Development and Validation of the Foot Inclinometer: A Novel Device for Assessing Standing Foot Posture

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Abstract

Background: Accurate assessment of foot posture is crucial in clinical and research settings for diagnosing and managing various lower limb ailments. Traditional methods, such as the Foot Posture Index (FPI), are prone to manual errors and inter-rater variability, highlighting the need for an innovative and reliable tool for foot posture measurement. This study introduces the Foot Inclinometer (FI), a novel device designed to provide objective, real-time measurements of static foot posture using sensor technology.
Objective: To develop and validate the Foot Inclinometer as a reliable and efficient tool for assessing foot posture in a clinical setting, with minimal human error and cost.
Methods: A cross-sectional study was conducted with 40 participants (17 males, 23 females) aged 20–60 years. The Foot Inclinometer consists of four pressure sensors placed on anatomical landmarks (first metatarsal, fifth metatarsal, midfoot, and calcaneum) and an accelerometer sensor on the Achilles tendon. Participants stood on the soles while a proximity sensor was held to the Achilles tendon for calibration. The device displayed foot posture (pronated, supinated, or neutral) and the degree of tilt. Data were collected for statistical analysis.
Results: The study found that 64% of participants had pronated feet, 24% had neutral feet, and 12% had supinated feet. Age-related variations in foot posture were observed, with a higher prevalence of pronated feet in older age groups. The results were consistent with previous research, demonstrating the Foot Inclinometer's ability to assess foot posture accurately and consistently.

Conclusion: The Foot Inclinometer is an effective, low-cost, and easy-to-use device for assessing static foot posture. It reduces human error and provides objective measurements, making it a valuable tool for clinicians and researchers. Further studies are recommended to establish reference values across different age groups and populations and to explore its application in dynamic foot assessment.

Keywords:
Foot posture, Foot Inclinometer, Foot Posture Index, sensor technology, static posture, foot assessment, lower limb injuries, biomechanical abnormalities

Introduction

Foot posture refers to the alignment and placement of the feet in relation to the ground, lower limbs, and surrounding objects. It plays a significant role in overall body mechanics, influencing not only walking but also standing posture and balance. Foot posture is generally classified into three primary categories: normal (rectus), low-arched (planus), and highly-arched (cavus). These classifications are based on the shape of the medial longitudinal arch, a key structural element of the foot (1). The alignment of this arch is crucial in maintaining the body's overall biomechanical efficiency and preventing strain on the lower limbs and spine. Proper foot posture ensures that forces during walking and running are evenly distributed, thereby reducing the likelihood of injury. In contrast, abnormal foot function, such as excessive pronation (rolling inward) or supination (rolling outward), can disrupt this balance, leading to various musculoskeletal conditions (2).

Pronation, for instance, is a natural movement of the foot that occurs during walking or running, but excessive or prolonged pronation can result in numerous lower limb problems. Abnormal foot posture has been implicated in the development of injuries like medial tibial stress syndrome (commonly referred to as shin splints) and patellofemoral discomfort (pain around the knee) (2). These conditions often arise when the natural alignment of the foot is compromised, resulting in altered lower limb mechanics and abnormal stresses on the joints and soft tissues. Over time, such biomechanical changes can contribute to chronic pain and long-term injury. Moreover, the influence of foot posture extends beyond the feet themselves; it affects the alignment of the knees,

hips, and lower back, leading to postural abnormalities and potential discomfort in these areas as well (3). These interrelated musculoskeletal issues highlight the importance of monitoring and assessing foot posture in clinical and rehabilitation settings.

Traditional methods of measuring foot posture, such as the Foot Posture Index (FPI), have been widely used in both clinical and research environments. However, these methods are often prone to inter-rater variability and manual errors, which can compromise the reliability and consistency of the results. The FPI, for example, requires visual observation and manual palpation of foot structures, making it susceptible to subjectivity and inconsistencies between different practitioners (2,3). Furthermore, other established techniques, such as radiographic imaging or pressure mapping, require specialized equipment and controlled environments, which may not always be feasible or accessible, particularly in routine clinical practice. These limitations underscore the need for a more practical and reliable tool for assessing foot posture in everyday clinical settings, where cost, time, and accessibility are often significant concerns.

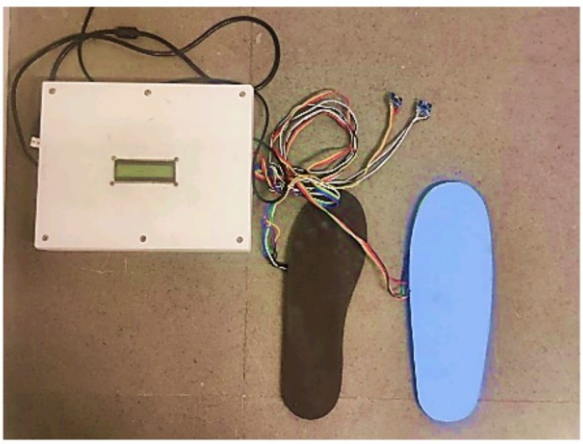
While laboratory settings provide the gold standard for objective foot posture assessment, they often involve expensive equipment and advanced testing procedures, which may not be readily available or practical in clinical practice. This presents a challenge for clinicians seeking to assess foot posture quickly and efficiently in their patients.

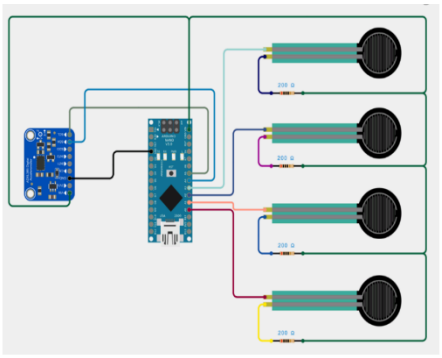
To address these challenges, there has been a growing interest in developing portable, user-friendly devices that can provide objective, real-time measurements of foot posture in clinical environments.

The Foot Inclinometer (FI) is one such device that has been developed to meet this need. Designed to overcome the limitations of traditional methods, the FI offers a cost-effective and reliable alternative for accurately assessing foot posture in clinical settings. Its portability and ease of use make it an attractive option for healthcare providers, allowing them to gather important diagnostic information quickly and efficiently. This study aims to validate the Foot Inclinometer, assessing its accuracy and reliability in capturing foot posture and comparing it to established methods of assessment. By doing so, the study seeks to establish the FI as a useful tool for clinicians in their ongoing efforts to monitor and manage foot-related conditions effectively.

Development of the Foot Inclinometer

The Foot Inclinometer (FI) was designed for use in a double-limb standing position to provide more accurate weight-bearing measurements, as these better represent foot function compared to non-weight-bearing assessments. The FI incorporates advanced sensor technology to reduce human error associated with traditional techniques. The device features four pressure sensors placed at key anatomical landmarks: the first metatarsal, fifth metatarsal, midfoot, and calcaneum, alongside an accelerometer sensor positioned on the Achilles tendon to monitor tilt and static acceleration forces. Data collected from the sensors are converted into digital measurements by an Arduino Nano processor, providing real-time feedback of foot posture. The system operates with minimal equipment, is easy to use, and provides objective visual feedback via a digital display. The device's low cost and ease of operation make it ideal for clinical use without requiring special training or installation.





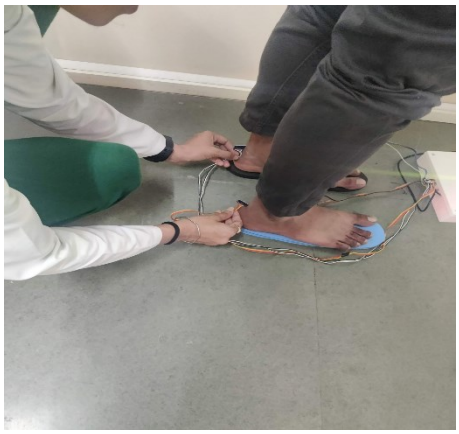
Methods

Study Design and Setting: A cross-sectional study was conducted in a community setting, with participants

aged 20–60 years. The study was approved by an ethical review board, and participants provided informed consent.

Participants:
The study included 40 participants (17 males, 23 females) aged between 20 and 60 years. Inclusion criteria included individuals with no history of lower extremity injury or surgery in the past 6 months. Exclusion criteria included conditions that could significantly affect foot posture (e.g., neurological disorders, severe foot deformities).

Procedure:
Participants stood on the soles of the Foot Inclinometer device (blue for the right foot, black for the left foot). The proximity sensor was placed on the Achilles tendon for calibration. After standing still for one minute, the device displayed foot posture readings, categorizing the foot as pronated, supinated, or neutral, along with the degree of tilt. Three readings were taken, and the mean value was recorded for statistical analysis.



Outcome Measures:

Foot Inclinometer – Ask the subject to stand on the sole. The subject will be asked to count till ten. This will give time to the foot to adapt a relaxed posture. The operator will stick the sensor to Achilles tendon and the device will show the reading of foot posture- Pronated, Supinated or Neutral along with the value of weight distributed on foot.

Results:

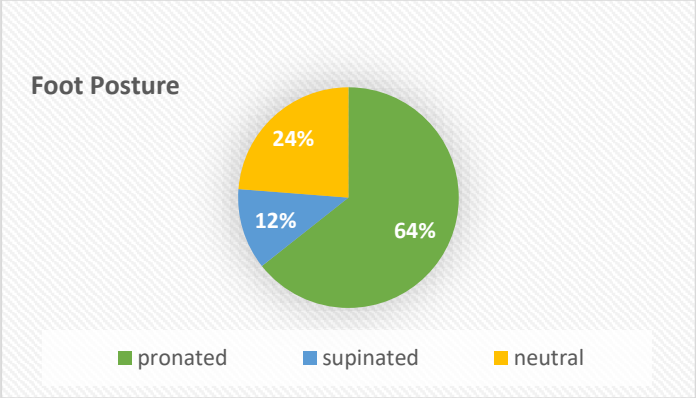
Statistical analysis was done by calculating the mean and standard deviation of age and the values of different postures of right and left feet from Foot Inclinometer. Percentage of gender distribution and foot posture distribution among the study samples was calculated.

Table 1: Demographic characteristics

Quantitative Variable	**Mean±SD**
Age (years)	38.7 ± 11.3
Qualitative variables	**Total**
Gender (n, %)	Male – 17 (41%)
	Female – 23 (59%)

Among the participated individuals, mean age was 38.7 ± 11.3. Total no of participated individuals was 40. Out of them, males were 17 and females were 23, constituting 41% and 59% respectively. (Table 1)

Figure 1: Distribution of foot posture



Among the total participants, a major population had pronated feet (64%). It was followed by neutral posture (24%) and the least individuals had supinated feet (12%).

Table 2: Foot Inclinometer

Age (years)	n	Supinated Mean ± SD		Pronated Mean ± SD		Neutral Mean ± SD	
		Right	Left	Right	Left	Right	Left
20- 30	14	0.93±0.1	0.3±0.1	1.54±0.8	1.12±0.3	0.21±0.9	0.63±0.3
31- 40	9	-	-	1.55±0.7	1.4±0.8	0.75±0.1	0.66±0.1
41- 50	9	0.94±0.09	0.55±0.4	1.69±0.8	1.57±1.01	1.5±0.3	0.79±0.8
51- 60	6	2.07±1.8	0.68±0.3	2.16±0.3	1.66±0.8	1.26±0.9	2.2±0.8

Table 2 shows the foot posture of individuals aged 20- 60 years. In the age group 20-30, 41-50 and 51- 60 years, the mean of left foot is less than the mean of right foot among supinated, pronated and neutral foot postures. Except in the group 20- 30 years of age. Here the mean value of left foot is more than right for neutral posture. In the group 31- 40 years of age, supinated posture was not found. Among the pronated and neutral postures, the mean of right foot was greater than the mean of left foot by a slight degree indicating almost values.

Discussion

Accurate assessment of foot posture is essential in both clinical and research settings, as it provides insights into biomechanical abnormalities and supports the identification and management of various ailments affecting the lower extremities. Traditional methods, such as radiographic techniques, anatomical measures, footprint evaluations, and dynamic analyses, have been employed to quantify foot posture. However, these methods often require specialized equipment, are time-consuming, and may expose patients to radiation. The Foot Inclinometer (FI) offers a more practical and accessible alternative, providing real-time data with minimal error, thereby enhancing clinical efficiency and patient safety (8).

Our study corroborates previous research indicating a higher prevalence of pronated feet, especially among adults. For instance, a study published in the *International Journal of Community Medicine and Public Health* found that 43% of participants exhibited pronated feet, with 14% having highly pronated feet (9). Similarly, a

study in the *Journal of Foot and Ankle Research* reported that 19% of participants had flat feet (pes planus), and 5.2% had high arches (pes cavus) (10). These findings underscore the prevalence of foot posture abnormalities in the general population.

Overpronation has been associated with various musculoskeletal injuries, including hallux valgus and low back pain. The Foot Inclinometer's ability to capture and quantify foot posture accurately is crucial for early diagnosis and intervention, particularly in populations prone to injury. For example, a study in the *Journal of Foot and Ankle Research* highlighted that overpronation can lead to increased stress on the medial structures of the foot, contributing to conditions like plantar fasciitis and posterior tibial tendon dysfunction (11). Additionally, overpronation has been linked to knee and hip pain, as altered foot mechanics can affect the alignment and function of the entire lower extremity (12).

The observed variations between left and right foot measurements align with prior studies, suggesting slight asymmetry in foot posture. Research indicates that such asymmetry is common, with one foot often exhibiting more pronation than the other. This asymmetry can influence gait and balance, potentially increasing the risk of injuries. Understanding these variations is essential for developing personalized treatment plans and interventions (13).

Moreover, the study's results are consistent with a U-shaped relationship between age and foot posture, where older adults tend to exhibit more pronation. A systematic review published in the *Journal of Musculoskeletal Research* found that the prevalence of flatfoot among adults increases with age, with a significant rise in individuals over 60 years old (14). This age-related change in foot posture may be attributed to factors such as ligamentous laxity, muscle weakness, and degenerative changes in the foot structures.

These findings underscore the need for further research to establish reference values for different age groups, as well as the potential role of the Foot Inclinometer in dynamic foot function assessments. Establishing age-specific reference values can aid clinicians in identifying deviations from normal foot posture and implementing timely interventions. Additionally, incorporating dynamic assessments can provide a more comprehensive understanding of foot function during activities like walking and running, which is crucial for developing effective rehabilitation strategies (15).

In conclusion, the Foot Inclinometer presents a valuable tool for assessing foot posture in clinical settings. Its ability to provide accurate, real-time data with minimal error enhances clinical efficiency and patient safety. The prevalence of pronated feet and associated musculoskeletal injuries highlights the importance of early detection and intervention. Further research is warranted to establish comprehensive reference values across different age groups and to explore the role of the Foot Inclinometer in dynamic assessments of foot function.

Limitations and Future Research

This study focused on static foot posture assessments. Further research is needed to explore the device’s application in dynamic environments and to compare its performance with other established methods in larger, more diverse populations. Establishing reference values across various age groups and clinical conditions will further enhance the utility of the Foot Inclinometer.

Conclusion

The Foot Inclinometer is a novel, reliable, and cost-effective tool for assessing static foot posture. It provides accurate, objective measurements and reduces human error, making it a valuable addition to clinical practice for diagnosing foot-related ailments. Further validation and development of reference values are recommended to enhance its applicability in diverse clinical settings.

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