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Correlation between Measurements Using a Universal Goniometer and a Smartphone Application for Ankle Range of Motion

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Abstract

Background: Goniometers are commonly used to measure ankle Range of Motion (ROM). Recently, clinicians and physiotherapists can measure the ankle-ROM using smartphone applications. However, these measurement methods cannot be done remotely and body integration is required. For this reason, our study aim is to develop a smartphone application that can measure ankle-ROM remotely and to investigate the its correlation with the universal goniometer.

Methods: Twenty-two of healthy university students with 44 feet were recruited in the study. DijiA application was developed for Android smartphone to measure ankle dorsiflexion and plantar flexion ROM remotely. 44 feet were evaluated by both universal goniometer and DijiA application. After completion of testing, all of the participant were filled out the System Usability Scale (SUS) survey for measuring usability of application.

Results: The variation in Pearson Correlation Coefficient between the Universal Goniometer and DijiA Smartphone App result showed that there was a moderate positive relationship Between the Universal Goniometer and DijiA (r=0.323 for DF, r=0.435 for PF).

Conclusion: Smartphone-based ankle ROM measurement with "DijiA"app can be used to assess active ROM of the ankle joint without weight-bearing. The result of the study showed that usability of DijiA app is satisfactory and above the standards.

Keywords: Ankle 1; Application 2; Range of motion 3; Smartphone

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Introduction

Ankle Range of Motion (ROM) is an important parameter for assessing the functional status of the ankle joint [1]. The assessment of ankle ROM is commonly performed in both clinical and research settings. Traditionally, ankle ROM measurements have been taken using a universal goniometer, which is a reliable and valid tool for measuring joint angles [2]. However, advancements in technology have led to the development of Smartphone applications that claim to be a simple and accurate alternative to the traditional goniometer [3].

In recent years, there has been a growing interest in using IMU (Inertial Measurement Unit) sensors and image processing techniques using a Smartphone camera system for analyzing the motion or posture of the foot and ankle region [4]. IMU sensors are small, wearable devices that can measure movement and orientation, and can be used to assess joint angles during ROM measurements [4,5]. The use of Smartphone camera systems has also gained popularity in recent years, as they can provide accurate measurements of joint angles without the need for additional equipment [6,7].

However, despite the potential benefits of these technologies, there is still a need for further research to validate their use in clinical settings. Larger patient sample sizes and more robust validation assessments are necessary to ensure that these technologies can provide reliable and accurate measurements of joint angles. Additionally, the use of these technologies may require specialized training for healthcare professionals to ensure proper use and interpretation of the data [8].

Despite the challenges, the use of mobile apps and new technologies for ROM measurements holds promise for improving the efficiency and accuracy of clinical assessments [9]. Many clinical tests have also been computerized using mobile apps. ROM or Goniometric Measurement has gained the attention due to its importance for clinical assessment, quick-and-easy procedures, and more mobile equipment [10,11]. ROM measurements have been developed for various joints, including the lumbar, knee, shoulder, and wrist [12]. Despite the fact that multiple studies have showed good reliability, more validation assessments with larger patient sample sizes have been identified as a general route for future research [12,13]. By providing quick and easy procedures, and more mobile equipment, these technologies could potentially increase patient access to care and improve patient outcomes [11-13]. As such, continued research and development in this area will be important for advancing the field of clinical assessment and enhancing patient care.

The aim of this study is to investigate the correlation between measurements of ankle ROM taken using a universal Goniometer and a Smartphone application. The use of a Smartphone application has the potential to reduce measurement errors and increase the efficiency of data collection. However, the accuracy and reliability of these applications need to be evaluated before they can be considered as a valid tool for measuring joint angles.

The findings of this study will provide valuable insights into the potential use of smartphone applications in the assessment of ankle ROM. This could have significant implications for the clinical and research settings, as it could provide a more convenient and cost-effective alternative to traditional goniometry. Furthermore, the results of this study may also inform the development of future Smartphone applications for measuring joint angles.

Materials and Methods

Fourteen patients with 28 feet (7 females and 7 males aged 21 to 29 years) who have the foot deformity were included in this study. Patients with ankle arthrodesis, acute fractures, or other major acute illness were excluded.

Study design

DijiA application was developed for Android smartphone to measure ankle DF and PF ROM remotely. The purpose of the pilot study was to test the reliability of DijiA in ankle DF & PF-ROM measurement compared with UG. According to this, twenty-two of healthy university students with 44 feet were recruited in Yeditepe University. All subjects were applied applications' evaluation* ([age, gender, existing chronic diseases, surgical conditions and injuries, morning, activity and severity of night pain and System Usability Scale (SUS) survey for android], Figure 2) form before testing. After completion of testing, all of the participant were filled out the System Usability Scale (SUS) survey for measuring usability of application [14].

Instruments

Smartphone application: The Smartphone App were created to collect sociodemographic and particular information about the foot and ankle region and were authored mostly in the native (Turkish) language. Individuals might access a consent page under the KVK's (Turkish Personal Data Protection) privacy policy before proceeding to the app's home page. The participants were then requested to provide information about their sociodemographic factors [age, gender, height, weight], dominant side, diabetes, neurological and internal disorders, history of ankle injury, trauma, and surgery. VAS was used to rate the degree of foot and ankle pain in the morning, during activity, and at night (Figure 3). To eliminate problems caused by a lack of technological understanding, the interface was designed to be user-friendly and straightforward.

In order to meet with the requirements described above, a system designed and implemented. As show in Figure 1, the system is formed by a mobile component and a cloud component.

The mobile component will consist of the mobile application (The DijiA app) developed in accordance with the mobile device and device operating system on which the software will run. Accordingly, the mobile component will consist of software that creates a user interface suitable for the screen sizes of the device used, instantly stores the collected user data, communicates with the cloud component, and safely directs the stored data to the right service.

A cloud component is a platform that keeps collected data on a designed system for access *via* a web server. It runs on Amazon Web Services (AWS) consisting of three EC2 Ubuntu servers which are functionally a web server, an application server, and a database server in a Virtual Private Cloud (VPC). The web server welcomes the data packets coming from the mobile component to the cloud component and provides access to information stored in the primary database

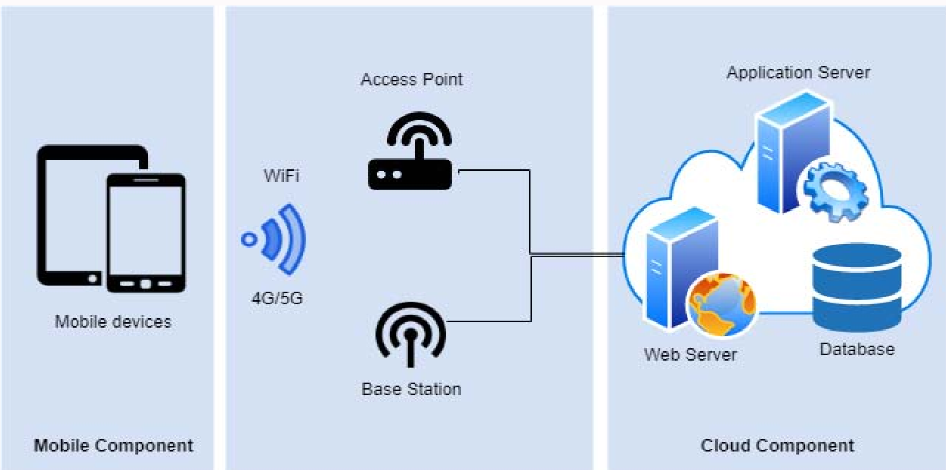

Figure 1: General architecture of the system.

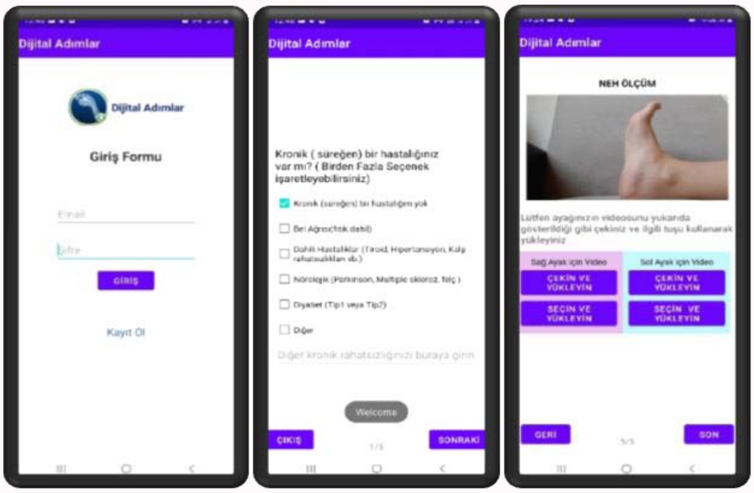

Figure 2: DijA screenshots.

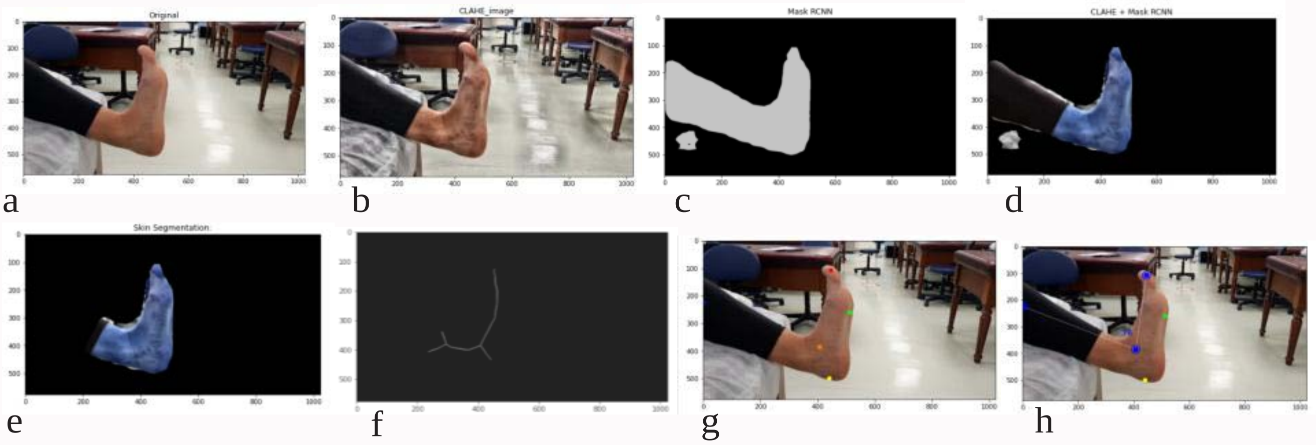

Figure 3: (a) Original frame; (b) Clahe enhancement; (c). Mask RCNN segmentation; (d) Clahe enhancement to the masked image; (e) Skin segmentation; (f). Thinning of the mask; (g) Getting extreme points and ankle; (h) Angle measurement.

which locates on the database server. Media files sent to the cloud component were kept in the file system of the database server as well. Application server runs a ROM measurement service which takes the media files from database and process to find the ROM angle of the patient. The mobile component, cloud component and ROM measurement service supplied by the cloud component are detailed in the paragraphs below.

The researcher created a systematic questionnaire and present to the user *via* mobile component. The first section of the questionnaire asked about age, weight, height, gender, existing chronic diseases, surgical conditions and injuries, morning, activity, and night pain severity. The second component of the questionnaire concentrated on the System Usability Scale (SUS), a "quick" and dependable tool. It is a ten-item questionnaire with five response options (strongly agree-strongly disagree) that evaluates a wide range of products and services (software, hardware, mobile devices, websites, and apps). According to studies, SUS scores above 68 are considered above average, while anything below 68 is deemed below ordinary [14].

The DijiA app, whose screenshots are shown in Figure 2, was initially available offline after being downloaded. Until the user has an internet connection, patient's data was saved in the local database (SQLite) on the mobile device. The video shooting step in the mobile app decided the ROMs of the patients. During the video recording phase, patients were requested to do DF and PF movements in a lengthy sitting position with a rolled towel or/and pillow under the knee. Patients were shown the steps of this procedure *via* video simulation *via* the app.

Following the completion of the mobile app's optimization and testing, those who volunteered to participate in the study were requested to download the mobile app to their phones in order to carry out the pilot study. Individuals uploaded their information onto the app, which they then downloaded to their phones and used to provide their ankle normal range of motion measures by capturing videos through the app.

Individuals completed the usability tests for evaluating the mobile app after uploading their videos to the system. The prototype of the mobile device app was tested for usability so that the latest releases contain messages that are clear, effective, consistent with the purpose, and easily understood by the target audience, and do not provoke negative responses. This test provided researchers with data on how individuals perform on questions and the app (colors, music, sounds, timing). Mixed methodologies (direct observation, interviews with

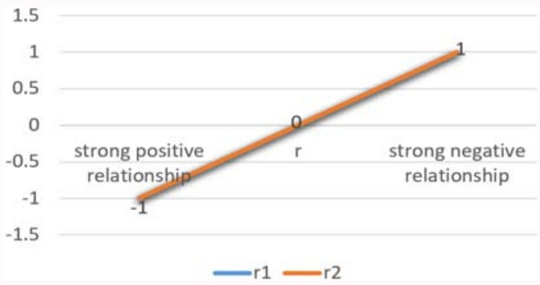

Figure 4: Pearson correlation coefficient relationship between the universal goniometer and DijiA Smartphone App.

individuals, and satisfaction surveys) were utilized in the pilot study to explain areas of progress in a cross-sectional way.

The information and video gathered from the patient are sent to the cloud component. The video file stored in database server is taken by the application server to be processed. This process can be named as a human pose estimation which is a challenge of estimating the articulated joint locations of a human body from one image or a sequence of photos of that person. This challenge has been tried to be solved with the methods developed over time. Thus, it has been observed that advances in computer learning provide more accurate human body part detection. In the light of these in-formation, we used deep learning and image processing techniques to determine the angle between leg and foot.

For segmentation of the ankle area, Mask-RCNN, a deep learning algorithm, trained with COCO dataset is used. After segmenting the region of interest, we applied image processing techniques such as CLAHE, skin segmentation, contouring and skeletonizing. The code is open source under the GNU General Public License v3.0 at https://github.com/gulsahgg/FootMaskApp. Figure 3, shows the steps to acquire the angle from a video frame.

Statistical analysis

Statistical analyzes were applied by using IBM SPSS Statistics 22 Program. The Kolmogorov–Smirnov test was applied to assess the distribution of the data. Descriptive statistics were used to define features of study groups. Pearson correlation coefficients were utilized to find significant correlations between the outcomes of two instruments. The 0.05 significance value was used.

Results

Twenty-two healthy university students with 44 feet (14 females and 8 males aged 18 to 24 years) were included in the study. DijiA pilot study participants' descriptive data (age, weight, and height) are presented in Table 1.

For comparing the Universal Goniometer (UG) and DijiA, 44 feet were available in Table 2. The mean of ROM measured with the UG were DF for 19.93 ± 8.00, PF for 38.59 ± 6.46 and measured with the DijiA were DF for 37.45 ± 29.52, PF for 78.55 ± 56.54.

According to Pearson Correlation Coefficient between the Universal Goniometer (UG) and the DijiA in measuring ankle dorsiflexion and plantarflexion were significant with DF; 95% CI = 0.06-0.65; PF; 95% CI = 0.21-0.64 (Table 3, $p<0.05$).

The variation in Pearson Correlation Coefficient between the Universal Goniometer and DijiA Smartphone App result was showed in Figure 4. According to these findings, there was a moderate positive relationship between the Universal Goniometer and DijiA ($r=0.323$ for DF, $r=0.435$ for PF, Figure 4).

The System Usability Scale (SUS) is a 10-item questionnaire with 5 response options (Appendix C). The Survey results for measuring usability of DijiA smartphone app were displayed in Table 4. In the literature, A SUS score of 68 or more is regarded above average, while anything below 68 is considered below standard. SUS score was report as 76.5 (higher perceived usability). It can be interpreted that the application usability is high and people liked it (Table 4).

The overall score given by the participants to the application was recorded by evaluating it out of 10, and the average was found to be 8.26. In addition, feedback was received from the participants expressing their opinions and suggestions for the application. Accordingly, 3 people out of 15 gave the feedback which is written in the Table 5.

Discussion

Chronic medical problems (osteoarthritis, diabetes mellitus, for example), anatomical (pes planus-cavus), better shoe wear, prolonged standing on hard surfaces, sports activity, and biomechanical (increased pronation subtalar joint, AT tightness, limited dorsi-plantar flexors weakness) factors are all associated with hindfoot pain [15-17]. Early recognition and assessment of HP risk factors can lead to successful control and prevention of these symptoms and their chronicity [15,18]. Many manual and device-based techniques are available in the literature for the early detection and evaluation of the risk factors listed above (especially foot deformity and ankle-ROM). Many techniques can be used to determine ankle joint mobility, including tape measures, digital gravity goniometers, visual estimation, inclinometers, or measurement of joint angles after radiographic visualization in maximal flexion or extension, and Universal Goniometers (UG) [19,20]. Using eye evaluation or mechanical goniometers is inexpensive, simple, and quick, but it has significant error. The higher exposure of radiographic examination prevents it from being widely employed, despite the fact that it is universally recognized as the reference procedure [21,22]. Other methods of ROM measurement (gait analysis, digital goniometers, or

Table 1: DijiA pilot study participants' descriptive data.

N=22	Minimum	Maximum	Mean ± SD
Age (years)	18	24	20.68 ± 1.72
Height (cm)	157	183	170.27 ± 9.21
Weight (kg)	47	91	65.09 ± 14.52

*Data expressed as mean ± standard deviation; N: Foot Number; ROM: Range of Motion; DF: Dorsiflexion; PF: Plantar Flexion; UG: Universal Goniometer; DijiA: Dijital Adımlar App

Table 2: Summary statistics for ankle Range of Motion (ROM) measurements in the study participants.

ROM (N=44)	Minimum	Maximum	Mean ± SD
UG			
DF	10	50	19.93 ± 8.00
PF	25	50	38.59 ± 6.46
DijiA			
DF	0	88.23	37.45 ± 29.52
PF	0	235.65	78.55 ± 56.54

*Data expressed as mean ± standard deviation; N: Foot Number; ROM: Range of Motion; DF: Dorsiflexion; PF: Plantar Flexion; UG: Universal Goniometer; DijiA: Dijital Adımlar App

Table 3: Pearson correlation coefficient between the universal goniometer and DijiA.

ROM	Pearson Correlation	%95 CI	P value
DF			
UG-DijiA	0.323	(.06-.65)	<0.01
PF			
UG-DijiA	0.435	(.21-.64)	<0.01

*Data expressed as mean ± standard deviation; N: Foot Number; ROM: Range of Motion; DF: Dorsiflexion; PF: Plantar Flexion; UG: Universal Goniometer; DijiA: Dijital Adımlar App

Table 4: Distribution of answers to the System Usability Scale (SUS) survey questionnaire for DijiA Smartphone App.

Questions	Disagree %(n)	Not sure %(n)	Agree %(n)
Complexity	86.6 (13)	6.6 (1)	6.6 (1)
Ease of use	0	6.6 (1)	93.33 (14)
Technical support need	66.6 (10)	20 (3)	13.33 (2)
Integration of functions	6.6 (1)	13.33 (2)	80 (12)
Presence of inconsistency	93.33 (14)	6.6 (1)	0
Quick use	0	20 (3)	80 (12)
App is slow	80 (12)	20 (3)	0
Confident Use	0	20 (3)	80 (12)
learn before use	66.6 (10)	26.66 (4)	6.6 (1)

Table 5: The application overall score, suggestions and feedback results for DijiA Smartphone App.

Application Overall Score (N=15) [minimum-maximum]	Feedbacks (N=3)
[0-10]	Video upload locations can be improved. The purple color used in the interface may be a different choice.
Total=124	very good
Mean=8.26	We didn't understand much. It took a short time to meet with the application, but I think it will make our work easier in the future, thank you.

imaging with computer image processing) are too time-consuming and expensive to be employed on a regular basis. Furthermore, the UG is inexpensive and widely used [21]. Munteanu et al. discovered that UG reliability (ICC 14 0.65-0.89) was worse than digital inclinometer (ICC 140.88) and acrylic plate apparatus dependability (ICC 14 0.89) in earlier research when they examined ankle joint DF in a weight-bearing position with the knee extended [23].

Moreover, Venturini et al. discovered that UG is simple to use and inexpensive; investigations have showed that goniometric results obtained by different examiners are inconsistent [24]. Despite this issue, UG remains the gold standard in clinical practice for measuring ROM [24,25]. Furthermore, because of their accessibility, low cost, and simplicity, a growing number of mobile applications on smartphones are being employed in medical settings instead of traditional measuring equipment such as UG [26]. Previously, the validity and reliability of numerous smartphone ROM measurement apps were tested, and they were discovered to be valid and trustworthy in measuring ROM in a range of joints (elbow, knee, and fifth metatarsophalangeal joints) [20,27]. According to Williams et al., who evaluated ankle DF-ROM in weight-bearing using the mobile goniometer app TiltMeter downloaded on a smartphone (ICC 0.8 or higher), measurement intra/inter-rater reliability with knee extend-flexed was shown to be excellent [28]. Two more studies [29,30] demonstrated moderate to excellent reliability and validity in the use of IOS-based goniometer applications to test weight-bearing DF-ROM. Weight-bearing the inter/intra-rater reliability of the DF-ROM assessment using the mobile goniometer software Spirit level plus loaded on an Android Smartphone was reasonable [31]. There could be several explanations for why their reliabilities were higher. The most prominent documented example is the use of various mobile goniometer applications on different types of devices with different operating systems (Android *vs.* iOS) [28]. Another consideration is that applications may have an impact on measurement differences, and their respective software platforms must be extensively evaluated. Any new version of the program that is released should be validated again [20,27].

Weight-bearing ankle-ROM assessments are nevertheless limited in that they cannot be used if weight-bearing is forbidden, and the process appears to be less objective than non-weight-bearing ones because the applied load is required to achieve the final position [23,32]. Cox et al. investigated ankle joint PF-ROM measurements in non-weight-bearing position and found that The Plaincode Smartphone app was a viable instrument for measuring PF-ROM (right foot r=0.92, p=0.00, left foot r=0.92, p=0.00, combination r=0.92, p0.00) [33]. Walaa et al. also investigated the validity and intra-rater reliability of the Smartphone app "Clinometer" for assessing ankle ROM in non-weight-bearing position using a digital inclinometer as the reference standard. Clinometer was shown to have moderate validity when compared to the digital inclinometer for ankle ROM (r=0.52-0.57) [34]. Similarly, in our investigation, we discovered a modest amount of Pearson Correlation between UG and DijiA (r=0.323, p=0.03 for DF; r=435, p.00 for PF, Table 3; Figure 4). Furthermore, a SUS score was regarded as having higher perceived usefulness, with a total average usability score of 76.5 (Table 4) [35].

The study has a few limitations. The first was the lack of a one-year follow-up assessment period and any outcomes from the combination treatment techniques' long-term impacts. Second, DijiA, one of the Smartphone apps we created, was for Android. These apps should be built into all phone OS, and their usefulness should be evaluated. Furthermore, based on the findings of the usability survey, we believe that the inter-face design of the DijiA application should be altered, and the correlation relationship should be strengthened by continuing optimization testing of the DijiA application.

Conclusion

HP can effectively reduce and avoid these symptoms, as well as their chronicity. As a result, we created a Smartphone application (DijiA) and studied its usefulness and correlation for assessing ankle range of motion. The "DijiA" app on a smartphone can be used to assess active ROM of the ankle joint without weight bearing. The study's findings revealed that the usability of the DijiA app is satisfactory and beyond industry standards. Smartphone ankle ROM assessment apps allow patients to monitor their possible risk factors without purchasing pricey hardware. This encourages patients to engage in enthusiastic self-rehabilitation and allows for the identification of risk factors in individuals suffering from hindfoot discomfort. Patients, physiotherapists, and doctors can use these apps to remotely monitor ROM at home or in the clinic using a mobile Smartphone. The findings of this study may influence practice guidelines for the management of hindfoot pain and the usage of Smartphone apps for injury prevention.

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