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Biomechanical Evaluation of Morton's Toe Effects on Plantar Pressure Distribution during Gait: A Preliminary Cross-Sectional Study

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Original Article

Abstract

Introduction: The foot's anatomical structure, particularly the toes, plays a crucial role in distributing forces and pressures on the sole. Morton's toe, a condition where the second toe is longer than the first, is a notable morphological feature that can impact foot stability and increase the risk of walking-related injuries. This study investigated the biomechanical effects of Morton's toe on plantar pressure during walking.

Materials and Methods: Thirty-two students from Tabriz University of Medical Sciences, Tabriz, Iran, were examined in two groups of 16 (Morton's foot and normal). The emed C50 plantar pressure measurement platform was used to record the data. The variables investigated included peak pressure, contact area, contact time, and pressure-time integral in 10 anatomical regions of the plantar foot.

Results: In individuals with Morton's foot, the peak pressure and pressure-time integral in the lateral midfoot region were higher than those in the normal group (P = 0.032 and P = 0.041, respectively). These values also showed a significant increase at the second metatarsal head (P = 0.002 and P = 0.004) and the third metatarsal head (P = 0.011 and P = 0.003). Additionally, the contact area at the second metatarsal was significantly increased (P = 0.028). In contrast, the peak pressure, contact area, and pressure-time integral in the hallux region decreased in the Morton's foot group (P = 0.014, P = 0.009, and P = 0.001, respectively). Furthermore, the peak pressure at the first metatarsal also decreased (P = 0.021). A significant reduction in the pressure-time integral was also observed at the fourth metatarsal (P = 0.019). Furthermore, in the second to fifth toes region, the peak pressure and pressure-time integral were significantly higher in the Morton's foot group (P = 0.025 and P = 0.033, respectively).

Conclusion: These findings suggest that Morton's foot alters plantar pressure distribution, potentially increasing the risk of musculoskeletal injuries. The study underscores the importance of designing appropriate footwear and using customized orthotic interventions to reduce pressure and improve foot function in individuals with Morton's toe.

Keywords: Morton's toe; Pressure distribution; Second metatarsal; Foot biomechanics; Gait

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Introduction

Considered one of the most complex yet natural human motor functions, walking requires precise coordination among the musculoskeletal system, the nervous system, and the body's biomechanical mechanisms (1). This function can serve as a key indicator for

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evaluating movement patterns and preventing lower limb injuries (2). Therefore, the anatomical structure of the foot, particularly the toe region, plays a decisive role in regulating and distributing forces applied to the foot sole (3).

One notable morphological feature of this function is the condition known as "Morton's toe", i.e., a situation where the second toe is longer than the big toe (first toe) (4, 5). Studies estimate that nearly 22% of the population shows this structural characteristic (6). This condition can change body weight distribution, reduce dynamic stability, and decrease motor function efficiency. Research has shown that individuals with Morton's toe typically experience greater pressure on the forefoot, especially on the head of the second metatarsal. This condition is associated with an increased likelihood of developing certain disorders, such as metatarsalgia and changes in the metatarsophalangeal joints (7, 8).

Regarding the biomechanical assessment of walking, plantar pressure distribution is one of the most important indicators, providing detailed and practical information on force transfer patterns and the movement of the center of pressure (9). Various variables, such as peak pressure, contact area, contact duration, and the pressure-time integral, are among the most critical mechanical parameters for examining foot loading patterns (10, 11). Increased peak pressure in the forefoot regions may indicate excessive loading and potential risk of local injury (12). Changes in the foot contact area with the ground can also signify abnormal movement patterns (13). Furthermore, evidence suggests that individuals with Morton's toe bear more pressure under the second metatarsal head, especially when wearing inappropriate footwear such as high heels (8).

Contact duration indicates the time length each area of the foot is in contact with the ground. This parameter influences how forces are transferred during different phases of gait. It can play an effective role in reducing or increasing movement stability (11, 14). Additionally, the pressure-time integral, calculated as the product of pressure intensity and contact time, represents the cumulative mechanical load on foot tissues (15). Examining these variables can provide a deeper insight into the impacts of Morton's toe on foot biomechanics.

Previous research findings have also shown that structural differences in toes, particularly in Morton's foot, can significantly alter plantar pressure distribution patterns (16, 17). Individuals with this morphological feature are more susceptible to certain abnormalities, such as hammer toe, calluses, and joint disorders, than others (18, 19). Some studies have even reported a maximum pressure increase of 30% in the second metatarsal region, and these pressure changes not only raise the risk of musculoskeletal injuries but also alter the force balance and cause displacement in the center of pressure (20).

Results from more recent research also suggest that load transfer to the distal parts of the foot occurs more rapidly in Morton's foot. It is a condition that increases pressure on the second toe, reduces dynamic stability, and consequently leads to a higher risk of overuse injuries (7, 21). While extensive research highlights Morton's foot as a factor in increasing pressure and chronic mechanical loading in these regions, empirical findings regarding specific changes in peak pressure and contact area remain inconsistent and controversial (10). However, these changes can also affect kinetic variables pertinent to motor function, including joint moments and ground reaction forces (22).

Despite existing studies, significant ambiguity remains regarding the precise mechanism by which Morton's toe influences gait biomechanics. One significant gap in this field is the lack of studies that control for confounding variables (e.g., body mass index, step cadence, ankle range of motion, and standing heel angle) to analyze the impact of this trait more accurately. Furthermore, most existing research has reported plantar pressure without distinguishing between Morton's and non-Morton's feet. By controlling for the aforementioned variables, the present study addresses this gap in the literature, seeking to elucidate the biomechanical differences between individuals with Morton's toe and those with normal foot morphology. The results of this research could be useful in preventing foot injuries, designing appropriate footwear, and developing biomechanical screening plans.

Materials and Methods

This study employed an applied cross-sectional, quasi-experimental design. The statistical population comprised male and female students from Tabriz University of Medical Sciences. Based on a power analysis using G*Power software (version 3.1.5, University of Düsseldorf, Germany), a sample size was determined for an independent t-test, assuming an effect size of 0.9, a significance level (α) of 0.05, and a statistical power (1-β) of 0.8. A total of 32 participants were recruited, consisting of 16 individuals with Morton's toe and 16 with a normal foot pattern (23). While a convenience and purposive sampling method was employed, stringent inclusion and exclusion criteria were implemented to mitigate potential sampling bias and ensure the homogeneity of the groups.

Clinical examination and physical assessments were conducted to identify individuals with Morton's foot. In this process, individuals whose second toe was 0.8 centimeters longer than the first toe were identified as having Morton's foot (Figure 1). Additionally, the length difference between the head of the first and second metatarsals was measured within the range of 0.8 to 2.8 centimeters (8). If necessary, foot radiography was performed to confirm the diagnosis.

Figure 1. Morton's toe view on the emed platform

The research inclusion criteria encompassed being male or female, having no congenital diseases or specific problems in the foot, showing no history of diseases affecting skeletal disorders, having no history of serious injuries (such as accidents, falls, or severe impacts), having no history of surgery in the foot area, being aged 18 to 30 years, and showing willingness to participate in the study. Participants were eligible if they had either healthy foot morphology (control group) or Morton's toe, defined as the second toe being at least 8 millimeters longer than the first. Exclusion criteria consisted of any history of surgery or injury to the trunk and lower limbs within the past year, or the presence of any musculoskeletal abnormalities that could interfere with the gait analysis.

The emed C50 plantar pressure measurement platform, developed by Novel GmbH (Munich, Germany), was used to record and analyze data. This platform has a sensor surface measuring 475 mm × 320 mm with 6080 sensors and a resolution of four sensors per square centimeter. Upon the application of force, the platform's sensors are activated, capturing the pressure distribution data, which is then transmitted to the software for analysis. The validity, reliability, and accuracy of this system have been previously established (24, 25). Before the test, the research procedure was fully explained to the participants, and they were asked to complete a consent form. They were also assured that their information would remain confidential and that they were permitted to withdraw from the study at any stage of the research. This study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee of Tabriz University of Medical Sciences. Participants completed a medical questionnaire and provided their written consent. None of the participants withdrew from the study.

The experiment was conducted over two consecutive days in the motion analysis laboratory of the Tabriz University of Medical Sciences Faculty of Rehabilitation. After their consent forms were obtained, participants were examined under controlled laboratory conditions. Their height and weight were recorded using a stadiometer and a digital scale. The emed platform was placed in the center of a 10-meter walkway, and the surface of the walkway was adjusted to minimize step variations (26). The device was calibrated according to the manufacturer's instructions. First, participants had five minutes to become accustomed to the test conditions. In the main test, participants stood two steps behind the platform and then walked barefoot across the platform at a speed between 1.6 and 2 meters per second. This speed was relatively brisk; however, most participants described it as normal. A metronome was utilized to control the speed. The starting position was adjusted so that the first step would be taken with the non-dominant foot and the second step with the dominant foot, which was recorded on the device (27). The dominant foot was determined using the ball kick test (28). Participants focused on a fixed point in front of them to avoid altering their gait pattern. Only trials in which participants achieved a natural foot strike on the center of the platform—without altering their habitual gait pattern—were included for analysis. A 30-second rest interval was provided between successive trials, and the mean of five successful repetitions was calculated for each participant (29).

For plantar pressure data analysis, multi-mask software (Novel GmbH, Munich, Germany) was used. The foot area was then divided in the emed Auto Mask software into 10 anatomical regions, as shown in Figure 2, which included the heel, medial midfoot, lateral midfoot, first to fifth metatarsals, hallux, and second to fifth toes (30). For each region, the mean peak pressure (kilopascals), contact area (square centimeters), contact duration (milliseconds), and pressure-time integral (Newton-seconds) were calculated.

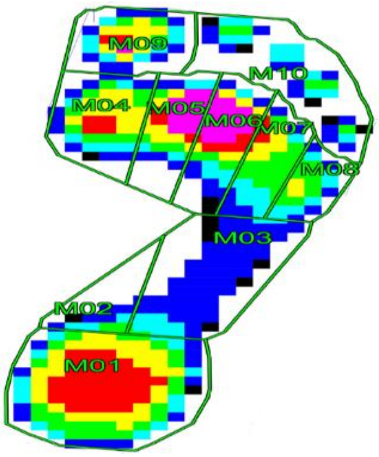

Figure 2. Different parts of the foot are based on the PRC mask method M01: heel, M02: medial-middle foot, M03: lateral-middle foot, M04: lateral-middle foot, M04: metatarsal 1, M05: metatarsal 2, M06: metatarsal 3, M07: metatarsal 4, M08: metatarsal 5, M09: first toe, M10: second to fifth toes.

The statistical analysis was conducted in SPSS (IBM SPSS Statistics, Version 24.0; IBM Corp., USA). The mean and standard deviation were used for data description. The Shapiro–Wilk test was used to examine the normality of data distribution. The results confirmed the normality of all parameters. The actual power of the study was calculated using the post-hoc power analysis in G-Power (G-Power 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Germany) based on the actual data for each variable. Differences between the two groups were examined regarding demographic characteristics, including age, sex, height, weight, body mass index, and foot arch index. The independent t-test was conducted to analyze data and demographic characteristics between the two groups. Furthermore, a statistical significance level of 0.05 was considered. Additionally, sex differences between groups were evaluated using the chi-square test.

Results

Table 1 presents the mean and standard deviation of the demographic characteristics of the participants. The results indicated that there were no significant differences between the two groups in any of these demographic characteristics (P > 0.05). Additionally, the feet of each group were classified using the first and third quartiles into high arch (0.11-0.21), normal arch (0.22-0.24), and flat arch (0.25-0.32) (8). A similar distribution of arch indices was evident between the groups, and the means did not differ significantly.

Significant differences were observed between the Morton's toe group and the control group in two primary variables. First, the length difference between the second and first toes was statistically significant; in the control group, the second toe was 0.8 cm shorter than the first, whereas in the Morton's group, it was 0.3 cm longer. Second, the metatarsal protrusion distance showed a significant discrepancy: the second metatarsal head was 0.4 cm shorter than the first in the control group, compared to 1.7 cm longer in the Morton's group.

The results of the independent t-test (Table 2) showed that there were no significant differences in some areas of the foot between the Morton's foot group and the normal group (P > 0.05).

Table 1. Comparing the demographic characteristics of the participants

Variable	Group Morton's Foot	Group Healthy Control	P-value
Age (Years) (mean ± SD)	27.9 ± 8.5	27.8 ± 9.9	0.955
Gender (Male) [n (%)]	9 (44%)	8 (50%)	0.781
Height (cm) (mean ± SD)	168.9 ± 8.6	167.6 ± 6.8	0.648
Weight (kg) (mean ± SD)	61.2 ± 12.5	64.4 ± 13.4	0.390
Body Mass Index (kg/m²) (mean ± SD)	22.1 ± 2.1	22.9 ± 3.2	0.324
Arch Index (cm) (mean ± SD)	0.24 ± 0.02	0.24 ± 0.03	0.950
Difference in length between the second and first Toe (cm) (mean ± SD)	0.3 ± 0.3	-0.8 ± 0.5	0.001*
Difference Length in Head of Second and First Metatarsal (cm) (mean ± SD)	1.7 ± 0.5	-0.4 ± 0.3	≤ 0.001*
Heel angle in standing position (mean ± SD)	6.8 ± 4.1	6.1 ± 3.7	0.615
Plantar-Dorsiflexion Range (mean ± SD)	58.4 ± 2.8	55.8 ± 9.8	0.315
Inversion-Eversion (mean ± SD)	29.5 ± 7.3	29.25 ± 5.7	0.914

*Significant difference at the 0.05 level

Table 2. Comparing the peak pressure, contact area, contact time, pressure-time integral in 10 different areas of the foot and the entire foot between the two groups

Region	Peak Pressure (kPa)	Contact Area (cm²)	Contact Time (ms)	Pressure-Time Integral (N.s)
Heel				
Group Morton's Foot	329.9 ± 146.7	33.6 ± 4.4	469.0 ± 94.0	154.7 ± 43.2
Group Normal	345.6 ± 89.2	32.6 ± 5.1	472.6 ± 76.6	163.3 ± 28.7
Medial Midfoot				
Group Morton's Foot	133.7 ± 44.1	5.9 ± 4.7	390.3 ± 93.5	52.2 ± 14.8
Group Normal	118.5 ± 30.7	7.8 ± 8.4	408.4 ± 98.0	48.4 ± 13.0
Lateral Midfoot				
Group Morton's Foot	174.8 ± 59.9*	22.2 ± 8.3	507.4 ± 106.5	88.7 ± 26.5*
Group Normal	126.5 ± 32.4	22.0 ± 8.4	509.8 ± 113.4	64.5 ± 17.3
First Metatarsal				
Group Morton's Foot	290.4 ± 121.0*	11.1 ± 4.3	617.8 ± 96.8	179.4 ± 112.4
Group Normal	364.4 ± 165.1	13.8 ± 4.6	632.5 ± 102.3	230.5 ± 45.9
Second Metatarsal				
Group Morton's Foot	722.5 ± 212.7*	12.6 ± 3.6*	676.1 ± 106.9	488.4 ± 78.1*
Group Normal	539.8 ± 229.2	10.5 ± 4.0	629.3 ± 53.9	339.5 ± 65.7
Third Metatarsal				
Group Morton's Foot	612.4 ± 142.5*	11.9 ± 3.4	657.1 ± 102.6	402.3 ± 43.9*
Group Normal	453.4 ± 203.7	12.3 ± 3.8	690.1 ± 111.9	312.8 ± 58.6
Fourth Metatarsal				
Group Morton's Foot	342.3 ± 118.7	10.5 ± 3.3	644.8 ± 98.4	220.6 ± 40.6*
Group Normal	382.9 ± 123.0	10.8 ± 3.3	671.6 ± 112.7	257.3 ± 39.0
Fifth Metatarsal				
Group Morton's Foot	232.9 ± 214.8	7.5 ± 2.9	607.1 ± 103.5	141.4 ± 81.9
Group Normal	253.7 ± 156.9	6.9 ± 2.8	598.5 ± 142.0	151.9 ± 41.1
Hallux (Big Toe)				
Group Morton's Foot	406.6 ± 56.6*	8.3 ± 2.5*	534.8 ± 97.6	217.12 ± 10.9*
Group Normal	532.1 ± 256.8	13.0 ± 3.9	552.3 ± 151.4	293.91 ± 83.2
Toes 2–5				
Group Morton's Foot	222.6 ± 111.2*	12.0 ± 5.2	510.5 ± 170.4	113.58 ± 33.2*
Group Normal	161.9 ± 86.1	10.6 ± 5.9	495.1 ± 167.8	80.19 ± 33.5
Whole Foot				
Group Morton's Foot	366.7 ± 225.64	135.9 ± 9.09	511.9 ± 207.24	254.8 ± 138.09
Group Normal	327.88 ± 215.13	140.3 ± 9.08	566.2 ± 145.67	260.5 ± 130.76

*Significant difference at the 0.05 level

In the lateral midfoot, the peak pressure and the pressure-time integral were significantly higher in the Morton's foot group than in the healthy group ($P < 0.05$). In the first metatarsal, the peak pressure was reported to be significantly lower in the Morton's foot group than in the healthy group ($P < 0.05$).

In the second metatarsal, participants in the Morton's foot group experienced higher peak pressure, and the contact area and pressure-time integral were significantly greater in this group than in the healthy group ($P < 0.05$).

In the third metatarsal, peak pressure and pressure-time integral were reported to be significantly higher in the Morton's foot group than in the healthy group ($P < 0.05$). However, at the fourth metatarsal, the pressure-time integral was recorded to be lower in the Morton's foot group than in the healthy group ($P < 0.05$).

In the hallux, peak pressure, contact area, and pressure-time integral were significantly higher in the healthy group than in the Morton's foot group ($P < 0.05$). Furthermore, in the second to fifth toes, participants in the Morton's foot group experienced higher peak pressure and pressure-time integral than the participants in the healthy group ($P < 0.05$).

As illustrated in Figure 3, Morton's toe group exhibited significantly higher peak plantar pressure in the metatarsal, hallux, and midfoot regions compared to the control group. These findings suggest an asymmetric pressure distribution resulting from structural foot variations. Conversely, no significant differences were observed in the heel and lateral midfoot regions between the two groups.

According to Figure 4 and its visual representation, in the hallux region, the Morton's foot group had a lower contact area than the control group, whereas, in the second metatarsal region, this pattern was reversed. These differences are statistically significant.

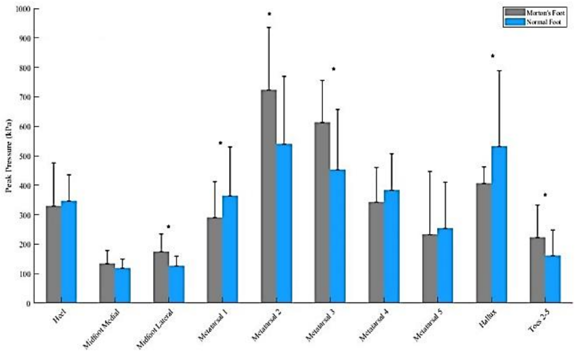

Figure 3. The comparison chart of the peak pressure in different areas of the foot between the Morton's foot group and the control group

*Existence of a significant difference

In other areas of the sole, no significant differences were observed between the two groups.

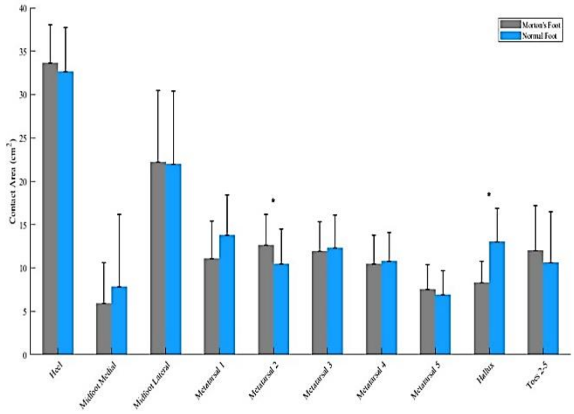

Figure 4. The comparison chart of the contact area in different areas of the foot between the Morton's foot group and the control group

*Existence of a significant difference

According to Figure 5 and its visual representation, no significant differences in contact time were observed in any area of the sole between the Morton's foot group and the control group. In other words, the temporal pattern of foot contact with the ground was approximately similar in both groups, and structural variations caused by Morton's foot had no significant effects on this variable.

According to Figure 6 and its visual representation, a significant difference was observed in the pressure-time integral between the two groups in several areas, with the greatest variation related to the second metatarsal region. In this region, the Morton's foot group had a higher pressure-time integral than the control group.

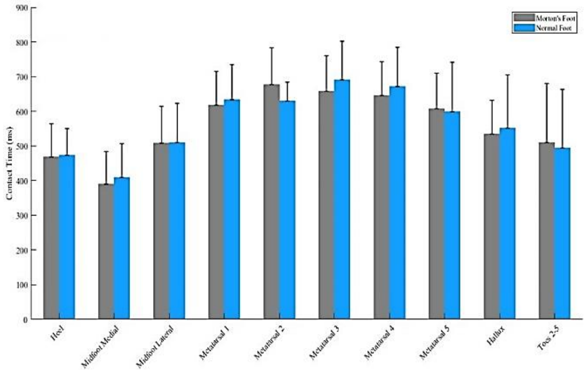

Figure 5. The comparison chart of the contact time in different areas of the foot between the Morton's foot group and the control group

*Existence of a significant difference

Other areas where significant differences were seen also indicated the effect of Morton's foot structure on pressure distribution over time.

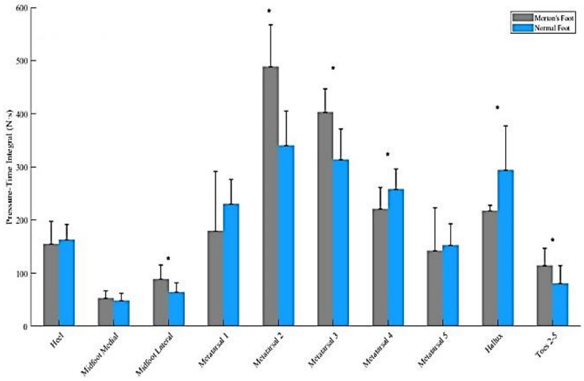

Figure 6. Comparing the chart of pressure-time integral in different areas of the foot between the Morton's foot group and the control group

*Existence of a significant difference

The post-hoc power analysis showed that the sample size was sufficient for most variables (power>0.8), although further studies with larger sample sizes should be conducted on other variables such as first metatarsal peak pressure (power=0.29, minimum suggested sample size 52 people per group), second metatarsal contact area (power=0.33, minimum suggested sample size 48 people per group), hallux peak pressure (power=0.46, minimum suggested sample size 38 people per group), and second to fifth toes peak pressure (power=0.39, minimum suggested sample size 42 people per group).

Discussion

The findings of this study demonstrate that the morphological characteristics of Morton's toe significantly influence plantar pressure distribution patterns during gait. Specifically, pressure profiles in these individuals deviated from normative patterns, characterized by a heightened force concentration on the forefoot, particularly at the second metatarsal head. These results suggest that subtle anatomical variations—such as a shortened first metatarsal or an elongated second toe—can lead to substantial functional alterations within the lower extremity kinetic chain."

Lateral Midfoot

In the lateral midfoot region, peak pressure and pressure-time integral were significantly higher in the Morton's foot group than in the healthy group. This finding is consistent with studies showing that individuals with Morton's toe tend to transfer more weight to the distal and lateral areas of the foot, a case which can be due to the displacement of the center of pressure and acceleration of weight transfer forward, consequently reducing dynamic stability (31, 32). Furthermore, these results align with evidence that reported an association between Morton's toe and variations in foot stability and pressure distribution (33, 34).

The increased pressure in this area may act as a compensatory mechanism to maintain lateral balance, especially when the longer second toe shifts the center of pressure outward. Under these conditions, the body attempts to maintain stability and prevent excessive deviation by increasing pressure on the lateral border of the foot (31). This condition can increase the risk of injuries such as ankle sprains or peroneal tendinitis (32).

However, some studies have presented different results. For instance, Vanderlich and Kavanagh (35) showed that factors such as foot arch, weight, gender, and overall foot structure might have a greater impact on pressure distribution than the length of the second toe. These inconsistencies are probably due to differences in methodology, type of samples, and lack of control for confounding variables.

First Metatarsal

An important finding of this study was a significant reduction in peak pressure in the first metatarsal region in individuals with Morton's toe compared to the healthy group. This finding is consistent with the hypothesis that a longer second toe can reduce the pressure on the first metatarsal and alter the weight distribution pattern of the foot. Such a change may be associated with clinical outcomes such as an increased risk of deformities like hallux valgus or other structural disorders (36).

Since the first metatarsal plays a key role in the propulsive phase of walking, reduced load in this area can decrease biomechanical efficiency and increase fatigue during movement (32). In this condition, compensatory force transfer to other parts of the foot may disrupt movement balance and, in the long term, cause secondary injuries in the knee or hip (36).

However, some research has presented contradictory results. For example, Krauss et al. (33) did not report a significant difference in pressure under the first metatarsal between the examined groups. This inconsistency may be related to certain confounding factors such as differences in measurement methods, demographic characteristics, type of footwear, and gait pattern (35).

Second and Third Metatarsals

In the second and third metatarsal regions, a significant increase was observed in peak pressure, pressure-time integral, and contact area in the Morton's foot group. This finding indicates a shift in the loading pattern from the first metatarsal towards the central parts of the foot, which probably occurs due to the greater length of the second toe and a change in the foot's center of pressure. This shift can increase dynamic pressures in the terminal stance phase and strengthen the pivotal role of the second metatarsal in maintaining balance along movement axes (4, 8, 37).

Previous studies also reported that the increased length of the second metatarsal was associated with higher peak pressure and pressure-time integral in this area (38). Moreover, Wearing et al. (39) indicated that the second and third metatarsals correlated with each other in terms of time to reach maximum force.

However, Naraghi et al. (40), in their study of individuals with Morton's neuroma, did not find a significant difference between the second and third metatarsal pressure regions. This inconsistency may be related to differences in the target population (anatomical feature versus neurological disease), measurement methods, and control of confounding variables such as weight, gender, and gait pattern.

Another important finding of this study was the increase in the plantar contact area in the Morton's group. This change can be interpreted as a compensatory mechanism for more uniform force distribution to prevent increased point stress. Evidence shows that in anatomical disorders such as increased metatarsal length or flat foot, the body prevents pressure concentration at a specific point by expanding the contact area in the forefoot region (4, 41).

However, the increased contact area is not always a sign of favorable adaptation. In some cases, this condition can lead to ineffective pressure distribution and chronic loading of the forefoot structures, which is ultimately associated with certain outcomes such as metatarsalgia, chronic pain, and pathological changes (12, 42). Therefore, the findings of this study underscore the importance of implementing corrective and preventive strategies for individuals with Morton's toe to mitigate the risk of associated pathologies."

Fourth Metatarsal

In the fourth metatarsal region, a significant decrease in the pressure-time integral was observed in the Morton's foot group compared to healthy individuals, indicating a change in the foot loading pattern. This decrease is probably due to the displacement of the center of pressure towards the more anterior parts of the foot and concentration of force in the more medial metatarsals, especially the second and third. This pattern was also confirmed by other findings of this study (34).

Under normal conditions, plantar pressure is distributed in a balanced manner among the metatarsals, and the fourth metatarsal plays a pivotal role in maintaining the transverse balance of the foot (3). However, in individuals with Morton's toe, decreased pressure in this area may be considered an adaptive mechanism in response to increased load on the more medial metatarsals. Therefore, the contribution of the lateral areas of the foot, including the fourth and fifth metatarsals, to force absorption decreases, and additional load is transferred to the more central areas.

This finding is consistent with studies showing that individuals with Morton's foot tend to transfer more weight to the distal and lateral areas of the foot (34). Such a distribution pattern can cause loading imbalance, increase the risk of overuse injuries, and result in other disorders such as metatarsalgia, inflammation of the metatarsophalangeal joint, and changes in the longitudinal arch of the foot (15, 16). Furthermore, reduced load on the fourth metatarsal may be a sign of the diminished role of this area in normal foot mechanics. This condition can weaken dynamic stability and cause compensatory strategies in walking.

Hallux

In the hallux region, a significant decrease in peak pressure, contact area, and pressure-time integral was observed in the Morton's foot group compared to the healthy group. This decrease is probably due to load transfer to other areas, especially the second and third metatarsals, and reduced active participation of the hallux in the gait cycle. The lower contact area indicates more limited interaction of this toe with the ground surface, and the reduction in pressure-time integral also shows a shorter duration of force application in this area. Given the key role of the hallux in the propulsive phase, these changes can decrease the biomechanical performance of the foot, reduce movement efficiency, and increase muscle fatigue. In the long term, the probability of structural or functional abnormalities will also increase. Previous studies have also reported reduced loading in the hallux region in individuals with Morton's foot (43, 44). Some research links this change to disorders such as hallux valgus or the reduced function of the first metatarsal. However, contradictory results also exist. For instance, Krauss et al. (33) did not report a significant difference in pressure under the hallux between groups. This inconsistency may be related to differences in the foot arch, lifestyle, or the use of different footwear (32). In summary, the findings of this study suggest that reduced pressure and loading time on the hallux in individuals with Morton's toe may indicate a compensatory pattern in walking that can have significant functional and clinical outcomes.

Second to Fifth Toes

In the second to fifth toes, a significant increase in peak pressure and pressure-time integral was observed in the Morton's foot group compared to the healthy group. This finding is probably due to the reduced supportive role of the first metatarsal and the displacement of the center of pressure towards the more anterior areas of the foot. In this condition, greater mechanical load is exerted on the lateral toes, which can increase tissue stress and cause pain or chronic injuries in these areas.

Kugler et al. (45) and Xiang Geng (46) have also reported that the shortness of the first metatarsal can cause load transfer to the second to fifth toes and increase pressure in these parts. These biomechanical changes may, in the long term, predispose individuals to certain abnormalities such as metatarsal pain, toe joint inflammation, and disruption of normal gait function.

However, some evidence does not align with these findings. For instance, Hoy et al. (47) reported that performing regular sports activities could improve pressure distribution in the foot and prevent the excessive concentration of force in specific areas. These inconsistencies may arise from differences in measurement methods, characteristics of research samples, or the level of physical activity of the participants.

Limitations

Despite presenting valuable findings, this study faced some limitations that should be considered in interpreting the results and designing future research. Firstly, the relatively limited sample size and the selection of participants from a specific population (students aged 18 to 30 years at Tabriz University of

Medical Sciences) could limit the generalizability of the results to other age groups or populations. Particularly, older adults, adolescents, or children, who might have different movement patterns, were not included in this research. Secondly, the cross-sectional nature of the study prevented inferring a causal relationship between Morton's toe and biomechanical changes. Therefore, although correlations were observed, one cannot definitively comment on the causal role of these structural patterns in the occurrence of movement disorders. To overcome these limitations, future research should be conducted with a population that is a more realistic sample of the community (e.g., diverse age groups and various occupations) to enable a more in-depth analysis of the lasting effects of Morton's toe on foot health and motor function.

Recommendations

Based on the results of this research, the following research avenues are recommended: investigating the effect of Morton's toe in different age and gender groups to achieve a more accurate understanding of its prevalence and effects in various populations; using advanced imaging methods such as MRI for more precise evaluation of the structure of the metatarsal bones and its relationship with pressure distribution patterns; studying the effect of corrective interventions or specialized exercises aimed at reducing pressure in the second and third metatarsal regions; increasing the sample size and examining participants from various occupations for greater generalizability of results; and finally, using a longitudinal design to examine changes in plantar pressure over time, which could provide a more in-depth view of the trend in these changes.

Conclusion

This study showed that the structure of Morton's toe, through disrupting the normal pattern of plantar pressure distribution, could increase local pressure and reduce dynamic stability, a condition that might ultimately increase the risk of overuse injuries. These findings emphasized the importance of designing customized orthotics and footwear, especially to reduce pressure in the second metatarsal region and improve force alignment. From a clinical perspective, these results could aid in developing prevention and treatment strategies for forefoot disorders such as metatarsalgia. Regarding sports and rehabilitation, such data can also be used in designing sports shoes and training programs tailored to the structural characteristics of the foot. Finally, it is suggested that future studies with longitudinal and interventional approaches evaluate the effectiveness of these strategies in improving motor function, reducing pain, and enhancing the quality of life of individuals with Morton's foot.

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Conflict of Interest

The authors did not have a conflict of interest.

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