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Is Morton's neuroma in a pes planus or pes cavus foot lead to differences in pressure distribution and gait parameters?

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A R T I C L E I N F O

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A B S T R A C T

Morton's neuroma (MN) is a compressive neuropathy of the common digital plantar nerve causing forefoot pain. Foot posture and altered plantar pressure distribution have been identified as predispoing factors, however no studies have compared individuls with different foot postures with MN. Thus, we aimed to compare the effect of MN on spatiotemporal gait parameters and foot-pressure distribution in individuals with pes planus and pes cavus. Thirty-eight patients with unilateral MN were evaluated between June and August 2021. Nineteen patients with bilateral pes planus and 19 age and gender-matched patients with pes cavus who had no prior surgery were recruited. A Zebris FDM–THM–S treadmill system (Zebris Medical GmbH, Germany) was used to evaluate step length, stride length, step width, step time, stride time, cadence, velocity, foot-pressure distribution, force and whole stance phase, loading response, mid stance, pre-swing and swing phase percentages. There were no significant differences between the groups in spatiotemporal gait parameters ($p > 0.05$). Patients with pes planus displayed the following results for step length (49.36 ± 8.38), step width (9.05 ± 2.12), stance phase percentage (65.92 ± 2.11), swing phase percentage (34.08 ± 2.12), gait speed (2.96 ± 0.55), and cadence (100.57 ± 8.84). In contrast, patients with pes cavus displayed the following results for step length (49.06 ± 8.37), step width (8.10 ± 2.46), stance phase percentage (64.96 ± 1.61), swing phase percentage (34.79 ± 1.60), gait speed (2.95 ± 0.65), and cadence (99.73 ± 13.81). Foot-pressure distribution values showed no differences were detected in force, forefoot, and rearfoot pressure distribution, except for midfoot force ($p < 0.05$). The forefoot, midfoot, and rearfoot pressure values for the pronated group were 32.14 ± 10.90, 13.80 ± 3.03, and 22.78 ± 5.10, and for the supinated group were 33.50 ± 11.49, 14.23 ± 3.11 and 24.93 ± 6.52. MN does not significantly affect spatiotemporal gait parameters or foot-pressure distribution in patients with pes cavus or pes planus.

1. Introduction

Morton's neuroma (MN) is a painful forefoot syndrome characterized by overload and altered pressure distribution within the foot due to tension in the calf muscle, usually associated with the third interdigital nerve [1]. MN is primarily caused by the compression and irritation of the plantar surface of the transverse intermetatarsal ligament [2]. Since the condition can be described as degenerative

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rather than neuroplastic, it cannot be termed as a real neuroma [3].

MN is more commonly seen in women between the ages of 50–55 [1]. Patients usually complain of burning and sharp pain in the plantar region and avoid loading on the forefoot to reduce pain [4]. Although the exact pathomechanism of MN is not fully understood, chronic trauma, local ischemia leading to nerve scarring, entrapment neuropathy, increased tension in the fasciae of the foot, and biomechanical factors have been suggested as underlying causes [5,6]. The reactive fibrosis observed in MN and described in the literature can be considered a consequence of nerve entrapment. Excessive fibrous content transforms the sheath into a rigid channel, and collagen deposition compresses the small vessels flowing within the sheath, causing nerve ischemia, which worsens the fibrosis [7].

Among the biomechanical factors, pes planus and pes cavus increase forefoot pressure and lead to repetitive trauma to the plantar intermetatarsal nerve [8,9]. Kim et al. have proposed that the underlying cause is the compression of the interdigital nerve between the adjacent metatarsal head and the metatarsophalangeal joint during walking [8]. In the literature, reported that MN is occurs in both pes planus and cavus foot [10].

The foot functions as a tripod in terms of architecture and functionality. When the foot is on the ground in a static position, the heel, the first metatarsal head, and the fifth metatarsal head are the three areas where the pressure is primarily absorbed. Varus or valgus alignment occurred by the changes in foot biomechanics, causes the foot pressure to shift medially or laterally, respectively [11]. Foot pressure increases in the medial part of the midfoot in pes planus and the lateral part in pes cavus [12,13]. Compared with feet with pes cavus and normal arch height, feet with pes planus showed higher pressure in the medial arch, central forefoot, and hallux, increased contact area values, while these parameters did not change in the lateral and medial forefoot. In contrast, compared with feet normal arch height and pes planus, feet with pes cavus displayed higher pressure at the heel and the lateral forefoot, and lower pressure at the midfoot and the hallux decreased contact area in the midfoot and hallux [14].

Adults with different foot postures display altered foot pressure distribution. Also, it has been stated that the gait parameters were affected and feet with pes cavus had less motion in the initial contact and midstance phases compared to feet with normal arch index and pes planus. Besides this, pre-swing phase duration decreased in individuals with pes planus [15]. Hillstrom et al. [16] compared individuals with pes planus and pes cavus and reported that stance phase duration decreased in patients with pes planus, and there were no differences in terms of cadence, speed, step length, stride length, and swing phase durations.During the toe – off phase of walking, most of the pressure is collected in this area in patients with MN and it may deteriorate the biomechanical condition of gait [17]. On the contrary no significant differences were found in terms of peak pressure, contact time, and arc index between patients with and without MN [18]. While there were no differences in plantar pressure distribution in individuals with and without MN who had a uniform foot posture, it is not known how it will affect individuals with pes planus and pes cavus foot posture.

No study has been found investigates the effects of MN accompanying two different foot postures on dynamic stability, and knowledge about the relationship betweeen foot posture and plantar pressure distribution characteristic is limited in patients with MN. Thus, there is a need for an extension of research to clarify this issue.

The aim of our study was to compare the effect of MN in feet with pes planus and pes cavus on foot pressure distribution and spatiotemporal gait parameters. We hypothesized that during walking, MN accompanying feet with pes planus and pes cavus may display differences in foot pressure distribution and gait parameters, especially to avoid the increased pressure of lateral forefoot, decreased midstance and total stance phase percentage, and increased swing phase percentage that can be seen in the pes cavus group.

2. Methods

The present study was designed as a cross-sectional study. Participants ($n = 38$) who applied to Fulya Foot Surgery Clinic between June and August 2021 were recruited. Ethical approval was obtained from the university ethics committee (ATADEK 2021- 09/58). Our study was completed following the "Declaration of Helsinki".

Patients were included if they had pain symptoms during gait (above 3/10 with Visual Analog Scale) due to unilateral MN for at least 6 months, had a painful Mulder's click sign, had been confirmed MN diagnosis with magnetic resonance imaging, had bilateral pes planus determined with navicular drop test (greater than 10 mm drop of navicula) [19], had bilateral pes cavus determined with Moreau-Costa-Bertani angle below 125° measured via a weight-bearing foot radiography [20] and had not received previous steroid injection, alcohol injection, and facial manipulation treatment. The exclusion criteria for both groups were: peripheral nervous system disease, preexisting musculoskeletal disease within the lower extremities, history of surgery within the lower extremity, history of trauma within the forefoot, preexisting of rigid finger deformity, and participation in a physical therapy program 3 months before the study.

All participants gave their written consent. The study included 19 patients with unilateral MN accompanying bilateral pes cavus and 19 patients with unilateral MN accompanying bilateral pes planus who were age (±1) and gender-matched with patients in the pes cavus group. This clinical trial was registered at www.clinicaltrials.gov. The assessor was unaware of the diagnosis of the participants and used the same assessment procedure.

2.1. Measurements

The demographic variables were recorded before the study. Changes in the step length (cm), stride length (cm), step width (cm), stance phase (%), swing phase (%), step time (sec), stride time (sec), cadence (steps/min), velocity (km/h) values, foot pressure distribution of forefoot, midfoot and rearfoot (N/m^2) and force (N), were evaluated using Zebris FDM–THM–S treadmill system (FDM-THM-S, Zebris Medical GmbH, Germany) [21]. The Zebris instrumented gait analysis system (FDM-THM-S, Zebris Medical GmbH) consists of a foot pressure platform placed within a treadmill. The pressure platform contains a 108.4 × 47.4 cm sensor area, including 7168 sensors, each approximately 0.85 × 0.85 cm [22]. The contact surface of the treadmill is 150 × 50 cm, and the speed can be adjusted from 0.2 to 22 km/h with 0.1 km/h increments [23]. While the patients are standing or walking on the treadmill, the sensors can make three-dimensional reactive and normal force measurements with a frequency of 120 Hz. The feet can be mapped in a high resolution to analyze even the smallest changes in force distribution. The timing can be monitored. The specially designed software integrates force signals and provides 2-D/3-D graphical representation [24]. The Zebris FDM-THM-S treadmill system is a valid and reliable measurement tool to evaluate the foot-pressure distribution and spatiotemporal gait parameters [21,25].

The treadmill was settled in a horizontal position and the patients were asked to walk barefoot on the treadmill. The patients walked at their comfortable walking speed that would not cause pain or disturb them. The self-selected gait speed was preferred because it gives the least variation in gait parameters and participants were blinded to the treadmil speed. Measurements were taken in a single session to eliminate the learning effect. The total test time was 10 min which was divided into familiarization and recording periods for the first 6 min and 4 min, respectively. The foot pressure distribution values and gait parameters were recorded for 10 s during the recording period. After the evaluation 1-min of break is provided for resting.

2.2. Sample size and statistical analysis

An independent sample-t-test was conducted to calculate the sample size according to foot pressure distribution values from the study of Burns et al. [26]. At least 19 participants were required to obtain a power of 0.80 and an alpha value of 0.05 (G Power 3.1 Düsseldorf, Germany). The normality of the data was analyzed using the Shapiro-Wilk test. Independent-t-test was used to compare variables in both groups and the Fisher's exact test to analyze categorical variables. Paired *t*-test was used to compare the spatiotemporal gait parameters and pressure distribution of feet within groups. P value at <0.05 was considered as significant. All statistical tests were performed using SPSS 21.0 for Windows (IBM Inc., Armonk, NY, USA).

3. Results

Ninety-three patients were evaluated for eligibility for the study. Fifty patients met the inclusion criteria. Among these patients, 21 were diagnosed with unilateral Morton's neuroma accompanying pes cavus, and 29 were diagnosed with Morton's neuroma accompanying pes planus. Three patients with pes cavus refused to participate in this study. A total of 38 patients with Morton's neuroma were divided into 19 pes cavus and age-gender matched 19 pes planus (±1 year).

There were no differences in the baseline characteristics of the groups (Table 1). The temporal and spatial gait parameters, geometric values (step length, stride length, step width), phase values (whole stance phase, loading response, mid stance, pre-swing and swing), and timing (step time, stride time cadence, velocity) were not significantly different between the two groups ($p > 0.05$) (Fig. 1). When the foot-pressure distribution and maximum force were compared, no significant differences were detected in any of the variables except midfoot force (Table 2) (Figs. 2 and 3).

In the comparison of the foot with pes planus and pes cavus within the group, no significant changes were found in the sole pressure distribution and spatiotemporal gait parameters of the pronated group with and without MN. In comparison to the supinated group with and without MN foot, a significant decrease was detected for total stance phase and midstance phase percentage and a significant increase in swing phase percentage and step time ($p < 0.05$) (Table 3).

4. Discussion

This study aimed to investigate the effect of MN on foot-pressure distribution and gait parameters in patients with pes planus and pes cavus. Our study showed that Morton's neuroma had similar effects in patients with pes planus and pes cavus on spatiotemporal gait parameters and foot-pressure distribution, except for midfoot force. Additionally, the stance phase percentage decreased while the swing phase and step time increased in the pes cavus group without MN.

MN is more common in female and they experience neuroma symptoms more often, which may be caused by shoe gear [27]. However, MN is not associated with anatomical foot structure, such as foot width, which is a sex-related factor. Gender was reported to be non-determinant for the location, size, and age of onset of MN [28].

Table 1
Demographic variables.

Variables	Pes Planus MN (N = 19)	Pes Cavus MN (N = 19)	*p*
	Mean (S.D)	Mean (S.D)	
Age (years)	50.52(9.58)	52.10(9.59)	
Height (cm)	168.94 (7.05)	167.78 (9.12)	.61
Body weight (kg)	73.42 (12.18)	72.53 (15.37)	.66
BMI (kg/m^2)	25.60 (3.06)	25.64 (4.34)	.84
Female/male	17/2	17/2	.97

MN:Morton's Neuroma.
SD: Standard Deviation, p* values obtained from the Independent Samples *t*-test.

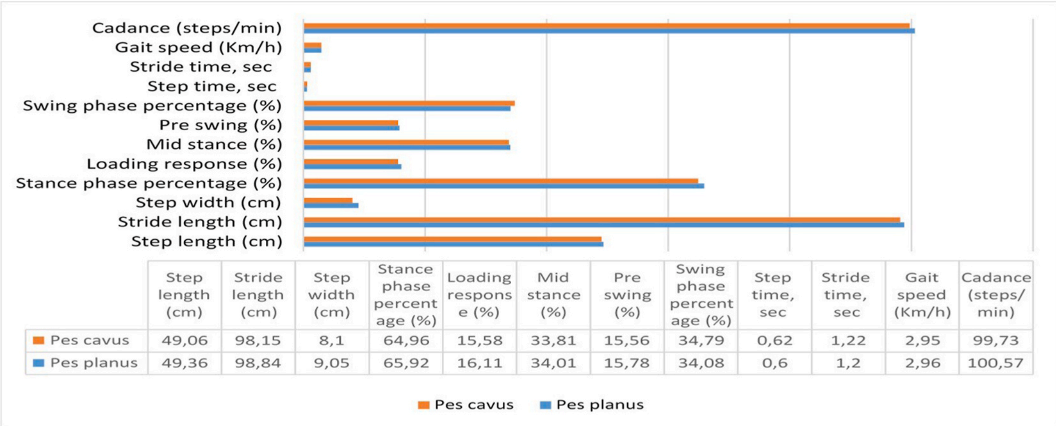

Fig. 1. Spatiotemporal gait parameters of groups.

Table 2
Spatio-temporal gait parameters and foot pressure distribution in groups.

Variables	Pronated MN (N = 19) Mean ± SD	Supinated MN (N = 19) Mean ± SD	Mean Difference (SE)	*P**	*95%CI*
Gait parameters					
Step length (cm)	49.36 ± 8.38	49.06 ± 8.37	0.30(2.71)	.911	−5.2 to 5,81
Stride length (cm)	98.84 ± 17.12	98.15 ± 17.25	0.68(5.57)	.903	−10.62 to 11,99
Step width (cm)	9.05 ± 2.12	8.10 ± 2.46	0.94(0.74)	.213	−0.56 to 2.46
Stance phase percentage (%)	65.92 ± 2.11	64.96 ± 1.61	0.95(0.61)	.127	−0.28 to 2.19
Loading response (%)	16.11 ± 2.12	15.58 ± 2.49	0.52(0.75)	.489	−1.00 to 2.05
Mid stance (%)	34.01 ± 2.27	33.81 ± 2.54	0.20(0.78)	.800	−1.39 to 1.79
Pre swing (%)	15.78 ± 2.20	15.56 ± 1.57	0.22(0.62)	.725	−1.04 to 1.48
Swing phase percentage (%)	34.08 ± 2.12	34.79 ± 1.60	−0.71(0.61)	.252	−1.94 to 0.52
Step time, sec	0.60 ± 0.57	0.62 ± 0.10	−0.02(0.02)	.410	−0.07 to 0.03
Stride time, sec	1.20 ± 0.10	1.22 ± 0.20	−0.02(0.05)	.599	−0.13 to 0.07
Gait speed (km/h)	2.96 ± 0.55	2.95 ± 0.65	0.01(1.96)	.957	−0.38 to 0.40
Cadance (steps/min)	100.57 ± 8.84	99.73 ± 13.81	0.84(3.76)	.824	−6.79 to 8.47
Foot pressure distribution (N/cm2)					
Forefoot	32.14 ± 10.90	33.50 ± 11.49	−1.35(3.6)	.711	−8.73 to 6.01
Middlefoot	13.80 ± 3.03	14.23 ± 3.11	−0.43(0.99)	.664	−2.45 to 1.58
Rearfoot	22.78 ± 5.10	24.93 ± 6.52	−2.14(1.90)	.267	−5.99 to 1.71
Foot force (N)					
Forefoot	543.54 ± 142.25	576.17 ± 158.49	−32.63(48.85)	.508	−131 to 66.45
Middlefoot	147.41 ± 54.38	100.53 ± 48.88	46.87(16.77)	**.008**	12.85 to 80.90
Rearfoot	371.77 ± 61.54	399.56 ± 68.66	−27.79(21.15)	.197	−70.69 to 15.10

SD: Standard Deviation, p* values obtained from the paired *t*-test.
CI: confidence interval.

Spatiotemporal gait parameters such as cadance, gait speed, and step lengths may differ by gender and fatigue, but it has been reported that one of the important factors affecting stride length and cadence is height. Gait speed is higher in men, while cadance is higher in women.

Still, after 40–50 age, gait speed decreases in every decade. Moreover, there was no significant difference in spatiotemporal gait parameters in healthy men and women under 60 years of age [29]. Since the mean age of our sample was below 60 years and group homogeneity was maintained in terms of gender, we think that there was no situation that would affect the results of our study, although the number of female patients was higher than the number of male patients.

Naraghi et al. compared patients with and without a diagnosis of MN in terms of foot-pressure distribution and stated that the results were similar in the two groups. They also reported no differences for the arch index in patients with and without MN. In our study, we compared patients with isolated pes planus and pes cavus instead of only one type of foot. Thus, we aimed to see which foot type was more affected by MN.

Hyperpronation or supination of the subtalar joint may overload the entire mechanical chain, especially during weight-bearing activities. Increasing abnormal load distribution leads to symptomatic soft tissue strains. MN accompanying these strains generally causes sharp and dull pain in the forefoot. It can be interesting to reveal the changes in forefoot pressure distribution that occurred due to pain. Especially, the lateral forefoot pressure changes during walking are sensitive to differences in the location of neuromas [30]. In our study, both groups included participants who had MN in the third web space, which causes the lateral part of the foot to be more

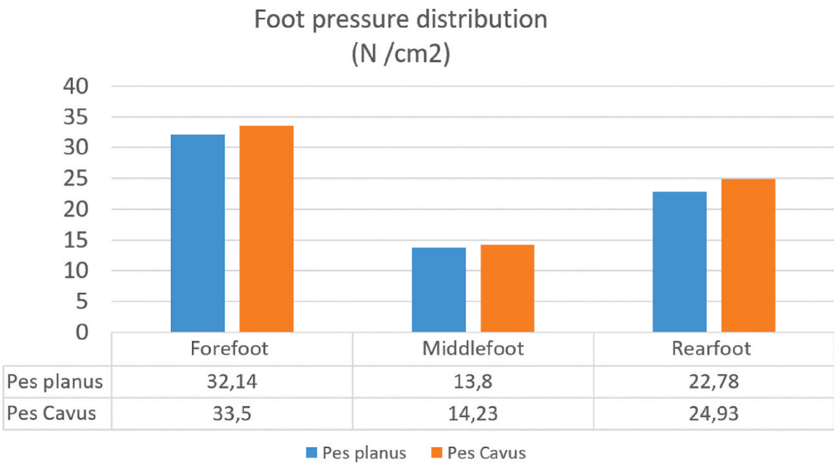

Fig. 2. Comparison of groups in terms of foot pressure distribution.

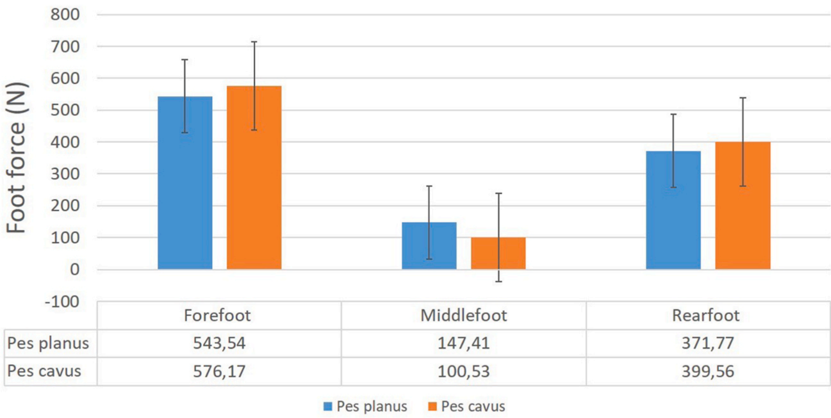

Fig. 3. Comparison of groups in terms of foot force.

Table 3
Comparation Spatio-Temporal Gait Parameters and Foot Pressure Distribution in patients with and without Morton neuromas foot in groups.

Variables	Pronated MN (N = 19) Mean ± SD			Supinated MN (N = 19) Mean ± SD		
	Foot without MN Mean ± SD	Foot with MN Mean ± SD	P	Foot without MN Mean ± SD	Foot with MN Mean ± SD	P
Gait parameters						
Step length (cm)	50,34 ± 7,78	49,36 ± 8,38	.156	49.26 ± 8.87	49.06 ± 8.37	.136
Stance phase percentage (%)	65,98 ± 2,29	65.92 ± 2.11	.873	66.17 ± 2.54	64.96 ± 1.61	**.013**
Loading response (%)	15,78 ± 2,21	16.11 ± 2.12	.415	15.54 ± 1.55	15.58 ± 2.49	.928
Mid stance (%)	34,08 ± 2,11	34.01 ± 2.27	.854	35.04 ± 1.61	33.81 ± 2.54	**.011**
Pre swing (%)	16,12 ± 2,13	15.78 ± 2.20	.389	15.57 ± 2.49	15.56 ± 1.57	.968
Swing phase percentage (%)	34,01 ± 2,29	34.08 ± 2.12	.863	33.82 ± 2.54	34.79 ± 1.60	**.036**
Step time, sec	0,60 ± 0,01	0.60 ± 0.57	.559	0.60 ± 0.1	0.62 ± 0.10	**.012**
Foot pressure distribution (N/cm2)						
Forefoot	33,43 ± 10,98	32.14 ± 10.90	.592	33,93 ± 10.43	33.50 ± 11.49	.559
Middlefoot	13,47 ± 2,10	13.80 ± 3.03	.527	14.88 ± 5.30	14.23 ± 3.11	.962
Rearfoot	22,56 ± 5,73	22.78 ± 5.10	.778	24.40 ± 4.90	24.93 ± 6.52	.803
Foot force (N)						
Forefoot	540,22 ± 124,07	543.54 ± 142.25	908	569.05 ± 152.61	576.17 ± 158.49	.635
Middlefoot	150,92 ± 53,62	147.41 ± 54.38	.673	100.19 ± 51.41	100.53 ± 48.88	.312
Rearfoot	364,44 ± 56,47	371.77 ± 61.54	.487	396.72 ± 61.74	399.56 ± 68.66	.542

SD: Standard Deviation, p* values obtained from the paired *t*-test.
CI: confidence interval.

affected and whether the patients had pes planus or pes cavus did not result in any differences in forefoot pressure distribution both within and between groups. In another study examining the plantar pressure distribution in different foot types in elderly individuals, it was observed that the pressure under the forefoot, 4th and 5th metatarsals of the patients with a supinated foot was significantly higher than in the pronated group [31]. Therefore, it was expected that Morton's neuroma in individuals with supinated foot structure would make a more significant difference. As a result of our study, MN accompanying different foot biomechanics showed similar results in forefoot pressure distribution. Furthermore, there was no difference between feet with and without MN in within groups. Accordingly, MN seen in both foot postures has a similar effect regardless of foot type. Hovewer, in our study, the sole of the foot was evaluated only as forefoot, midfoot and hindfoot. We think that further studies are needed by dividing the sole of the foot into more regions to evaluate foot posture for MN.

The gait kinematics and spatiotemporal parameters of healthy individuals with high, low and normal arch indexes displayed similarity [32]. It has been reported that step length is correlated with foot structure and it has been emphasized that this correlation is related to age and height [32]. In our study, the age factor was ruled out by matching the patients in both groups. Since height was homogeneously distributed between the groups, having MN accompanying pes planus or pes cavus did not lead to an atypical gait pattern in terms of step length.

During walking, medial longitudinal arch collapses in the first part of the stance phase and provides compliant structure. Thus, the forefoot remains stable through the midstance phase. During the late stance phase, the metatarsal arch and medial longitudinal arch restore their position, and the mediolateral metatarsal height increases to its maximum value. Abduction and eversion occur in the medial forefoot, while adduction and inversion occur in the lateral forefoot [33]. Duerincket et al. reported that the changes in mediolateral metatarsal height were strongly correlated with forefoot pressure through the final propulsion phase. Pressure under the second and thirth metatarse heads coincided with an increase of mediolateral metatarsal height [34]. In our study, total stance and midstance phase percentages decreased in the pes cavus group. As it is well-known, the mediolateral metatarsofalangial height is higher in pes cavus than pes planus. Therefore, the forefoot pressure of a supinated foot is more than that of a pronated foot from midstance to pressing phase. Stance phase may be shorter and swing phase could be longer in the pes cavus group to avoid the forefoot pressure. Increased lateral forefoot pressure also prolongs the step time in the foot with MN, as shown in our study. The lack of any significant differences in spatiotemporal gait parameters and plantar pressure distribution in individuals with MN, regardless of foot posture, may be a new finding that may guide the conservative treatment of MN.

Although the current literature primarily focuses on non-invasive treatment modalities such as orthotics, low heeled footwear, metatarsal padding, and manipulation-mobilisation, there are few randomized controlled studies on this subject [35,36].

Killmartin et al. have used supination and protonation foot wedges in patients with MN and found no difference in pain and lower extremity functionality between the two groups [37]. Orthotic approaches applied considering the foot type change the kinematics, kinetics, plantar pressure, and muscle activity of the foot [35]. In our study, since MN accompanying different foot types did not show any difference in plantar pressure and gait parameters, our results support the study because while the subtalar joint was forced into supination or protonation, it did not cause differences with patients with MN. Instead of non-invasive approaches which may disrupt foot biomechanics and gait patterns, local approaches should be used to reduce the effects of MN. Since the complication ratio of local applications is very low, it can be preferred in the restoration of possible gait disorders due to MN [38].

This study has some limitations. The diagnosis of MN was confirmed with clinical evaluation by an experienced orthopedic surgeon and MRI. In previous studies, the validity of ultrasound in the diagnosis of MN was reported to be high [39,40]. Additionally, the classification of the foot types of the patients could be supported by a more quantitative value such as the Foot Print Index. Objective evaluations that determine the foot type can be added in addition to clinical and radiographic evaluations to minimize the margin of error in future studies. Finally, a group of individuals with neutral foot structure could be added to the study so the predisposing effect of foot type to MN could be further clarified. It would be more useful for future studies to consider these limitations.

5. Conclusion

Our study showed that there are no differences in the spatiotemporal gait parameters and foot-pressure distribution of patients with MN in the supinated or pronated foot structure, except for midfoot force. In addition, a decreased stance phase, increased swing phase, and step time were seen in pes cavus foot with MN. Therefore, it will be more effective to focus only on interventions to reduce the symptoms of MN rather than approaches to change the foot biomechanics of patients. However, MN affects spatiotemporal gait parameters of patients with pes cavus more than patients with pes planus compared to an asymptomatic foot. Gait synchronization may be impaired in the supinated foot, which should be considered for clinical assessment.

Author contribution statement

1) Conceived and designed the experiments; Özlem Feyzioğlu.
2) Performed the experiments; Özlem Feyzioğlu, Selim Muğrabi.
3) Analyzed and interpreted the data; Özgül Öztürk.
4) Contributed reagents, materials, analysis tools or data; Selim Muğrabi.
5) Wrote the paper, Özlem Feyzioğlu.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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