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The Comparison of Validity and Reliability of a Novel Smartphone-based Tool with Foot Scanner for Hallux Valgus Angle Measurement

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ABSTRACT

Objective: This study aimed to assess the validity and reliability of a novel smartphone-based tool (NSBT) for measuring the hallux valgus angle (HVA) compared to a foot scanner.

Methods: Thirty-five feet with hallux valgus underwent two measurement sessions using both the NSBT (Hallux-Valgus-meter app) and a DSI foot scanner (Iranian Daneshsalar Company). Intra- and inter-rater reliability for each tool were assessed using Cronbach's alpha and ICC(2,K). Agreement between tools was evaluated using Pearson's correlation coefficient and Bland-Altman analysis. Statistical analyses were performed in SPSS v27 ($\alpha = 0.05$).

Results: The NSBT demonstrated excellent inter-evaluator reliability (ICC = 0.952, Cronbach's alpha = 0.953) and intra-evaluator reliability (ICC = 0.943, Cronbach's alpha = 0.939) (all $p < 0.001$). The NSBT also showed strong agreement with the foot scanner ($r = 0.93$, $p < 0.001$). Bland-Altman analysis confirmed this agreement with a small mean difference (0.34 degrees) and minimal data scatter.

Conclusion: The NSBT offers a valid, reliable, and consistent method for HVA measurement. Compared to traditional methods, it presents advantages of portability, ease of use, reduced cost, and eliminates radiation exposure. This technology has the potential to improve accessibility and efficiency in hallux valgus assessment within physiotherapy practice.

Keywords: *Hallux valgus angle, mobile health, reliability, validity.*

1. Introduction

Proper body posture, or appropriate postural alignment, is a cornerstone of good physical health (1). Repetitive movements and static postures can overload and stress the body, disrupting its natural mechanics and leading to musculoskeletal dysfunction (2). Hallux valgus, a common foot deformity, manifests as lateral deviation of the big toe (hallux) and inward angulation of the first metatarsal bone (3). Left untreated, it can not only cause deformities and pain in the big toe but also affect the entire foot. Monitoring hallux valgus progression is crucial because increased

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severity progressively diminishes quality of life and increases the risk of other lower limb disorders, potentially impacting other body regions over time.

Therefore, accurate evaluation and measurement of hallux valgus are essential for implementing preventive measures and corrective interventions to improve the big toe's condition. Researchers and specialists utilize various methods for hallux valgus assessment, including radiography, goniometry, plantar pressure measurement, foot scanning, and photogrammetry (4, 5). Radiographic imaging remains the gold standard for hallux valgus evaluation (6). However, limitations like invasiveness, cost, required expertise, and logistical challenges restrict its use (7).

Mobile phone applications have emerged as a promising tool for examining postural abnormalities, including hallux valgus (8, 9). Innovative mobile phone software with foot scanning capabilities has been proposed as a potential tool for this purpose (10). Simons et al. (2015) compared the reliability of a smartphone goniometer app with a traditional goniometer for measuring hallux valgus in 25 patients. They found both methods to be moderately reliable, with the mobile app demonstrating slightly higher reliability (10).

In 2021, Tianji Huang et al. presented a study titled "A novel rapid measurement of hallux valgus parameters using the built-in photo edit function of smartphones" This novel method utilizing the intrinsic photo-editing system of smartphones was deemed precise, reliable, and demonstrated high repeatability compared to radiographic methods (11).

When employing a new assessment tool, its validity and reliability are paramount. The tool must be accurate and consistently measure the desired variable (12). This study aims to assess the accuracy and validity of a novel smartphone-based tool (NSBT) by comparing its reliability and validity with a foot scanner that closely resembles radiography in measuring the hallux valgus angle.

2. Methods and Materials

2.1 Study Design and Participants

This study employed a descriptive correlational design. Following an initial screening process, a sample of 35 female students from Shahid Rajaee Teacher Training University were recruited through convenience sampling. These participants had a mean age of 22.17 ± 3.87 years, mean height of 161.33 ± 6.44 cm, mean weight of 53.17 ± 8.87 kg, and a mean body mass index (BMI) of 20.32 ± 2.34 kg/m^2.

A power calculation confirmed that a sample size of 25 feet was required, which was broadly in line with previous work in this field (13). Prior to data collection, all participants received a thorough explanation of the research process and measurement procedures. Informed consent was gained from each participant, confirming their voluntary participation in the study. Participants were included in the study if they met the following criteria: 1) Female gender; 2) Age range of 18-35 years; 3) Presence of Hallux Valgus (greater than 15 degrees); 4) BMI between 18 and 25; 5) Confirmation of physical health by a physician; 6) No history of degenerative or inflammatory joint disease, any neurological disorder, or recent foot surgery; 7) Absence of neurological disorders affecting standing posture.

2.2 Measurement Procedures

Following participant recruitment (n=193), a rigorous screening process was implemented based on predefined inclusion and exclusion criteria. This yielded a final sample size of 25 participants, contributing data for a total of 35 feet.

The reliability and validity of the NSBT were established through three sets of data: 1- Concurrent Validity**:** The accuracy of the hallux valgus angle (HVA) obtained by the NSBT was compared with measurements acquired using a foot scanner method, which has a reported correlation coefficient (r) of 0.94 and coefficient of determination (R^2) of 0.89 with radiography (14). This comparison assesses how well the NSBT aligns with an established method; 2- Inter-rater Reliability**:** The NSBT inter-rater reliability was evaluated based on HVA measurements taken by two different evaluators in the same location and at the same time (n = 35). This assesses the consistency of measurements between different evaluators; 3- Intra-rater Reliability**:** The NSBT method's intra-rater reliability was assessed by comparing HVA measurements obtained by the same evaluator on two separate occasions with a one-week interval (n = 35). This assesses the consistency of measurements by a single evaluator over time. The researcher provided detailed instructions to the second evaluator on the measurement technique using the NSBT and landmark identification (the first metatarsophalangeal joint (MTPJ1)) based on a standard anatomical reference (color atlas of skeletal landmark definition) for improved measurement accuracy. This step ensured standardized application of the NSBT and minimized potential variability due to individual variations in palpation skills.

2.3 Hallux Valgus Assessment by Foot Scanner

The HVA was assessed using a DSI foot scanner (Danesh Salare Iranian) with established validity and reliability (correlation coefficient with radiography: r = 0.94, R^2 = 0.89) (14). Participants were instructed to stand barefoot on the scanner platform, distributing their weight equally across both feet. An indicator label was positioned parallel to the previously marked MTPJ1 joint line. After a 10-second period of static standing, the scanner captured a plantar foot image and saved the footprint data in JPG format (15).

The HVA was measured using Digimizer software (Version 4.6.2.0, copyright © 2005-2014 MedCalc software) based on the captured 2D footprint image. The software calculated the angle between two digitally drawn lines: one along the medial border of the first metatarsal (MT1) and the other along the medial border of the proximal phalanx of the hallux (Fig. 1). This method demonstrates good correlation with radiographic HVA measures (16).

2.4 Hallux Valgus Angle Measurement Using a Novel Smartphone-Based Tool

The next stage involved measuring HVA using a newly developed smartphone-based tool and application. This tool comprised a graduated surface measuring 34 cm in length and 24 cm in width, equipped with a movable arm and a mobile phone holder. The graduated surface incorporated a cutout to secure the movable arm, which in turn held the smartphone pre-loaded with the Hallux-Valgus-meter software (Fig. 2A).

To initiate the HVA measurement, the Hallux-Valgus-meter application was activated in "ready mode" and positioned on the designated area of the graduated surface. The participant was then instructed to stand still and place the target foot on the specified area. The application was subsequently reset. Subsequently, the evaluator adjusted the tool's movable arm along the longitudinal axis of the participant's foot until it reached the distal end of the forefoot, where it was secured in place. The application then displayed the degree of forefoot deviation. To record the value, the "freeze" option was selected. All measurements were performed in triplicate, and the average was considered the HVA (Fig. 2B).

To minimize evaluation bias and assess the inter-rater reliability of the NSBT method, both evaluators performed measurements on subjects under identical conditions. Subsequently, with the subjects' consent, the same evaluator re-evaluated them at the same time and location within a one-week interval. Notably, only the NSBT method was used during this second evaluation. This approach allowed for the calculation of intra-rater reliability, which reflects the correlation between measurements obtained by the same evaluator on two separate occasions.

2.5 Statistical Method

Descriptive statistics were presented as means and standard deviations. Data normality was assessed using the Shapiro-Wilk test. Intra-observer and inter-observer reliability were evaluated using the intraclass correlation coefficient (ICC(2,k)). Interpretation of ICC values followed established criteria: 0.90–1.00 indicated excellent reliability, 0.75–0.90 good reliability, 0.50–0.75 moderate reliability, and less than 0.50 poor reliability (17). Pearson's correlation coefficient was calculated to analyze the correlation between variables. Bland-Altman plot analysis was used to assess the level of agreement between different measurement methods. All statistical analyses were performed using SPSS version 27, with a significance level of alpha set at 0.05.

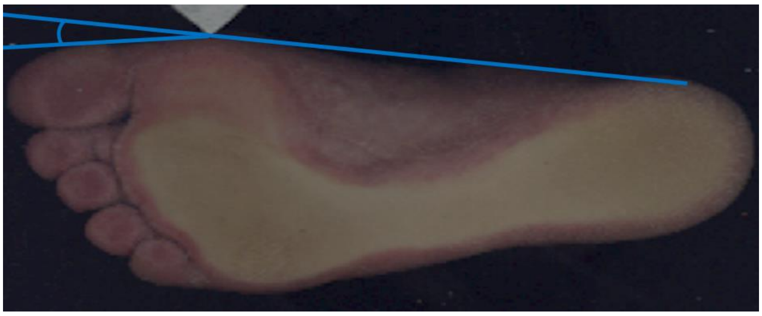

Figure 1. The measurement of hallux valgus angle (HVA) from a 2D foot scan outline.

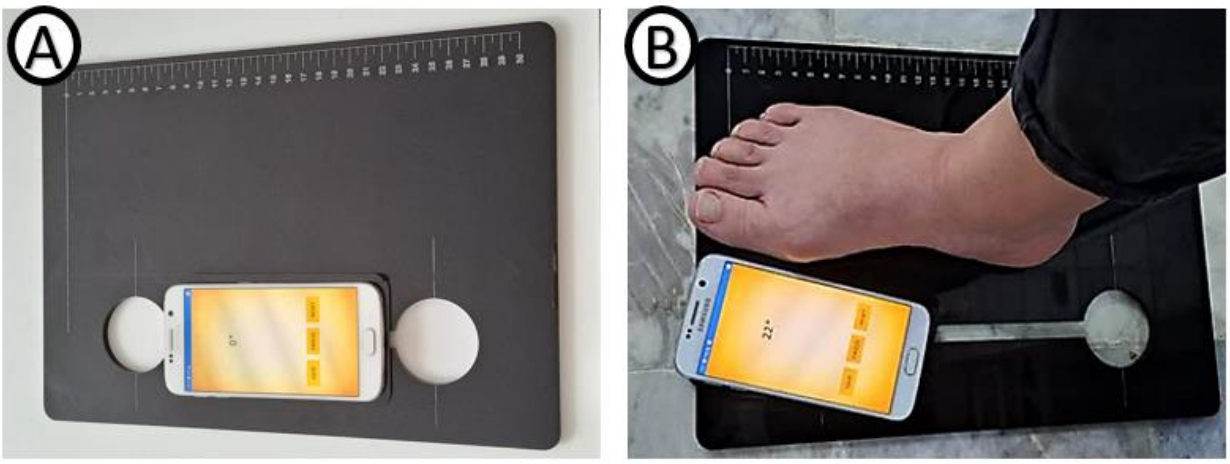

Figure 2. The measurement of hallux valgus angle (HVA) with using novel smartphone-based tool method.

3. Findings and Results

The results of measurements obtained from two different evaluators using the NSBT demonstrated excellent inter-evaluator reliability. ICC and Cronbach's alpha values were 0.952 and 0.953, respectively, with a 95% confidence interval (CI) ranging from 0.907 to 0.976 (p = 0.000). The degrees of freedom for the first factor (df1) were 34. The mean (standard deviation) HVA measurements for Evaluator 1 and Evaluator 2 were 16.77 (3.51) and 16.94 (3.86) degrees, respectively.

Similarly, excellent intra-evaluator reliability was observed for Evaluator 1 across two different days. ICC and Cronbach's alpha values were 0.943 and 0.939, respectively, with a 95% CI ranging from 0.877 to 0.970 (p = 0.000). Degrees of freedom for the first factor (df1) were 34. The mean (standard deviation) HVA measurements for the two testing sessions were 16.46 (3.99) and 17.03 (3.57) degrees for set 1 and set 2, respectively (Table 1).

The NSBT demonstrated a strong correlation with the established foot scanner method, with a Pearson correlation coefficient (r) of 0.93 and a statistically significant p-value (p = 0.000). Figure 3 presents the Bland-Altman analysis for HVA measurements. As shown in Figure 3, the mean difference between the two methods was 0.34 degrees, indicating good agreement. Additionally, most data points representing the difference between the methods exhibit minimal scatter, suggesting high consistency. Notably, the average differences fall within acceptable limits, as defined by the mean difference ± 2 standard deviations (SD).

Table 1. Intraclass Correlation Coefficient (ICC) and Cronbach's Alpha for Hallux Valgus Angle Measurements with the NSBT method.

	95% Confidence interval				
	ICC	Lower Bound	Upper Bound	*P*	Cronbach's Alpha
Evaluator 1 and 2	0.952	0.907	0.976	0.000	0.953
Evaluator 1 in two different days	0.943	0.877	0.970	0.000	0.939

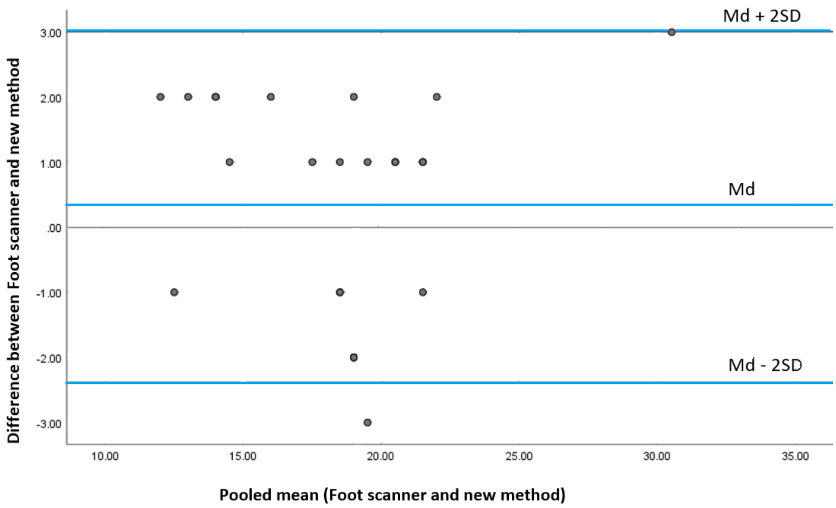

Figure 3. Plot of differences between foot scanner method and a novel smartphone-based tool method vs. the mean of the two measurements.

4. Discussion and Conclusion

This study investigated the validity and reliability of a novel smartphone-based tool method for measuring the hallux valgus angle (HVA) compared to a foot scanner. The NSBT demonstrated excellent inter-evaluator reliability (ICC = 0.952, Cronbach's alpha = 0.953) and intra-evaluator reliability (ICC = 0.943, Cronbach's alpha = 0.939) with high statistical significance ($p < 0.001$). This indicates consistent measurements between different evaluators and by the same evaluator on separate days. Additionally, the tool showed strong agreement with the established foot scanner method ($r = 0.93$, $p < 0.001$). Bland-Altman analysis confirmed this agreement with a small mean difference (0.34 degrees) and minimal data scatter within the limits of agreement. These results support the reliability and validity of the NSBT for HVA measurement.

Our results align with previous studies by Meng et al. (18), Otter et al. (10), Hayato et al. (19), Walter et al. (20), Yamaguchi et al. (21), Huang et al. (11), demonstrating consistency in HVA measurement across various tools. This consistency may be due to the similarity of the measured angles and advancements in mobile phone technology.

Several studies have explored alternative HVA measurement techniques. Catal et al. (22) employed 3D foot models from CT scans for HVA in ballet dancers. Jansen et al. (23) compared goniometry, radiography, and foot pressure measurements in diabetic patients, finding higher agreement between radiography and goniometry. Nix et al. (12) investigated the validity and reliability of digital photography for HVA, suggesting it as a suitable alternative to radiography. Yamaguchi et al. (21) proposed self-photography as a non-radiographic approach with good reliability. Huang et al. (11) introduced a method using mobile phone photo editing features for HVA measurement, demonstrating its accuracy and efficiency. Meng et al. (18) compared traditional goniometry with an iPhone app, finding both methods accurate but the app faster. Otter et al. (10) compared a smartphone goniometer app with traditional goniometry, finding similar reliability with a slight advantage for the app. Similarly, Hayatoshi et al. (19) developed a smartphone screening method for HVA with diagnostic capabilities comparable to radiography. Walter et al. (20) evaluated a smartphone app for measuring HVA, intermetatarsal angle (IMA) and distal metatarsal articular angle (DMAA), finding it reliable for HVA, IMA, and DMAA. Finally, Fong et al. (5) assessed a smartphone app for measuring the bunion angle, demonstrating its reliability as a potential tool for HVA assessment.

Our study builds upon this existing research by demonstrating the validity and reliability of a novel mobile phone software method for HVA measurement. This method offers advantages like portability, ease of use, reduced cost, and eliminates radiation exposure compared to traditional methods like goniometry or radiography.

This study has some limitations. The study focuses solely on female students. Results may not generalize to males or other populations with different foot characteristics. Since the study focuses on students, the age range may be limited. The validity and reliability of the tools might differ in younger or older populations. The study specifies a 2D foot scanner. Limitations of 2D scanners compared to 3D scanners (if applicable) might not be addressed. Generalizability to clinical settings might be limited since the study involved healthy student volunteers, not patients seeking treatment for hallux valgus. Additionally, future studies could investigate the long-term reliability of the mobile phone method and explore its use in different clinical settings.

As the findings indicated the novel smartphone-based tool can be employed as a reliable and consistent approach for measuring the hallux valgus angle. Compared to traditional methods like goniometry or radiography, the smartphone-based tool offers several advantages, including portability, ease of use, reduced cost, and elimination of radiation exposure. Additionally, the tool's non-invasive nature makes it suitable for use in various settings, including clinical practice, research, and home-based monitoring.

Further research is warranted to explore the wider application of the smartphone-based tool in physiotherapy practice. Studies could investigate its use in different patient populations, its efficacy in monitoring treatment outcomes, and its potential for remote assessment and interventions. By establishing the clinical utility of this novel tool, we can enhance the assessment and management of hallux valgus, improving patient outcomes and reducing healthcare costs.

Authors' Contributions

H.S. conceptualized the study, designed the research methodology, and supervised the overall project implementation. M.D. conducted the measurement sessions, assisted in data collection, and contributed to the literature review. A.B. performed the statistical analyses, interpreted the results, and contributed to drafting and revising the manuscript. All authors participated in discussing the findings, critically reviewed the manuscript for important intellectual content, and approved the final version for publication.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants. The study was approved by the ethics committee of Sport Sciences Research Institute of Iran with the code IR.SSRC.REC.1402.150.

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