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ORIGINAL ARTICLE

Validity of KineFeet for Assessing Medial Longitudinal Arch Deformation During Gait in Individuals with Flat and Non–Flat Feet

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ABSTRACT

Introduction: Accurate assessment of medial longitudinal arch (MLA) deformation during gait is essential for diagnosing and managing foot-related musculoskeletal disorders. KineFeet is a novel, depth-camera–based web application developed for real-time foot kinematic analysis. This study aimed to evaluate the validity of KineFeet in measuring MLA angles during the stance phase of walking.

Methods: A total of 89 healthy adults (74.2% female; mean age: 30.9 ± 2.5 years) were recruited and classified into flat-footed and non-flat-footed groups based on the navicular drop test. Each participant walked on a treadmill while MLA angles were recorded using KineFeet and manually measured using Kinovea software as a reference. Measurements were taken across seven subphases of the stance phase. Statistical agreement and correlation with static foot posture were analyzed.

Results: In non-flat-footed individuals, MLA angles obtained from KineFeet showed no significant differences compared to Kinovea across all stance subphases ($p > 0.05$), indicating good validity. However, in flat-footed participants, significant discrepancies were observed in the initial contact, loading response, and midstance phases ($p < 0.05$). Weak positive correlations were found between navicular drop test scores and dynamic MLA angles, particularly during initial contact, hallux extension, and initial swing ($r = 0.23$–0.29).

Conclusion: KineFeet demonstrated acceptable validity for assessing medial longitudinal arch (MLA) dynamics in individuals with normal foot posture and showed potential for clinical use in detecting flexible flatfoot deformities during walking. Further algorithm refinement is recommended to enhance its accuracy, particularly for early stance phases in individuals with flat feet.

Keywords: Correspondence Detail: KineFeet; medial longitudinal arch; gait analysis; flat feet; navicular drop test; depth came

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INTRODUCTION

The medial longitudinal arch (MLA) plays a crucial role in the foot's function during walking. It helps absorb shock, distributes body weight, and supports forward motion. When arch height deviates from the norm, it can interfere with the transfer of force through the foot, placing added stress on the tarsal bones and increasing the risk of ankle injuries.[1,2] Understanding the dynamic behavior of this arch throughout the stance phase of walking is essential for assessing foot function and identifying potential biomechanical abnormalities.[3] In many clinical settings, foot posture and mobility are assessed using quick and minimally invasive tools—often by measuring the arch height.[4]

Previous studies found that foot kinematics cannot be accurately inferred from clinical observations of foot posture alone.[5] Flatfooted subjects showed kinematic changes in their gait patterns. This will have a significant impact on biomechanical changes during walking. Therefore, kinematic evaluation is very important.[6] Dynamic assessments can capture the intricate motions of the foot as it interacts with varying forces and muscle activations. However, variations in foot structure and mechanics greatly influence the motion of the lower extremity, and the foot's complex anatomy, comprising numerous bones and articulations, makes accurate motion analysis a difficult task.[5,7]

KineFeet is a new web application that uses depth camera technology to track real-time foot movements. One of the parameters it provides is the medial longitudinal arch angle measured at each subphase of the stance phase, which helps show changes in the arch height during walking.
To evaluate the validity of KineFeet, it is imperative to compare its measurements against a well-established and reliable standard, such as Kinovea, which has demonstrated its utility in biomechanical analysis. Kinovea, an open-access video analysis software, has shown good to excellent inter-observer reliability for measuring various foot angles during walking at different speeds.[8] Preliminary research found Kinefeet to be reliable and valid for measuring foot kinematics, especially during the mid-to-late stance phase in the sagittal plane.

The current study represents a subanalysis of a larger KineFeet validation study, with a specific focus on assessing medial longitudinal arch (MLA) deformation during gait in individuals with and without flat feet. This comparison is essential, as in individuals with flat feet, changes in the MLA angle during walking may occur in smaller degrees, potentially making them more difficult to detect with motion-tracking tools. Therefore, this subanalysis aims to investigate whether KineFeet can accurately detect pathological foot conditions such as flatfoot by capturing subtle arch deformations during gait. Furthermore, the investigation will explore the potential correlation between medial arch height measured statically and changes in the longitudinal arch during walking, as measured by both KineFeet and Kinovea.

MATERIALS AND METHODS

Study Design

This investigation employed a cross-sectional approach to evaluate the validity and correlation of our findings, utilizing an observational analytic research framework. Data collection took place at the Department of Physical Medicine and Rehabilitation at Dr. Cipto Mangunkusumo Hospital. The research protocol received approval and registration from the Research Ethics Committee at the Faculty of Medicine, University of Indonesia (KET-1736/UN2. F1/ETIK/PPM.00.02/ 2024).

Participants

The study included 89 healthy individuals selected through consecutive sampling. Participants had to be between 25 and 59 years old, free from any conditions that could influence gait and posture, not using orthotic devices or gait aids, and capable of walking on a treadmill at a minimum speed of 3 km/h. All participants provided written informed consent before taking part in the study.

Instrumentation

Conducting gait analysis with KineFeet software requires specific equipment, including a treadmill, two Microsoft Azure Kinect DK cameras, two tripods, two softbox lights, and three standing backgrounds. The cameras are positioned 52 cm to its side. Mounted on tripods, the cameras are placed at a height of 40 cm above the floor, measured from the base of the camera to the ground (Figure 1). To compare results, we used Kinovea (version 2023.1.2) software to manually measure the same kinematic angles on the same video as those measured by Kinefeet.

Data Collection Procedures

The examination in this study was performed in a single session. Before the examination, each subject was briefed on the protocol, which included a physical examination to rule out deformities in the lower limb and gait analysis using KineFeet. To determine whether a person has flat or non-flat feet, the static posture of the foot was evaluated using the navicular drop test. Sociodemographic data, including age, sex, weight, and height, were collected before the examination. Measurements were taken only after confirming that subjects had no lower limb deformities that could affect gait.

Subjects were instructed to wear shorts that extended above the knee and to use the provided red socks. Three white markers were attached to the red socks with adhesive tape, each corresponding to temporal gait bony landmarks on both feet. The marker locations included the medial side of: 1) the head of the first metatarsal, 2) the navicular tuberosity, and 3) the calcaneal tuberosity (Figure 2). The medial longitudinal arch (MLA) angle was calculated using the dot product between two vectors created with the navicular tuberosity as the apex.[9]

Subjects were instructed to walk barefoot on a treadmill with their arms at their sides and looking straight ahead. Treadmill acclimatization involved gradually increasing the speed from 1 to 3 kilometers per hour until stable performance was reached. Data were collected for 5 seconds once subjects appeared comfortable walking on the treadmill, with recordings made simultaneously by Microsoft Azure Kinect cameras from the lateral perspectives. The Kinefeet web application automatically measures the angles of the medial longitudinal arch.

MLA angle measurement was again manually performed by an expert using Kinovea software on the same video. The angle was formed by the line connecting the head of metatarsal 1 and the tuberosity of the navicular and the line between the tuberosity of the navicular and the posteromedial calcaneus.

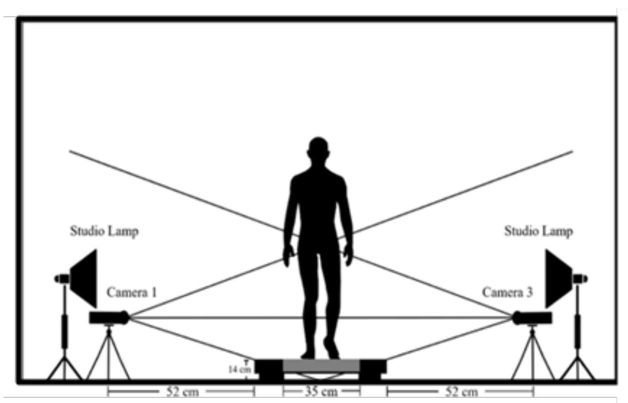

Figure 1. Overview of the environment and cameras set up

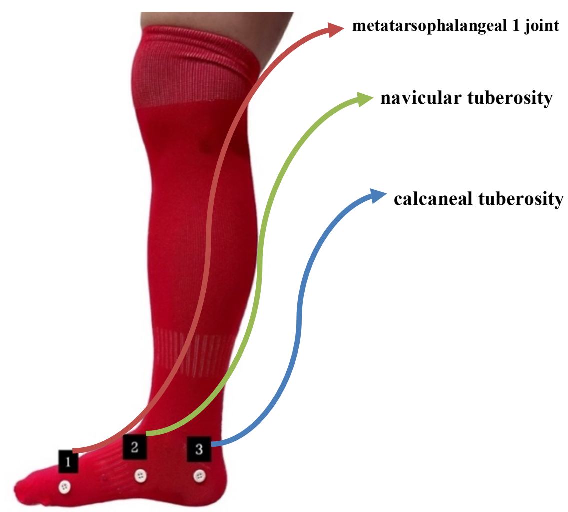

Figure 2. Placement marker on the right foot

Kinefeet will report the measurement results of the angles at certain times, namely:

a) Initial Contact (IC): When the foot touches the floor surface for the first time, usually at the heel
b) Foot Flat / Loading response (LR): when the entire sole is flat on the floor (marked MTH touching the floor), just before the tibia anterior inclination
c) Beginning of Midstance (MSt): when the opposite leg is lifted off the floor for the first time
d) Beginning of Terminal Stance (TSt): when the opposite leg passes the supporting leg, tibia vertical
e) Beginning of Pre Swing (PSw): when the contralateral leg touches the ground for the first time
f) Maximal Hallux Extension(HE): When the thumb reaches maximum extension, just

before the metatarsal head is lifted off the ground

g) Beginning of Initial Swing (ISw): When the big toe is lifted off the floor for the first time

RESULT

Eighty-nine subjects, most of whom were female (74.2 %) with an average age of 30,91 ± 2.5 years, were recruited for dynamic foot posture examination using Kinefeet and Kinovea. Of the total participants, 53 were categorized as non-flat foot and 36 were flat foot. The participants did not report any foot pain or walking difficulties.

Comparison of MLA Angle Measurement Validity Across Foot Types

The comparative analysis of MLA angle measurements using KineFeet and Kinovea across flat feet and non–flat feet groups revealed important differences in validity, especially regarding statistical agreement.

In the non–flat feet group, no statistically significant differences were observed between KineFeet and Kinovea across any subphase of the stance phase (all $p > 0.05$). Mean MLA angles recorded by KineFeet were consistently close to those captured by Kinovea, with differences typically within 2–3 degrees and small standard deviations. This shows that KineFeet provides acceptable validity for individuals with normal foot arches, with relatively low measurement variability.

In contrast, the flat feet group showed significant differences in three subphases: Initial contact ($p = 0.035$), Loading response ($p = 0.011$), and Midstance ($p = 0.020$). For the other subphases in flat feet (terminal stance, preswing, hallux extension, and initial swing), no significant differences were observed ($p > 0.05$). However, measurement variability was still higher than in the non–flat feet group (Table 1).

Table 1. Results of MLA angle measurements by Kinefeet and Kinovea based on static foot posture

Static foot posture	Gait Subphase	Kinefeet	Kinovea	*p-Value*
Non flat feet	Initial Contact (mean)	152.72 (8,7)	155.38 (9.4)	0.103
	Loading response (mean)	154.18 (9.1)	156.98 (9.5)	0.094
	Midstance (mean)	155.89 (7.7)	158.81 (9.4)	0.06
	Terminal stance (mean)	159.29 (7.9)	162.40 (39.54)	0.481
	Preswing (mean)	162.39 (42.19)	163 (40.3)	0.193
	Hallux extension (mean)	150.45 (11.69)	152.42 (11.07)	0.335
	Initial swing (mean)	148.97 (9.98)	146.79 (10.7)	0.241
Flat feet	Initial Contact (mean)	153.64 (8.53)	156.48 (9.29)	0.035
	Loading response (mean)	156.28 (43.5)	158.31 (9.52)	0.011
	Midstance (mean)	156.44 (7.21)	160.45 (9.49)	0.02
	Terminal stance (mean)	160.71 (39.54)	162.80 (43.5)	0.156
	Preswing (mean)	162.95 (42.19)	164.8 (43.2)	0.108
	Hallux extension (mean)	151.46 (11.41)	153.63 (10.69)	0.193
	Initial swing (mean)	152 (46.43)	148.99 (10.46)	0.225

Correlation Between Navicular Drop Test Result and Dynamic MLA Angles in each gait subphase

The correlation test results between NDT values and the medial longitudinal arch (MLA) angle showed different strengths of the relationship during each gait subphase, for measurements obtained with both Kinefeet and Kinovea.

In the Kinefeet measurements, significant correlations between NDT values and MLA angle were found in three subphases: Initial Contact (r =

0.252, p = 0.017), Hallux Extension (r = 0.229, p = 0.031), and Initial Swing (r = 0.241, p = 0.023). The correlation coefficient values suggest a positive relationship with weak strength. However, other subphases, such as Loading Response, Midstance, Terminal Stance, and Preswing, did not show statistically significant correlations ($p > 0.05$).

Meanwhile, in measurements using Kinovea, significant correlations were observed in almost all subphases, except Pre swing (r = 0.179, p = 0.093) and Initial swing (r = 0.291, p = 0.948). The strongest correlations appeared in the Midstance and Hallux Extension, with r 0.295 and 0.291, respectively (Table 2). Overall, Kinovea's correlation coefficient values were slightly higher than those of Kinefeet in most subphases, and they were more consistently statistically significant.

These findings indicate that the MLA angle during specific gait cycle phases has a weak correlation with the clinically measured longitudinal arch height using NDT, especially in the early and late stance phases and the early swing phase.

Table 2. Correlation test between NDT value and MLA angle based on measurement tools.

Measurment Tools	Gait Subphase	*p-value*	r
Kinefeet	Initial Contact (mean)	0.017	0.252
	Loading response (mean)	0.239	0.126
	Midstance (mean)	0.197	0.138
	Terminal stance (mean)	0.526	0.068
	Preswing (mean)	0.184	0.142
	Hallux extension (mean)	0.031	0.229
	Initial swing (mean)	0.023	0.241
Kinovea	Initial Contact (mean)	0.028	0.233
	Loading response (mean)	0.023	0.24
	Midstance (mean)	0.005	0.295
	Terminal stance (mean)	0.021	0.245
	Preswing (mean)	0.304	0.179
	Hallux extension (mean)	0.048	0.291
	Initial swing (mean)	0.948	0.291

DISCUSSION

Validity of KineFeet Compared to Kinovea

The results indicate that KineFeet provides similar MLA angle measurements to Kinovea in individuals with normal foot posture (non-flat feet), with no statistically significant differences across the stance sub-phases. This suggests that KineFeet could be a practical, low-cost alternative for dynamic MLA assessment in healthy people.

This study found significant differences between MLA measurements obtained using Kinefeet and Kinovea, especially during initial contact to midstance, in the flat feet group. This may be because Kinefeet struggles to detect minimal flattening of the medial longitudinal arch when the navicular is already low. However, the improved accuracy of the MLA angle measurement in the mid-to late stance phase (terminal stance, pre-swing, hallux extension, and initial swing) shows that Kinefeet still has great potential to provide valuable info for assessing changes in foot posture during gait. During the midstance-to-preswing phase, the ground reaction force shifts from the back of the ankle to the front, passing through the midfoot to the forefoot. During this phase, ankle pronation must be controlled by the supinator pedis muscles to prevent excessive medial arch collapse. The controlled flattening of the medial arch peaks in the early preswing phase.

The medial arch rises again during hallux extension in the late preswing phase due to the windlass effect.[10] Without sufficient supination force, causing excessive medial arch flattening, the increase in MLA angle will be well detected by Kinefeet during the terminal stance and preswing phases. Kinefeet can also determine whether this flattening is fixed or still flexible by observing the MLA angle during hallux extension. In flexible flat feet, the MLA angle reaches its maximum in the late terminal stance or early preswing (MLA_PSw) and decreases as the hallux extends maximally (MLA_HE angle). Conversely, in fixed flat feet, the MLA_HE angle will not differ significantly from the MLA_PSw angle.

Correlation between static foot posture and MLA angle changes during gait.

Proper foot biomechanics rely on the medial longitudinal arch (MLA) because it supports propulsion, shock absorption, and load distribution. During gait phases like initial contact and midstance, this study observed weakly positive correlations between dynamic MLA angles and navicular drop test (NDT) values. These connections were stronger with Kinovea compared to Kinefeet. Higher NDT values signified greater static arch collapse and more dynamic arch deformation during specific phases of walking.

These findings are consistent with Buldt et al. (2015), who observed that lower static arch heights result in increased pronation and changed kinematics, and Zifchock et al. (2019), who identified connections between static foot posture and dynamic gait, especially during midstance.[11,12] Our results support this, showing a weak correlation in midstance ($r = 0.295$, $p = 0.005$ using Kinovea).

The windlass mechanism plays a key role during hallux extension by helping restore the arch before push-off. According to Kelly et al. (2020), individuals with flatter arches may experience delays in arch recoiling, which can influence loading patterns and MLA angles during late stance.[13] This aligns with the correlation between NDT and MLA angle during hallux extension.

Significant correlations were also observed during the initial swing phase, suggesting that arch posture influences extend beyond stance phases due to lingering mechanical effects. Nourbakhsh et al. (2025) indicated that swing phase foot posture is influenced by previous stance kinematics, particularly in those with flexible flatfoot deformities.[14]

Our correlation values ($r = 0.23–0.29$) do not align with the literature, which reports moderate associations ($r = 0.2–0.4$) between static and dynamic arch measures. This indicates that static evaluation alone cannot predict dynamic foot behavior, as dynamic foot posture results from a complex interaction between passive structures (ligaments, bones), active structures (muscles), and external forces during walking. Therefore, static arch assessment does not necessarily reflect the arch's biomechanical behavior in motion, and both methods should complement each other in clinical and research settings.

Clinical Implications

From a clinical perspective, this study supports the potential of KineFeet as a dynamic gait analysis tool to evaluate changes in foot posture during walking, both in individuals initially identified as having flat feet through static examination and in those who appear normal. The inability of the supinator muscles to properly control excessive pronation may only become evident during walking, especially in individuals with weak or underdeveloped muscles. Therefore, dynamic posture assessment with KineFeet or Kinovea is highly recommended in cases where foot pain caused by excessive pronation only occurs during walking and not when standing. Understanding changes in foot posture during movement will help determine whether an insole with medial arch support effectively reduces foot pain.

Limitations

This study is limited by its sample size, which may restrict generalizability, especially for subgroup comparisons. Additionally, Kinovea, although considered valid for 2D analysis, is not a gold standard like 3D motion capture, which might weaken the validation strength. Future research should include pathological populations and investigate longitudinal tracking of treatment outcomes using KineFeet.

CONCLUSION

KineFeet demonstrated acceptable validity in measuring medial longitudinal arch (MLA) angles during gait in individuals with normal foot posture. However, its accuracy declined in people with flat feet, particularly during early stance phases. These findings highlight the need for further refinement of KineFeet to improve its accuracy and clinical usefulness, especially for those with altered foot structure. Future studies should focus on improving the algorithm and broadening validation to cover a wider range of foot conditions.

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