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An investigation of the relationship between quadriceps femoris and hamstring muscle strength and balance in individuals with pes planus

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ABSTRACT

Aims: This study aimed to examine the relationship between quadriceps femoris and hamstring muscle strength and balance in individuals with pes planus.

Methods: The study was conducted with 64 participants with pes planus, including 48 female and 16 male. Individuals were identified using the navicular drop test and the Feiss line test. Based on the Feiss line test results 29 of the participants had grade 2, 24 of participants had grade1 and 11 of participants had grade 3 pes planus. Muscle strength was assessed using the Lafayette Manual Muscle Tester. Balance measurements were performed using the Biodex Balance System under three different conditions: double-leg stance with eyes closed, single-leg stance on the pes planus side with eyes open, and single-leg stance on the pes planus side with eyes closed. In these measurements, we examined the Anteroposterior Index (APSI), Mediolateral Index (MLSI) and Overall Stability Index (OSI). The Spearman's correlation analysis was performed to evaluate the relationship between variables.

Results: In the single-leg stance with eyes closed the OSI, APSI and MLSI were recorded as 2.39±1.18, API 1.87±1.10 and 1.10±0.64 respectively. A weak, statistically significant positive correlation was found between the MLSI values obtained during single-leg stance with eyes closed and quadriceps femoris muscle strength (rho=0.270, p=0.031). A weak, statistically significant positive correlation was also found between the MLSI value obtained under the same single-leg, eyes-closed condition and hamstring muscle strength (rho=0.293, p=0.019). In the double-leg stance with eyes closed, OSI, APSI, and MLSI were determined to be 0.98±0.53, 0.83±0.49 and 0.38±0.26, respectively. In the single-leg stance with eyes open, the OSI, APSI, and MLSI were found to be 0.79±0.56, API 0.54±0.44 and 0.42±0.35, respectively. No statistically significant relationship was found between quadriceps femoris and hamstring muscle strength with OSI (p>0.05) and with APSI (p>0.05).

Conclusion: Our results demonstrated that, in balance measurements performed in individuals with pes planus, only the MLSI showed weak positive correlation with quadriceps femoris and hamstring muscle strength. OSI and APSI values were independent of muscle strength. These findings suggest that dynamic balance performance, particulary in terms of mediolateral stability, may vary depending on task difficulty and visual input in individuals with pes planus.

Keywords: Pes planus, quadriceps femoris, hamstring muscles, postural balance, muscle strength

INTRODUCTION

Pes planus is a common condition in which the entire plantar surface of the foot contacts the ground during both static and dynamic movements. Evidence suggests that asymptomatic pes planus affects 13.60% to 26.62% of the population.[1] In individuals with pes planus, disruption of the medial longitudinal arch may lead to excessive pronation of the foot and may result in excessive inward rotation of the foot during running or walking. The medial longitudinal arch provides shock absorption and stability during weight-bearing activities and plays an important role in foot biomechanics. Over time, this condition may affect not only the feet but also other lower-extremity components, such as the knee and hip, in terms of musculoskeletal problems due to altered alignment and mechanical factors. Comparisons of range of motion and muscle strength between individuals with pes planus and those with a normal medial longitudinal arch indicate that the severity of pes planus deformities in adults and children is associated with reduced flexibility.[2] In a study by Son et al.[3] investigating tibiotalar joint mechanics while walking in 10 individuals with pes planus and 10 healthy individuals, altered foot biomechanics were shown to increase lateral contact forces in individuals with pes planus. This highlights how structural changes related to pes planus affect overall lower-extremity biomechanics beyond merely reflecting muscle strength deficits. Abnormal foot mechanics, such as excessive pronation and supination, may disrupt load distribution in the knee joint.[4]

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Malalignment of the knee joint may cause changes in the length-tension relationship of the surrounding musculature, and these changes may result in the transmission of abnormal afferent information. It has been hypothesized that alterations in afferent input to the central nervous system may affect efferent output to the muscles, inhibit the kinetic response of the muscle, and consequently lead to muscle atrophy.[5] In a study conducted by Chang et al.,[6] electromyographic (EMG) measurements revealed significant differences in muscle activation between individuals with pes planus and healthy controls, specifically affecting both distal and proximal musculature, including the tibialis anterior, gastrocnemius, vastus lateralis, and biceps femoris. The loss of supportive function in the medial longitudinal arch in individuals with pes planus leads to increased compensatory activation in the proximal musculature surrounding the knee and hip joints, thereby triggering proximal compensation mechanisms. Subtalar joint closed-chain pronation is characterized by calcaneal eversion alongside talar adduction and plantarflexion. Due to its position within the ankle mortise, the talus serves as a linkage mechanism, converting foot pronation into tibial rotation across both the subtalar and midtarsal joints. This rotation functions in temporal coordination with hip kinematics, in which rearfoot pronation corresponds to femoral internal rotation, while rearfoot supination coincides with hip external rotation. Impairments in this kinematic coupling mechanism are considered to be a contributing factor to various musculoskeletal injuries of the lower extremity.[7] Although the literature indicates that lower extremity biomechanics and balance control are altered in individuals with pes planus, studies directly examining the relationship between quadriceps femoris and hamstring muscle strength and balance performance across different support conditions remain limited. Therefore, the primary objective of this study was to determine the relationship between quadriceps femoris and hamstring muscle strength and balance performance under various support base conditions in individuals with pes planus. We hypothesize that lower quadriceps femoris and hamstring muscle strength in individuals with pes planus would be significantly associated with reduced balance performance, particularly under conditions with reduced base of support (single-leg stance).

METHODS

Ethics

Ethical permission and approval for the study were obtained from the Gazi University Rectorate Institute of Health Sciences Ethics Committee (Date: 03.07.2025 Decision No: 26/03). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Individuals were included in the study after completing the informed consent form required by the relevant ethics committee.

Study Design

This study was a correlational study investigating the relationship between quadriceps femoris and hamstring muscle strength and balance in individuals with pes planus. The study was conducted between September 2025 and June 2026 with the participation of 64 individuals with pes planus (48 female, 16 male). Volunteers aged 18-35 years were included in the study. The inclusion criteria for the study were as follows: individuals aged between 18 and 35 years, with a body-mass index (BMI) of less than 30 kg/m^2, and identified with pes planus based on the Navicular Drop Test, Additionally, participants report no pain during daily living activities, and voluntarily agree to participate in the study by signing an Informed Consent Form. The exclusion criteria were scoliosis or postural deformities (such as genu valgum,genu varum), lower-extremity injury or surgery with in six months, lower limb length discrepancy, a history of neurological or rheumatological disease, malignancy, and pregnancy. Lastly candidates with psychiatric or cognitive impairments that could impede communication were excluded from study. The study was conducted in the Orthopedics Unit of the Faculty of Health Sciences, Gazi University.

The sample size was determined using G*Power. Based on α=0.05, α power of 80% (β=0.20), and effect size of 0.3, α minimum total of 64 participants was required for the study. Of the 71 individuals who agreed to participate in the study, one could not participate due to scoliosis, two due to chronic ankle instability, and four due to meniscal rupture in the knee. Therefore, the study was completed with a total of 64 participants. Both feet were evaluated during the study; however, only the side presenting with pes planus was included in the analysis. Participants were identified using the navicular drop test, and their pes planus grade was then recorded using the Feiss line test. Consequently, participants were definitively diagnosed with pes planus if they exhibited a navicular drop test result of ≥10 mm in conjunction with a grade 1 or higher displacement on the Feiss Line Test assessment.

The participants' age, height, body weight, gender, dominant side, side with pes planus, and pes planus grade were recorded. Quadriceps femoris and hamstring muscle strength were measured on the side with pes planus, and balance was assessed. These measurements were completed on the same day. In the literature, the dominant side of the lower extremity is defined as the side used for mobilization during activities, whereas the side providing support and stabilization is defined as the non-dominant side.[8]

Navicular Drop Test

The navicular drop test is applied in sitting and standing positions to determine the change in medial longitudinal arch height. The navicular tuberosity is marked while the participant is seated, and the distance between the tuberosity and the floor is recorded in millimeters on a card. The participant is then asked to stand up and after weight bearing, the navicular tuberosity is marked again on the same card, and the distance in millimeters between the two lines is recorded as navicular drop. A navicular drop of 6-9 mm is classified as normal, whereas 10 mm or more is classified as pes planus.[9]

Feiss Line Test

The Feiss line method was used to determine the degree of pes planus in the participants. During the measurements, participants were asked to stand upright on a firm surface while distributing weight equally on both feet. For the assessment, a reference Feiss line was drawn by connecting the center of the medial malleolus to the midpoint of the first metatarsophalangeal joint. Based on the principle that the navicular tuberosity should lie on this line in a healthy foot, pes planus was graded according to the amount of downward displacement of the tuberosity below the line. Accordingly, if the navicular tuberosity dropped by one-third of the distance between the Feiss line and the floor, it was classified as grade 1 pes planus; if it dropped by two-thirds, it was classified as grade 2 pes planus; and if it was in complete contact with the floor, it was classified as grade 3 pes planus.[10]

Muscle Strength Assessment

The strength of the quadriceps femoris and hamstring muscles was measured using a Nicholas Manual Muscle Tester (model 01160, The Lafayette Instrument Company, Lafayette, Indiana, USA). For the quadriceps femoris measurement, the participant was seated with the legs hanging over the edge of the examination table and the knee flexed at 90 degrees; the participant was asked to fully extend the knee, and measurement was performed during this maneuver. For hamstring muscle strength, the participant was positioned prone with the knee flexed at 45 degrees and was asked to pull the heel toward the buttock; measurement was performed during this maneuver.[11] All measurements were repeated three times, and the mean value was recorded.

Balance Assessment

Static balance assessments were conducted via the Biodex Balance System. Three different measurements were performed on a stable surface using the Biodex Balance System.[12] Before the measurements, each participant completed a 10-second demonstration test to adapt to the test procedure with both feet on the balance platform and the eyes open. Participants were asked to keep the point, which moved according to their weight shifts without moving their feet, in the exact center of the circle. Participants were asked to maintain an upright position and minimize the movement as much as possible during the testing procedure. Because participants performed practice trials on both feet balance platform with eyes open during the demonstration phase, this position was not included in the main experiment. The first measurement was performed with both feet on the balance platform and the eyes closed. Each measurement lasted 20 seconds and was repeated three times, with 10-second rest periods between repetitions. The second measurement was performed on the pes planus side with the eyes open and again consisted of three 20-second trials. The final measurement was performed on the pes planus side with the eyes closed, again with three 20-second repetitions and 10-second rest periods. The test was repeated for all participants who lost balance or moved their foot. As a result of the tests, the Anteroposterior Index (APSI), Mediolateral Index (MLSI), and Overall Stability Index (OSI) were obtained.

Statistical Analysis

All data analyses were performed using IBM SPSS Statistics 30.0 (SPSS Inc., Chicago, IL, USA). The normality of numerical variables was examined using visual methods (histograms and probability plots) and analytical methods (Shapiro-Wilk test, skewness and kurtosis values, and coefficient of variation). Descriptive statistics were presented as frequency and percentage for categorical variables and as mean and standard deviation, median, and minimum-maximum values for numerical variables.[13,14] The Spearman correlation test was used to examine relationships between variables because the data did not meet the assumption of normal distribution. Correlation coefficient values were interpreted as follows: 0.00-0.20, very weak; 0.21-0.40, weak; 0.41-0.60, moderate; 0.61-0.80, strong; and 0.81-1.00, very strong.[13,14] Results with a type I error level below 5% were considered statistically significant.

RESULTS

Selected sociodemographic and clinical characteristics of the participants are presented in Table 1. The mean age of the participants was 24.17+/-3.68 years. Mean body weight was 70.47+/-12.29 kg, mean height was 166.98+/-9.16 cm, and mean BMI was 25.27+/-2.92 kg/m². When gender distribution was examined, 75% of the participants were female (n=48) and 25% were male (n=16). In terms of dominant side, right-side dominance was identified in 85.94% of the participants (n=55), whereas left-side dominance was identified in 14.06% (n=9). Pes planus was present in the right foot in 70.31% of participants (n=45) and in the left foot in 29.69% (n=19). According to the Feiss line test results, grade 2 pes planus was detected in 45.31% of participants (n=29), grade 1 in 37.50% (n=24), and grade 3 in 17.19% (n=11).

Table 1. Sociodemographic and clinical characteristics of the participants (n=64)

	X̄±SD	Median (min/max)
Age (years)	24.17+/-3.68	23.50 (19/34)
Body weight (kg)	70.47+/-12.29	70 (51/95)
Height (cm)	166.98+/-9.16	165 (152/192)
BMI (kg/m²)	25.27+/-2.92	25.29 (17.51/27.23)
	n	**%**
Gender		
Male	16	25
Female	48	75
Dominant side		
Right	55	85.94
Left	9	14.06
Side with pes planus		
Right	45	70.31
Left	19	29.69
Feiss line test		
Grade 1	24	37.50
Grade 2	29	45.31
Grade 3	11	17.19

SD: Standard deviation, Min: Minimum, Max: Maximum, BMI: Body-mass index

The quadriceps femoris and hamstring muscle strength values of the participants are presented in Table 2. Mean quadriceps femoris muscle strength was 186.49+/-44.65 N, and mean hamstring muscle strength was 154.15+/-60.87 N.

Table 2. Muscle strength values of the participants (n=64)

	X̄±SD	Median (min-max)
QF muscle strength (N)	186.49+/-44.65	181.37 (120.50/316.33)
Hamstring muscle strength (N)	154.15+/-60.87	148.60 (55.23/363.50)

SD: Standard deviation, Min: Minimum, Max: Maximum, QF: Quadriceps femoris, N: Newton

The Biodex balance measurement results of the participants are presented in Table 3. In double-leg stance with eyes closed, the OSI was 0.98+/-0.53, the APSI was 0.83+/-0.49, and the MLSI was 0.38+/-0.26. In single-leg stance with eyes open, OSI was 0.79+/-0.56, APSI was 0.54+/-0.44, and MLSI was 0.42+/-0.35. In single-leg stance with eyes closed, OSI was 2.39+/-1.18, APSI was 1.87+/-1.10, and MLSI was 1.10+/-0.64.

Table 3. Balance measurement values of the participants (n=64)

		X̄±SD	Median (min-max)
Double-leg stance (eyes closed)	OSI	0.98+/-0.53	0.85 (0.20/2.70)
	APSI	0.83+/-0.49	0.70 (0.20/2.40)
	MLSI	0.38+/-0.26	0.30 (0.10/1.10)
Single-leg stance (eyes open)	OSI	0.79+/-0.56	0.60 (0.30/3.30)
	APSI	0.54+/-0.44	0.40 (0.20/3.10)
	MLSI	0.42+/-0.35	0.30 (0.10/1.80)
Single-leg stance (eyes closed)	OSI	2.39+/-1.18	2.10 (1/7.70)
	APSI	1.87+/-1.10	1.60 (0.60/7)
	MLSI	1.10+/-0.64	0.90 (0.40/4.60)

SD: Standard deviation, Min: Minimum, Max: Maximum, OSI: Overall Stability Index, APSI: Anterior-posterior Stability Index, MLSI: Mediolateral Stability Index

The relationship between participants' muscle strength values and balance measurement results was examined using Spearman correlation analysis, and the results are presented in Table 4. A weak, statistically significant positive correlation was found between the MLSI value obtained during single-leg stance with eyes closed and muscle strengths of both the quadriceps femoris (rho=0.270, p=0.031) and hamstring (rho=0.293, p=0.019). Conversely no statistically significant correlation was found between eighter quadriceps femoris and hamstring muscle strength and any of the balance indices (OSI, APSI) during the double leg eyes closed and single leg eyes open conditions, nor with OSI and APSI values during the single leg eyes closed condition. (p>0.05).

Table 4. Relationship between participants' muscle strength values and balance measurement results (n=64)

			QF muscle strength	Hamstring muscle strength
Double-leg stance (eyes closed)	OSI	rho	-0.082	-0.186
		p	0.519	0.140
	APSI	rho	-0.111	-0.172
		p	0.384	0.173
	MLSI	rho	0.011	-0.103
		p	0.932	0.417
Single-leg stance (eyes open)	OSI	rho	-0.102	-0.174
		p	0.424	0.168
	APSI	rho	-0.102	-0.173
		p	0.424	0.172
	MLSI	rho	-0.088	-0.149
		p	0.488	0.239
Single-leg stance (eyes closed)	OSI	rho	0.203	0.205
		p	0.107	0.105
	APSI	rho	0.178	0.139
		p	0.159	0.273
	MLSI	rho	0.270	0.293
		p	0.031	0.019

rho: Spearman correlation coefficient, QF: Quadriceps femoris, OSI: Overall Stability Index, APSI: Anterior-Posterior Stability Index, MLSI: Mediolateral Stability Index

DISCUSSION

The primary aim of this study was to examine the relationship between quadriceps femoris and hamstring muscle strength and balance parameters in individuals with pes planus. The notable statistical finding was that, during single-leg stance with eyes closed, both quadriceps femoris and hamstring muscle strength showed weak positive correlations with the MLSI (rho=0.270, p=0.031; and rho=0.293, p=0.019, respectively).

The literature indicates that pes planus deformity alters the kinematics of the ankle and proximal joints and therefore affects balance. Studies examining the effects of foot posture on dynamic balance have shown that individuals with pes planus have increased postural sway and that this negatively affects balance strategies.[15] In our study, the unfavorable change in balance strategies observed particularly during single-leg stance with eyes closed supports this view in the literature.

In our study, the weak positive relationship found between MLSI values during single-leg stance with eyes closed and quadriceps femoris and hamstring muscle strength indicates that as muscle strength increased, the MLSI also increased, reflecting an unfavorable change in balance. Given the weak statistical results, further clinical studies are required, and these finding do not warrant a definitive conclusion. This finding can be explained by compensatory mechanisms in the presence of pes planus. It has been reported that lower-extremity alignment disorders in individuals with pes planus may alter loads on the knee and hip joints, potentially causing excessive contractions in proximal muscle groups.[16] In conditions in which the eyes are closed and mechanoreceptors on the sole of the foot are insufficient because of pes planus deformity, the body places greater demand on the knee and hip joints to maintain balance. According to the "Foot Core System" theory, when intrinsic muscle activation in the foot is insufficient, extrinsic muscles and larger proximal muscles attempt to assume the role of stabilization.[16] Therefore, it is likely that the individuals with pes planus in our study used proximal muscle groups, namely the quadriceps femoris and hamstring muscles, more intensively as a compensatory strategy to control MLSI values. As a potential biomechanical hypothesis, the increased MLSI associated with higher proximal muscle strength may reflect a compensatory strategy.[16,17] In individuals with pes planus, insufficient intrinsic foot muscle activation might lead to an over-reliance on larger proximal muscles to maintain stability. This proximal co-contraction strategy could result in increased joint stiffness unintentionally increasing balance sway.[18,19] Future studies combining EMG and 3D motion analysis are warranted to test this hypothesis.

The contribution of muscle groups around the knee to mediolateral stability, rather than anterior-posterior stability, in foot deformities remains debated in the literature. The relationship between lower-extremity muscle strength and pes planus has been examined during gait, and impairments in foot mechanics have been shown to create direct changes in loading at the knee joint.[17] In our study, the fact that the correlation was observed only for MLSI supports the interpretation that subtalar joint eversion and internal rotation torque in individuals with pes planus destabilize the trunk more in the medial-lateral axis and that the knee joint is affected more in this axis than in the anterior-posterior axis.

Limitations

This study has several limitations. Although the sample consisted of 64 participants, most participants were female when the gender distribution was examined. This distribution, with a higher number of female participants, limits the generalizability of the data obtained. Although our findings showed a relationship between muscle strength and the MLSI under eyes-closed conditions, participants' joint position sense or ankle proprioception levels were not objectively measured. Another limitation of this study is the absence of a healthy control group, which restricts the ability to make direct comparative evaluations. Additionally, the side presenting with pes planus deformity did not correspond to the dominant side in all participants, representing another limitation regarding functional side to side symmetry. A further limitation is that the quadriceps to hamstring strength ratio was not included in the analysis, limiting deeper insights into agonist-antagonist muscle balance. Finally, EMG and muscle firing patterns were not recorded in this study, nor were proprioception parameters directly evaluated.

Future studies should include a more homogeneous sample according to pes planus grade and gender distribution. In addition, including ankle proprioception parameters in the assessment process would help future studies obtain more objective results.

CONCLUSION

As a result, this study demonstrates that young adults with unilateral pes planus exhibit significant deficits in proximal muscle strength, particularly in the quadriceps femoris and hamstring on the affected side, which are weakly associated with impaired medioateral stability index. While proximal muscle strength plays a contributing role in lower extremity control, the weak correlation magnitudes suggest that proximal capacity alone is insufficient to fully compensate for distal biomechanical alterations during dynamic single-leg tasks. Clinicians should therefore adopt an integrative rehabilitation approach that combines proximal muscular strengthening with distal structural and sensorimotor interventions rather than relying solely on proximal training to enhance postural control in individuals with pes planus. From a clinical perspective, these findings suggest that while proximal muscle capacity plays a contributing role in lower extremity stabilization, relying solely on proximal muscle strengthening in rehabilitation programs may not be sufficient to fully restore dynamic postural balance in individuals with pes planus. Therefore, clinicians are encouraged to adopt a comprehensive treatment paradigm that integrates proximal muscle training with distal structural support and sensorimotor re-education. Future research should incorporate EMG muscle activation patterns, ankle biomechanics, and proprioceptive tracking to further clarify the underlying motor control mechanisms and proximal compensation strategies during functional tasks.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Gazi University Rectorate Institute of Health Sciences Ethics Committee (Date: 03.07.2025 Decision No: 26/03).

Informed Consent

Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Author Contributions

Concept: İY, SÇ; Design: İY, SÇ; Control: İY, SÇ; Resources: İY, SÇ; Materials: İY, SÇ; Data Collection and/or Processing: İY, SÇ; Analysis and/or Interpretation: İY, SÇ; Literature Review: İY, SÇ; Writing the Article: İY, SÇ; Critical Review: İY, SÇ.

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