 3 times and the average of the values was recorded.

Plantar Pressure Distribution Analysis. Plantar pressure distribution analysis of the participants was performed using Digital Biometry Scanning System and Milletrix software (Diagnostic Support; Diasu Health Technologies, Rome, Italy) and a 3 × 1-m sensor walking platform.[30] To analyze static PPD, individuals were asked to stand on the platform for 60 seconds in a position where they looked straight at a reference point and felt comfortable with their arms extended at the sides of their trunk (Fig 4).[13,26] For dynamic PPD analysis, individuals were asked to walk at a normal speed and return to their starting position on a 3-m-long force-plate−embedded walking platform (Fig 5).[13,26]

Plantar surface of the foot was divided into 9 different zones, and the peak pressure of each zone was recorded in Newtons per square centimeter so that static and dynamic PPDs could be analyzed for each individual for the same zone (Figure 6). These 9 zones were: the peak pressures of the exact midpoint of the medial (1) and lateral (2) sides of the heel; the peak pressures of the midpoints of the 5 different metatarsal bones (3, 4, 5, 6, 7); the peak pressure value of the midpoint of the distal phalanx of the hallux (8); and the average peak pressures of the second, third, fourth, and fifth toes (9).[13,26]

To minimize measurement errors that might arise from various individual differences, and considering the fact that 3 of the participants were left dominant and 22 were right dominant, in estimating LM thickness, the data of the dominant side of all participants were used. To determine dominant side, a "kicking ball" test was used.[38,39]

Sample Size

To our knowledge, possible factors related to the foot−ankle complex influencing LM muscle thickness have not been investigated to date. Therefore, we could not find any study related to multiple linear regression analysis to calculate sample size. Koppenhaver et al[27] have examined the association between history and physical examination factors and the changes in lumbar multifidus muscle thickness after spinal manipulation in patients with lower back pain. Their findings ($R^2 = 0.27$; $P < .05$) were used to calculate the minimum required sample size for a multiple linear regression analysis as 25 participants for the probability level of 0.05 (α), with 9 determinants (the peak pressures of the exact midpoint of the medial and lateral sides of the heel, the peak pressures of the midpoints of the 5 different metatarsal bones, the peak pressure value of the midpoint of the distal phalanx of the hallux, and the average peak pressures of the second, third, fourth and fifth toes). In this model, the anticipated effect size was set as 0.369, and the statistical power level as 80% using G*Power Software (version 3.1.9.2).

Statistical Analysis

The IBM SPSS Statistics for Windows software (version 20.0; IBM, Armonk, NY) was used to analyze the data. The variables were investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov-Simirnov/Shapiro-Wilk test) to determine whether the data were normally distributed.[28] Parametric analysis was used for the normally distributed data. Values were expressed as mean ± standard deviation, standard error of mean, and 95% confidence intervals for continuous variables. Values were expressed as a ratio (%) for categorical variables. The Pearson product-moment correlation coefficients were used to examine the correlations between LM muscle thickness and other variables. Correlation coefficients >0.5 were

Fig 4. *Static plantar pressure distribution analysis.*

considered a strong correlation; 0.3 to 0.5 was considered moderate correlation; and 0.2 to 0.3 was considered a weak correlation.[29] The level of significance was set at $P < .05$. The stepwise multiple linear regression analysis was used to determine the variables that have the greatest influence on LM muscle thickness. Significantly correlated variables with LM muscle thickness were included in the regression model. In addition, the regression equation formula of the study was also calculated. Cook's distance and centered leverage value were used to identify and treat outliers.

Regression describes the relationship between an independent variable (x) and a dependent variable (y), and regression equation can be used to predict y by using x. Regression equation is a mathematical formula that can be applied to the explanatory variables to best predict the dependent variable you are trying to model. Regression equation: $Y = b_0 + b_1x_1 + b_2x_2 ... + b_nx_n$.

As the aim of this study was to determine whether different plantar pressure zones could be factors influencing LM muscle thickness, regression analysis was sound for 9 determinants of LM thickness.

RESULTS

Twenty-five asymptomatic individuals (40% female) with an average age of 26.36 ± 1.52 years and average body mass index of 21.65 ± 1.86 kg/m^2 were included in the study. Descriptive statistics related to ultrasonographic imaging and PPD analysis of the subjects included in the study are shown in Table 1.

Plantar Pressure Zones Influencing Static LM Thickness

In static position, there was a correlation between LM muscle thickness and the peak pressure of the heel medial ($r = -0.526$; $P = .007$) and the peak pressure of the first metatarsal bone ($r = -0.516$; $P = .008$). There was also a correlation between LM muscle thickness and the peak plantar pressure of the heel lateral ($r = 0.428$; $P = .033$), and the peak pressures of the forth metatarsal bone ($r = 0.403$; $P = .046$), fifth metatarsal bone ($r = 0.464$; $P = .020$), and the hallux ($r = -0.474$; $P = .017$) in the static position (Table 2).

In static assessments, peak pressures of the heel medial, first metatarsal bone, heel lateral, forth metatarsal bone, fifth

Fig 5. *Dynamic plantar pressure distribution analysis.*

metatarsal bone, and hallux were included as independent variables in the regression model to determine possible factors of static LM thickness. The stepwise multiple regression analysis demonstrated that the peak pressures of heel medial and heel lateral were significant and independent factors of the static LM thickness with 39.5% of the variance (Table 3).

The regression equation formula of the dependent variable (static LM muscle thickness) was calculated using explanatory variables (peak pressures of the heel medial and heel lateral) and coefficients (Table 3).

The regression equation formula for static LM muscle thickness is:

$$\begin{aligned}&\text{Static LM Thickness}\\&\quad= 31.002 + (-1.599 \times \text{Static Peak Pressure of the Heel Medial})\\&\qquad+ (1.435 \times \text{Static Peak Pressure of the Heel Lateral}).\end{aligned}$$

Plantar Pressure Zones Influencing Dynamic LM Thickness

In dynamic positions, there was a correlation between LM muscle thickness and peak pressure of the fourth metatarsal bone ($r = 0.504$; $P = .010$). There was also a correlation between LM muscle thickness and peak pressure of the heel medial ($r = -0.421$; $P = .036$), heel lateral ($r = 0.459$; $P = .021$), and peak pressure of the first metatarsal bone ($r = -0.405$; $P = .045$; Table 4). In dynamic assessments, peak pressures of the fourth metatarsal bone, heel medial, heel lateral, and first metatarsal bone were included as independent variables in the regression model to determine the possible factors of dynamic LM thickness.

The stepwise multiple regression analysis demonstrated that the peak pressures of heel medial and the fourth metatarsal bone were significant and independent factors of the dynamic LM thickness with 38.7% of the variance (Table 5).

The regression equation formula of the dependent variable (dynamic LM thickness) was calculated using explanatory variables (peak pressures of heel medial and the fourth metatarsal bone) and coefficients (Table 5).

The regression equation formula for dynamic LM muscle thickness is:

$$\begin{aligned}&\text{Dynamic LM Thickness}\\&= 26.962 + (2.208 \times \text{Dynamic Peak Pressure of the Fourth Metatarsal bone})\\&\quad+ (-1.331 \times \text{Dynamic Peak Pressure of the Heel Medial}).\end{aligned}$$

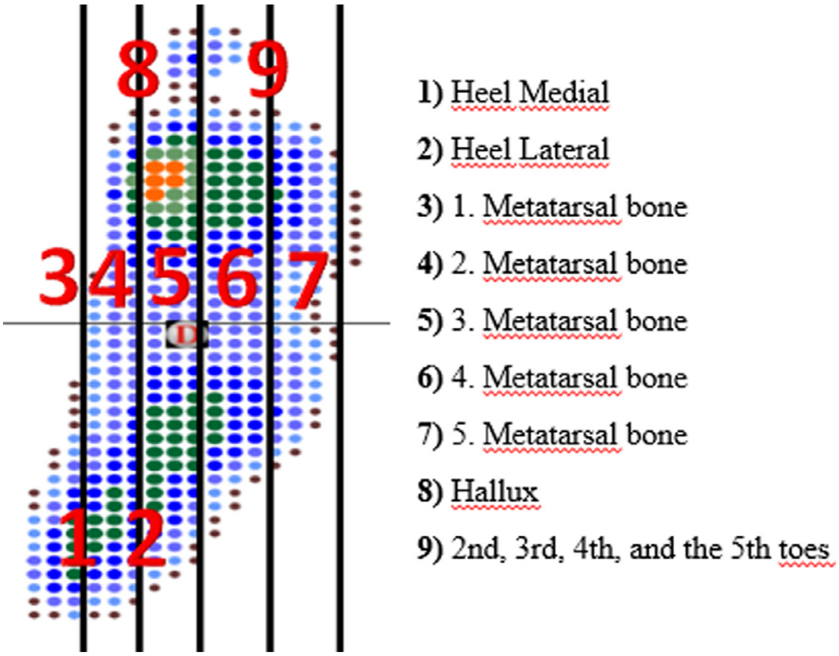

Fig 6. *Nine different zones for plantar pressure distribution analysis.*

Discussion

The main findings of the study demonstrated that peak pressures of the heel medial and heel lateral have the greatest influence on LM muscle thickness in static position, whereas these variables explain 39.5% of the variance in the ultrasonography. In addition, the results of the study demonstrated that peak pressures of heel medial and fourth metatarsal bone have the greatest influence on LM muscle thickness in dynamic position, whereas these variables explain 38.7% of the variance in the ultrasonography. In both static and dynamic measurements, as the peak pressure on the medial of the foot increased, there was a reduction in thickness of LM.

Table 1. *Descriptive Statistic of Variables*

Variables	Mean ± SD	SEM	95% Confidence Intervals	
			Lower Bound	Upper Bound
Static LM thickness	28.80 ± 3.63	0.727	27.29	30.30
Dynamic LM thickness	30.65 ± 3.56	0.712	29.18	32.12
Heel Medial (S/D)	6.76 ± 1.16/7.49 ± 1.14	0.232/0.229	6.27/7.01	7.24/7.96
Heel Lateral (S/D)	6.00 ± 1.04/6.60 ± 1.04	0.208/0.208	5.57/6.17	6.42/7.03
1. Metatarsal bone (S/D)	3.12 ± 1.20/3.65 ± 1.22	0.240/0.245	2.62/3.14	3.61/4.15
2. Metatarsal bone (S/D)	4.68 ± 1.31/5.39 ± 1.28	0.262/0.256	4.13/4.86	5.22/5.92
3. Metatarsal bone (S/D)	7.24 ± 1.42/7.90 ± 1.14	0.284/0.228	6.65/7.42	7.82/8.37
4. Metatarsal bone (S/D)	5.68 ± 1.02/6.18 ± 0.82	0.205/0.164	5.25/5.84	6.10/6.52
5. Metatarsal bone (S/D)	2.36 ± 0.81/2.87 ± 0.98	0.162/0.196	2.02/2.46	2.69/3.27
Hallux	4.20 ± 1.15/4.76 ± 1.08	0.230/0.217	3.72/4.31	4.67/5.20
2nd, 3rd, 4th, and the 5th toes	0.37 ± 0.19/0.54 ± 0.20	0.038/0.041	0.29/0.45	0.45/0.62

D, dynamic; *LM*, lumbar multifidus; *SD*, standard deviation; *SEM*, standard error of the mean; *S*, static.

Table 2. *Relationship Between Static Lumbar Multifidus Muscle Thickness and Static Plantar Pressure Distribution Analyzes*

		Ultrason LM Muscle Static	Heel Medial	Heel Lateral	1. Metatarsal Bone	2. Metatarsal Bone	3. Metatarsal Bone	4. Metatarsal Bone	5. Metatarsal Bone	Hallux	2nd, 3rd, 4th, and the 5th Toes
Ultrason LM Static	**r**	1									
	P										
	N	25									
Heel Medial	**r**	−0.526[a]	1								
	P	.07									
	N	25	25								
Heel Lateral	**r**	0.428[b]	−0.034	1							
	P	.033	.870								
	N	25	25	25							
1. Metatarsal bone	**r**	−0.516[a]	0.647[a]	0.033	1						
	P	.008	.001	.874							
	N	25	25	25	25						
2. Metatarsal bone	**r**	−0.332	0.656[a]	0.061	0.395	1					
	P	.105	.001	.772	.051						
	N	25	25	25	25	25					
3. Metatarsal bone	**r**	0.068	−0.014	−0.366	−0.139	−0.448[b]	1				
	P	.745	.947	.072	.506	.025					
	N	25	25	25	25	25	25				
4. Metatarsal bone	**r**	0.403[b]	−0.067	0.194	−0.271	−0.140	−0.002	1			
	P	.046	.751	.352	.190	.503	.991				
	N	25	25	25	25	25	25	25			
5. Metatarsal bone	**r**	0.464[b]	−0.567[a]	0.247	−0.260	−0.279	−0.006	0.144	1		
	P	.020	.003	.234	.209	.177	.978	.493			
	N	25	25	25	25	25	25	25	25		
Hallux	**r**	−0.474[b]	0.440[b]	−0.381	0.222	0.209	0.020	−0.119	−0.303	1	
	P	.017	.028	.060	.286	.317	.923	.570	.141		
	N	25	25	25	25	25	25	25	25	25	
2nd, 3rd, 4th, and the 5th Toes	**r**	0.253	−0.313	−0.147	−0.112	−0.454[b]	0.364	−0.175	0.068	−0.163	1
	P	.223	.127	.483	.593	.023	.073	.402	.747	.436	
	N	25	25	25	25	25	25	25	25	25	25

LM, lumbar multifidus.

[a] Correlation is significant at the .01 level (2-tailed).

[b] Correlation is significant at the .05 level (2-tailed).

Table 3. *Stepwise Multiple Linear Regression Model of Static Lumbar Multifidus Muscle Thickness*

Model		Coefficients[a] Unstandardized B	Std. Error	Standardized β	*t*	*P* Value
1	(Constant)	39.907	3.795		10.515	<.001
	Heel medial	−1.643	.554	−.526	−2.968	.007
2	(Constant)	31.002	4.840		6.405	<.001
	Heel medial	−1.599	.496	−.512	−3.224	.004
	Heel lateral	1.435	.555	.411	2.584	.017

[a] Dependent variable: static lumbar multifidus muscle thickness. R = .667; R^2 = .445; adjusted R^2 = .395; $P < .001$.

The LM is known to play an important role in maintaining lumbopelvic stability, retraining the stability by counteracting gravity and counterbalancing the loads over the lower limbs during movements.[31] Lumbopelvic stability might be adversely affected in the various pathomechanical conditions of the lower extremity because of the tight association of the lower extremity movements and the LM.[14,32-34] Ogon et al[35] investigated the effect of foot arc height on the lumbopelvic region during running. They reported that normal medial longitudinal arc height is important for shock absorption and optimal plantar loadings, both of which result in less stress on the lumbopelvic region. In their study with 14 participants, Pinto et al[36] examined the effects of increased calcaneal eversion on the lumbopelvic region. Using a 3-dimensional motion analysis system, they reported that when both feet were laterally tilted, the pelvis tilted 1.57 degrees anteriorly. According to normative data, this deviation in the 3-dimensional orientation of the pelvis adversely affects the lumbopelvic muscles and lumbopelvic stability.[36] In a similar but larger study with 51 participants, using a combination of surface anatomy recording and computer processing, Betsch et al[39] showed that an anterior pelvic tilt (compared with the contralateral innominate) can be induced on the side of subtalar pronation, but that subtalar supination does not affect pelvic tilt. Recording from infrared markers placed on surface anatomy landmarks of the tibia, femur, pelvis, and lumbar spine, Duval et al[40] measured lumbopelvic postural changes in 15 healthy volunteers. They found that subtalar pronation and supination caused internal or external rotation of the tibia and femur, respectively. These investigators reported a weak association between subtalar pronation or supination and anterior or posterior pelvic tilt, respectively.

As there were no other similar studies related to PPD as a factor influencing LM thickness in the literature, the current study design was based on results of the aforementioned studies.[35,36] In static analysis, we found that peak pressures of the heel medial and heel lateral could be important factors influencing LM muscle thickness in static measurements. Here, it was observed that although the pressure on the medial side of the heel was a negative factor, the pressure on the lateral side was positive. In dynamic analysis, however, peak pressure values on heel medial and on the fourth metatarsal bone were found to be effective factors influencing LM muscle thickness in dynamic measurements. The peak pressure of the heel medial was a negative factor, and the peak pressure of the fourth metatarsal bone was a positive factor. Our preliminary study is the first to demonstrate that PPD could be a factor influencing LM muscle thickness. The present study also supports previous studies[35,36] regarding the fact that any increased pressure on the medial side of the foot negatively affects lumbopelvic stability.

Because of a lack of studies investigating the association between PPD and lumbopelvic region, we analyzed the studies examining the relationship between foot and lumbopelvic complex to be able to compare our results. Zhou et al[34] have investigated the influences of foot placement on lumbopelvic rhythm during trunk flexion. Their results showed that angled foot placement conditions generated more lumbopelvic coordination patterns during trunk flexion motions. In another study, Kendall et al[37] investigated the effect of foot posture on the lower limb and lumbopelvic muscles. They reported an association between foot function, particularly pronation, and low back pain. Foot posture leads to changes in firing patterns of lower limb and pelvic musculature. Increased and prolonged pronation causes increased contact and pressure in the medial line of the foot. Hence, the results of these studies support our findings that peak pressure on medial side of the foot can be a negative factor influencing muscle thickness of the LM, whereas peak pressure on the lateral side of the foot can be a positive factor in both static and dynamic measurements.

Although this study was conducted with asymptomatic individuals, the design of the study and the obtained data might be clinically important in terms of the ability to

Table 4. *Relationship Between Dynamic Lumbar Multifidus Muscle Thickness and Dynamic Plantar Pressure Distribution Analyzes*

		Ultrason LM Muscle Dynamic	Heel Medial	Heel Lateral	1. Metatarsal Bone	2. Metatarsal Bone	3. Metatarsal Bone	4. Metatarsal Bone	5. Metatarsal Bone	Hallux	2nd, 3rd, 4th, and the 5th Toes
Ultrason LM Dynamic	**r**	1									
	P										
	N	25									
Heel Medial	**r**	−0.421[a]	1								
	P	.036									
	N	25	25								
Heel Lateral	**r**	0.459[a]	0.095	1							
	P	.021	.653								
	N	25	25	25							
1. Metatarsal bone	**r**	−0.405[a]	0.527[b]	−0.016	1						
	P	.045	.007	.938							
	N	25	25	25	25						
2. Metatarsal bone	**r**	−0.310	0.481[a]	−0.042	0.545[b]	1					
	P	.31	.015	.843	.005						
	N	25	25	25	25	25					
3. Metatarsal bone	**r**	−0.089	0.152	−0.214	0.066	−0.240	1				
	P	.671	.469	.304	.754	.249					
	N	25	25	25	25	25	25				
4. Metatarsal bone	**r**	0.504[a]	0.015	0.534[b]	−0.069	−0.113	0.119	1			
	P	.010	.944	.006	.743	.590	.571				
	N	25	25	25	25	25	25	25			
5. Metatarsal bone	**r**	0.039	−0.038	−0.093	0.021	−0.352	0.377	−0.063	1		
	P	.852	.856	.660	.922	.085	.064	.766			
	N	25	25	25	25	25	25	25	25		
Hallux	**r**	−0.117	0.511[b]	0.087	0.367	0.199	0.501[a]	0.285	−0.024	1	
	P	.579	.009	.681	.071	.341	.011	.167	.909		
	N	25	25	25	25	25	25	25	25	25	
2nd, 3rd, 4th, and the 5th Toes	**r**	0.128	0.047	0.024	0.373	−0.121	0.075	0.005	0.118	0.150	1
	P	.542	.822	.909	.067	.564	.722	.979	.573	.474	
	N	25	25	25	25	25	25	25	25	25	25

LM, lumbar multifidus.

[a] Correlation is significant at the .05 level (2-tailed).

[b] Correlation is significant at the .01 level (2-tailed).

Table 5. *Stepwise Multiple Linear Regression Model of Dynamic Lumbar Multifidus Muscle Thickness*

		Coefficients[a]				
Model		Unstandardized Coefficients		Standardized Coefficients	*t*	*P* Value
		B	Std. Error	β		
1	(Constant)	17.158	4.857		3.533	.002
	4. Metatarsal bone	−2.181	.778	.504	2.802	.010
2	(Constant)	26.962	5.650		4.772	<.001
	4. Metatarsal bone	2.208	.691	.511	3.197	.004
	Heel medial	−1.331	.496	−.429	−2.684	.014

[a] Dependent variable: dynamic lumbar multifidus muscle thickness. R = .662; R^2 = .438; adjusted R^2 = .387; $P < .001$.

produce preliminary data in the diagnosis and treatment of disorders related to the foot, ankle, and LM. For example, pes planus deformity causes an increase in the contact and pressure in the medial line of the foot, and this can cause LM weakness. Pes cavus deformity, on the other hand, causes an increase in the contact and pressure in the lateral line of the foot, and this can cause LM spasm because of the frequent contraction and relaxation of muscle. These results were initial data for commenting on LM status in pathologic cases and for determining the treatment program, although further research is required.

This study has some limitations. First, although the age range of the participants was determined as young adults (18-65 years) according to the criteria determined by the World Health Organization, the average age of the participants in our study was 26.36 ± 1.52 years. Categorizing the age of the participants in intervals of decades can be an important feature in the overall availability and generalization of the results. Second, as the study population was asymptomatic individuals, the results of the study cannot be interpreted for pathologic conditions affecting the LM muscle. Therefore, there is a need for further study involving subjects with pathologies affecting the LM. Third, because of differences in muscle thickness that might be due to gender, it is recommended that future studies consider this difference when planning their population. Finally, as the dominant foot of the participants was taken into account, asymmetries between dominant and nondominant foot might have affected the final results.

Conclusion

Our study shows that the assessment of relevant plantar pressure zones by the clinician could be a useful factor in commenting on LM muscle thickness. To our knowledge, this study is the first to investigate whether PPD can be a factor influencing LM thickness. Examining foot−ankle biomechanics might provide information about the limitations of the stability of the LM.

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Contributorship Information

Concept development (provided idea for the research): C.K., S.B., B.B., Ö.B.
Design (planned the methods to generate the results): C.K., S.B., B.B., Ö.B.
Supervision (oversight, organization and implementation, writing of the manuscript): C.K., S.B., B.B., Ö.B., N.B.
Data collection/processing (experiments, organization, or reporting data): C.K., Y.D.
Analysis/interpretation (statistical analysis, evaluation, and presentation of the results): C.K., B.B., Ö.B., İ.Ö.
Literature search (performed the literature search): C.K., S.B., B.B., Ö.B., Y.D., İ.Ö., N.B.
Writing (responsible for writing a substantive part of the manuscript): C.K., S.B., B.B., Ö.B., İ.Ö., N.B.
Critical review (revised manuscript for intellectual content, not spelling, grammar): Ö.B., N.B., native speaker

Practical Applications

- Plantar pressure distribution could be effective on LM thickness.
- Correctly distribution of plantar pressure could increase lumbopelvic stability.
- Foot−ankle postural disorders could affect lumbopelvic muscles.

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