An observational study on the relationship between Foot posture index and lower extremity alignment in participants with asymptomatic pronated foot

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Abstract

A pronated foot is a condition in which the medial longitudinal arch (MLA) collapses or becomes lowered. Previous studies have suggested that a pronated foot may cause malalignment of the lower extremities, resulting in structural deficits during weight-bearing activities. The study aimed to observe the relationship between the Foot Posture Index (FPI-6) and lower extremity alignment in participants with asymptomatic pronated foot. Fifty feet, 25 subjects (13 women and 12 men, average age 25.08 ± 4.47 years, weight 64.65 ± 12.22 kg, height 165.01 ± 8.22 cm, and BMI 23.52 ± 3.13 kg/m^2) with asymptomatic pronated feet were included in the study. Participants with Foot Posture Index (FPI-6) scores between 6 to 12 were recruited to the study. The lower extremities were assessed with the degree of deviation of forefoot, rearfoot, 1st metatarsal dorsiflexion (1st MTP-DF), 1st hallux valgus (1st HV), Tibial torsion, Craig's test, and Q-angle by goniometer. Statistical analysis was performed with Spearman correlation to examine the relationship between the variables. The results revealed a correlation between FPI-6 with rearfoot alignment during weight-bearing *(r_s = 0.488, $p < 0.001$***)*, Q-angle *(r_s = -0.396, $p = 0.004$**)*, and Craig's test *(r_s = -0.280, $p = 0.049$*)*. No significant correlations were found in forefoot alignment, 1st MTP-DF, 1st HV, and Tibial torsion. The present study demonstrated that foot pronation is associated with alterations in lower extremity alignment, particularly in rearfoot alignment during weight-bearing, as well as changes in the Q-angle and Craig's test measures. Pronation of the foot appears to influence the alignment of the hip, knee, and ankle joints. The clinicians should be aware that when addressing biomechanical imbalances or increased risk of lower extremity injuries, foot alignment should be examined as a contributing factor.

Keywords**:** *Pronated foot; Lower extremity alignment; rearfoot; Craig's test; Q-angle; FPI-6; Foot Posture Index.*

1. Introduction

The alignment of the lower extremities plays a critical role in maintaining proper biomechanics during standing and walking. One of the components influencing lower extremeties alignment is foot posture, particularly when the foot demonstrate pronation (Murphy et al., 2003). A pronated foot is characterized by an abnormal posture involving a lowered medial longitudinal arch (MLA) and pronation at the subtalar joint, leading to increased calcaneal valgus, increased plantarflexion of talus, and reduced navicular height (Levinger et al., 2010). Several physical factors have been associated with the development of a pronated foot, including laxity of the spring ligament, elongation of the plantar fascia, tightness of the gastrocnemius and peroneal muscles, and weakness of the tibialis posterior muscle (Toullec, 2015).

Following the collapse of navicular, resulting in altered load shift more medially and unsual load distribution (Lee et al., 2015). Futhermore, the lowering of the MLA during gait activity may influence with biomechanical compensations throughout the kinetic and kinematic chain (Pimwadee Permsombat & Praneet Pensri, 2021). However the mal-alignment of foot may progress to adult-acquired flatfoot, it can elevate the risk of various lower extremity disorders, such as hallux valgus, plantar fasciitis, Achilles tendinitis, patellofemoral pain syndrome, and knee osteoarthritis (Chen et al., 2020). Furthermore, previous studies have reported a potential risk between foot pronation and low back pain (Van Boerum & Sangeorzan, 2003).

The Foot Posture Index (FPI-6) has been developed as a reliable tool to quantify foot posture in a clinical setting (Redmond et al., 2006). It provides a multi-dimensional assessment of the foot based on visual and palpatory criteria. Several studies have suggested a relationship between abnormal foot posture and changes in lower extremities alignment, including alterations in the rearfoot and forefoot angles, tibial torsion, femoral anteversion (measured by Craig's test), knee alignment in frontal plane (measured by Q-angle), and pelvic aignment (Khamis & Yizhar, 2007; Pinto et al., 2008). However,

the understanding the association between foot posture and lower extremity alignment in asymptomatic individuals is important for identifying subclinical biomechanical patterns that may predispose to future injury or dysfunction. Moreover, investigating these relationships could inform preventative strategies and early interventions in both clinical and athletic populations.

Therefore, the objective of this study was to investigate the relationship between Foot Posture Index (FPI-6) scores and lower extremity alignment measures in participants with asymptomatic pronated feet during static standing. Correlation analyses were performed to determine the strength and direction of associations between FPI scores and various lower limb alignment parameters, provide informations into the biomechanical between foot structure and posture of the lower extremities alignment.

2. Objectives

The objective of the study was to observe the relationship between Foot posture index and lower extremity alignment in participants with asymptomatic pronated foot.

3. Materials and methods

Participants

Participants with asymptomatic pronated foot and highly pronated foot were recruited for the study. The participants age ranged between 20 to 40 years. Potential participants were screened and recruited into the study if they had a Foot Posture Index (PFI-6) score from 6 to 12. Individuals were excluded if they had a previous history of traumatic lower extremity injury and body mass index over 30 kg/m^2. Furthermore, participants were excluded if they had lower extremity pain at the time during the experiment or between.

The participnats were screened by straight leg raising (SLR) test and leg length measurement. If subject was feeling painful along the sciatic nerve pathway, she/he was excluded. While the participants who had leg length difference more than 10 millimeters was excluded from the present study. All participants signed a consent form approved by the Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group of Chulalongkorn University.

Protocol

The objective and process of the study were explained by the main researcher to all participants prior to the experiment. The participants who meet the inclusion criteria were asked to fill the 3 parts of self-administered questionnaire. Part 1 required a subject to indicate his/her sex, age, weight and height. Part 2 required the subject to report his/her medical history. And, part 3 required the subject to identify physical activity level, using the Thai version of the International Physical Activity Questionnaire (IPAQ) - short form.

When the participants completed this questionaires, they will be asked to examine their foot by FPI-6. Then, the participants were assessed the Lower extremities alignment measurements.

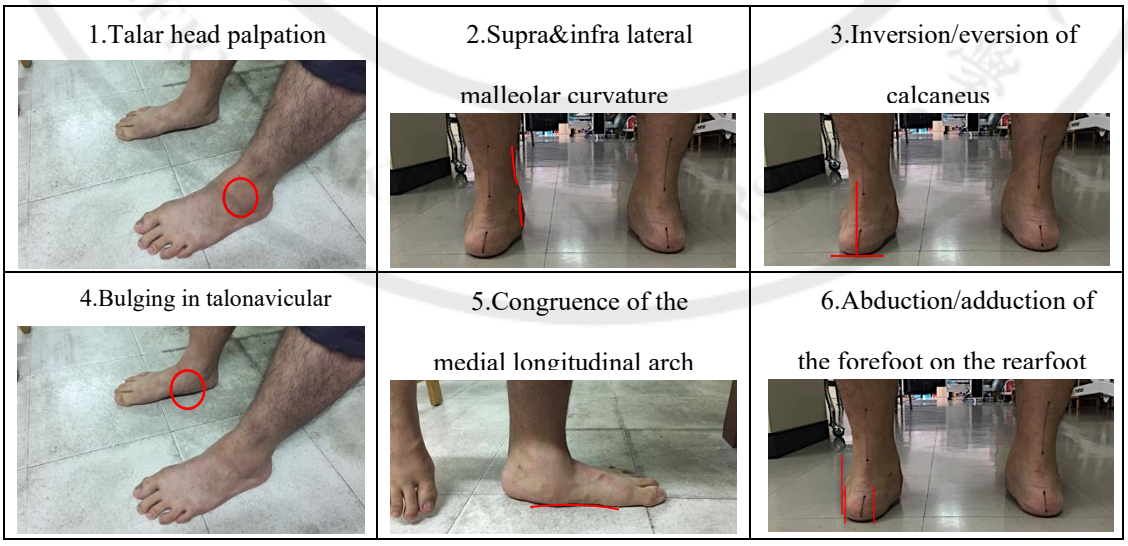


Figure 1. Foot posture index (FPI) measurement

Foot posture index (FPI-6)

The FPI-6 was developed by (Redmond et al., 2006) to classify the foot posture into normal, pronated and supinated foot. The participant was asked to march, then stand in relax position on double leg barefoot with arms by side and looking straight ahead about 2 minutes. During the assessment, the examiner observed the foot in all planes and scored the FPI-6. The examiner evaluated with the six items shown in Figure 1: 1) talar head palpation, 2) curvature at the lateral malleoli, 3) inversion/eversion of the calcaneus, 4) talonavicular bulging, 5) congruence of the medical longitudinal arch, and 6) abduction/adduction of the forefoot on the rarefoot.

Each item was graded from -2 to +2 (0 for neutral, –2 for clear signs of supination, and +2 for clearsigns of pronation), and all scores were shown in Table 1 (Lee et al., 2015). Total score from the FPI-6 was used to classify the foot posture into 5 types consisting of normal (ranged from 0 to 5), pronated (ranged from 6 to 9), highly pronated (ranged from 10 to 12), supinated (ranged from -1 to -4) and highly supinated (ranged from -5 to -12). The subject who had pronated or highly pronated foot was included into the study.

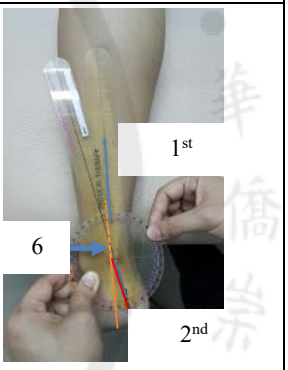
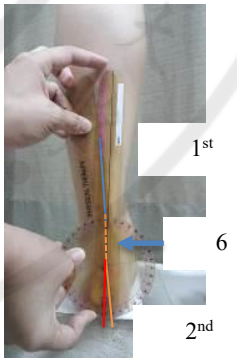
Table 1 Foot Posture Index scoring

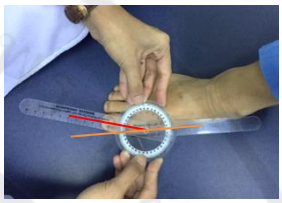
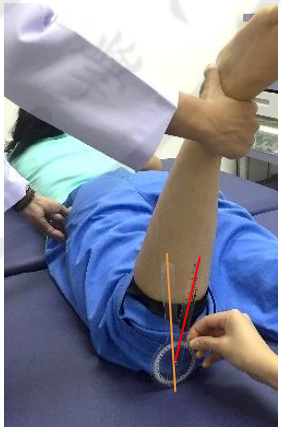
Scores	-2	-1	0	1	2
1) Talar head palpation,	Talar head palpable on lateral side /but not on medial side	Talar head palpable on lateral side /slightly palpable on medial side	Talar head equally palpable on lateral and medial side	Talar head slightly palpable on lateral side /palpable on medial side	Talar head not palpable on lateral side /but palpable on medial side
2) Curvature at the lateral malleoli	Curve below the mallolus either straight or concex	Curve below the mallolus concave, but flatter /more shallow than the curve above the malleolus	Both infra and supra mallolus curves roughly equal	Curve below the mallolus more concave than the curve above the malleolus	Curve below the mallolus Markedly more concave than the curve above the malleolus
3) Inversion/eversion of the calcaneus	More than an estimated 5° inverted (varus)	Between vertical and an estimated 5° inverted (varus)	Vertical	Between vertical and an estimated 5° everted (valgus)	More than an estimated 5° everted (valgus)
4) Talonavicular (TNJ) bulging	Area of TNJ markedly concave	Area of TNJ slightly, but definitely concave	Area of TNJ flat	Area of TNJ bulging slightly	Area of TNJ bulging markedly
5) Congruence of the medical longitudinal arch	Arch high and acutely angled towards the posterior end of the medial arch	Arch moderately high and slightly acute posteriorly	Arch height normal and concentrically curved	Arch lowered with some flattening in the central portion	Arch very low with severe flattening in the central portion high arch making ground contact
6) Abduction/ adduction of the forefoot on the rarefoot	No lateral toes visible. Medial toes clearly visible	Medial toes clearly more visibe than lateral	Medail and lateral toes equally visible	Lateral toes clearly more visibe than medial	No medial toes visible. Lateral toes clearly visible

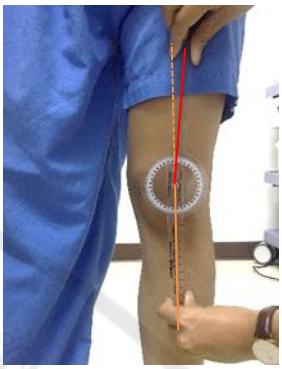
Lower extremities alignment measurements

Lower extremities alignment measurements were adopted from the clinical assessment that consisted of the measurements of the forefoot angle, rearfoot angle (non-weight and weight bearing), 1st metatarsal dorsiflexion angle (1st MTP-DF), 1st hallux valgus angle (1st HV), Tibial torsion angle, Craig's test (femoral anteversion angle), and Q-angle by goniometer (Piva et al., 2006). The average degrees calculated from two trials of each test was recorded. These tests were assessed by a trained physical therapist (PT) who was assigned to perform the specific assessment as shown in Table 2.

Table 2 Lower extremities alignment measurements

Measurements	Starting position	Passive by examiner	Goniometer
Forefoot angle (Buchanan & Davis, 2005)	Prone lying with knee extension and heel hanging off the couch	Passive the subtalar joint into neutral position.	
Rearfoot angle during non-weight bearing (Buchanan & Davis, 2005)	Prone lying with knee extension and heel hanging off the couch	Passive the subtalar joint into neutral position and created two lines, 1st line connecting two calcaneal points and 2nd line connecting two leg points.	
Rearfoot angle during weight bearing (Buchanan & Davis, 2005)	Standing position	The angle between these two lines was measured. The rearfoot angle was determined from these two lines during relaxed bilateral stance.	

Measurements	Starting position	Passive by examiner	Goniometer
1st metatarsal dorsiflexion angle (Otter et al., 2015)	Supine lying	Passive 1st metatarsal dorsiflexion.	
1st hallux valgus angle (Iliou et al., 2015)	Supine lying	The stationary arm was parallel to the first metatarsal bone, and the movable arm was parallel to the first phalange bone.	
Tibial torsion angle (Kwon et al., 2009)	Prone lying: the tested leg was positioned in 90° flexion of knee and neutral position of hip and ankle without rotation	Marking a trans-malleolar line between the medial and lateral malleolus. The angle was formed between the transmalleolar line and a perpendicular line to the long axis of femur.	
Craig's test (femoral anteversion angle) (Magee & Manske, 1992)	Prone lying: the tested leg was positioned in 90° flexion of knee and neutral position of hip and ankle without rotation	The femur was rotated internally until the greater trochanter was most prominent. The axis was placed on the middle patella; the stationary arm was in vertical line and the movable arm was parallel to the shaft of the tibia.	

Measurements	Starting position	Passive by examiner	Goniometer
Q-angle (Magee & Manske, 1992)	Standing position	The angle at the center of patella was formed between a line from ASIS and a line from tibial tuberosity.	
Stationary arm Movable arm			

The intra-tester reliability values of the trained physical therapist who was assigned to conduct the lower extremities alignment measurements was examined in 10 healthy subjects aged between 18 and 25 years before collecting data**.** All tests were conducted for 2 times within time-length interval at least 24 hours**.** The intra-class correlation coefficient **(**ICC**)** model **(**3,1**)** was then calculated. In the present study, the intra-class correlation coefficient between two repeated measurements was showed ranging from 0.908 to 0.994.

Data analysis

The data were processed using statistical analysis software. Demographic data and measurement of lower extremities alignment of the participants were presented by mean and standard deviations for numerical data. For analysis, if the data were normal distribution, the Pearson's correlation coefficient was used to determine the correlation. While the correlation between variables was assessed using Spearman's correlation coefficient due to non-normal data distribution.

The correlations between FPI-6 and the lower extremities alignments were explored by correlation analysis. Spearman's correlation coefficient was used to assess the correlations between the FPI and each variables. A p-value < 0.05 and acorrelation coefficient closer to 1 or –1 indicate a strong correlation, whereas a correlation coefficient closer to 0 indicates weak or no correlation. The data were double-entered, and the results were compared.

4. Results

Partcipant characteristics

Twenty-five adults (13 females and 12 males) with 50 feet were included in the study. The average age of the participants was 25.08 ± 4.47 years (range, 20 – 40 years), average weight was 64.65 ± 12.22 kg, average height was 165.01 ± 8.22 cm, and average BMI was 23.52 ± 3.13 kg/m^2. Mean difference in FPI-score, forefoot alignment, rearfoot alignment during non-weight bearing, 1st HV, 1st DF, and Tibial torsion. The mean FPI-score was 9.14 ± 1.40 and the alignment of lower extremities was showed in Table 3.

Table 3 Mean values of the Foot Posture Index (FPI-6) and the lower extremities.

	Mean	SD	Minimum	Maximum	Shapiro-Wilk test
FPI-score	9.14	1.40	6.00	12.00	0.014*
Forefoot	7.09	4.60	2.00	24.00	<.001*
Rearfoot	8.80	3.06	3.00	18.00	0.108
Rearfoot-NW	8.42	3.82	3.00	19.00	0.012*
1st MTP-DF	47.85	9.96	30.50	71.00	0.218
1st HV	10.13	8.46	1.50	44.00	<.001*
Tibial torsion	12.91	5.80	3.50	25.00	0.016*
Craig's test	3.56	9.71	-16.50	27.00	0.221
Q-angle	8.57	2.75	3.50	16.50	0.397

*Non-normal distribution

Correlation analysis

We performed a correlation analysis between FPI-score and the lower extremities alignment. A significant correlation was observed between the FPI-score with rearfoot alignment during weight-bearing (r_s = 0.488, p < 0.001***), Q-angle (r_s = -0.396, p = 0.004**), and Craig's test (r_s = -0.280, p = 0.049*). No correlation was detected between FPI-score with forefoot (r_s = 0.251, p = 0.079), rearfoot during non-weight bearing (r_s = -0.199, p = 0.166), 1st MTP-DF (r_s = 0.053, p = 0.715), 1st HV (r_s = 0.107, p = 0.460), and Tibial torsion (r_s = -0.178, p = 0.216). The results of the correlation analysis are shown in Table 4.

Table 4 Correlation analysis result

	FPI-score	
	Spearman's rho (r_s)	**p-value**
FPI-score	-	-
Forefoot	0.251	0.079
Rearfoot	0.488***	<.001
Rearfoot-NW	-0.199	0.166
1st MTP-DF	0.053	0.715
1st HV	0.107	0.460
Tibial torsion	-0.178	0.216
Craig's test	-0.280*	0.049
Q-angle	-0.396**	0.004

Values are presented as correlation coefficient between the Foot Posture Index and other variables; Spearman correlation matrix, rearfoot alignment, Craig's test, and Q-angle.
* p < .05, ** p < .01, *** p < .001.

5. Discussion

In this study, three lower extremity alignment measurements related to the Foot Posture Index (FPI-6) scores. The results were demonstrated that individuals with asymptomatic pronated foot shown significant correlations between Foot Posture Index (FPI-6) scores and lower extremity alignment measurements, particularly rearfoot alignment during weight-bearing, Craig's test for femoral anteversion,

and the Q-angle. There were significant ($P < .05$) correlations among all of the lower extremity alignment measurements that was shown in Table 4.

The result of this study was supported the notion that abnormal foot posture, even in the absence of symptoms, can influence the alignment of proximal joints through alterations in the kinetic chain. Specifically, the strong correlation between FPI scores and rearfoot alignment suggests that calcaneal valgus positioning may play a crucial role in the increasing of compensatory changes at the level of the tibia and femur. Consequently, the calcanues valgus or eversion position was indicating that pronation of the foot can influence subtalar joint mechanics and subsequently alter rearfoot alignment under loading.

These findings are consistent with previous literature suggesting that excessive foot pronation able to affect to biomechanical disturbances proximally, affecting knee and hip joint alignment (Levinger et al., 2010; Redmond et al., 2006). Similarly with Tateuchi, 2011 was demonstarted that eversion of calcaneus affects the three-dimensional kinematics of the thorax through the hip joint (Tateuchi et al., 2011).

Additionally, the significant relationship with Craig's test implies that pronated foot posture may be related with internal rotational changes at the hip, likely as a compensatory mechanism to maintain stability during static standing. The internal rotation of femur may contribute to altered weight distribution more medially, so the tibia was posibly to internal rotation by the rotate of femur bone. Ohi et al. and Chen et al. demonstrated that the correlation between pronated foot and knee valgus alignment(Ohi et al., 2017) . There were

Accordingly, the observed correlation between FPI and Q-angle indicates that pronated foot may contribute to altered frontal plane knee alignment, potentially increasing the knee valgus. An increased Q-angle is commonly associated with altered patellofemoral mechanics, potentially predisposing individuals to future knee pathologies even in the absence of current symptoms. Similarly with the previous study, Letafatkar et al. shown that there was significant relationship between Q-angle increasing in dominant leg and flat foot deformity (Letafatkar et al., 2013).

Meanwhile, Cebulski-Delebarre et al. found that no rotational abnormalities of the lower extremities in adult patients with primary symptomatic flat foot (Cebulski-Delebarre et al., 2016). Their purpose was to identify rotational abnormalities of the lower limb in adult with primary flatfoot by radiographs and measurements hip and knee rotations. This differs from the present study, which investigated correlations between foot posture and static lower limb alignment in asymptomatic individuals using non-radiographic clinical assessments.

The results of this study emphasize the clinical importance of assessing foot posture in asymptomatic individuals. Although participants did not present with any clinical symptoms, the presence of biomechanical deviations suggests a potential predisposition to future musculoskeletal disorders. The screening of foot posture using the FPI-6 may help identify individuals at risk of developing lower extremity injuries. Particularly, interventions aimed at improving rearfoot alignment and addressing proximal compensation patterns may play a critical role in injury prevention strategies.

The limitation of this study is the absence of a comparison group with normal foot posture and the lack of assessment of dynamic alignment during walking or running. These factors are important for understanding the broader biomechanical implications of foot posture. To enhance the predictive value of foot posture assessment for injury risk, future studies should include participants with lower extremity pathologies to examine the relationship between Foot Posture Index (FPI) scores and symptomatic conditions. Longitudinal research is also warranted to explore how abnormal foot posture influences lower limb kinematics and injury development over time. Additionally, evaluating the effects of interventions targeting foot alignment may provide valuable insights into strategies for reducing stress on proximal joints and preventing musculoskeletal injuries.

Future studies should explore longitudinal changes in individuals with pronated foot posture to determine whether early deviations in lower extremity alignment predict the development of symptomatic conditions. Dynamic assessment techniques, such as three-dimensional gait analysis, should also be incorporated to better understand how foot posture influences movement patterns during body weight loading.

6. Conclusion

The study demonstrated significant associations between Foot Posture Index (FPI-6) scores and measures of rearfoot alignment, femoral anteversion, and Q-angle in participants with asymptomatic pronated foot. The pronated foot can be altered alignment of the lower extremity, especially rearfoot alignment during weight-bearing, Q-angle, Craig's test. The altered of femoral anteversion, which might be internal rotation of femur or knee valgus alignment. Moreover, rearfoot alignment was showed strong relation with FPI-score caused by malalignment of the calcaneus.

The limitation of this study was that, to compare with normal foot alignment. Clinicians should recognize that foot posture plays a critical role in biomechanical imbalances and may contribute to an increased risk of lower extremity injuries. These findings emphasize that even in the absence of clinical symptoms, abnormal foot posture can significantly affect lower limb alignment, highlighting the importance of early identification and intervention to prevent potential musculoskeletal complications.

7. Acknowledgements

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9. Authors Biodata

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