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A Smartphone Application Designed To Analyze Foot Deformity: A Descriptive Pilot Research (Correlation Study)

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Abstract

Introduction: An X-ray, CT scan, or foot analysis machines are important diagnostic tools for foot deformity. In the literature, several studies have investigated their effectiveness for correct diagnose. However, these methods cannot be used in a remote manner and patients have to spend considerable amount of time and money to make physical clinical visits.
Objective: We aimed to develop a low-cost, contactless system using the smartphone application to remotely evaluate foot deformity and to investigate the correlation between the smartphone application and pedographic analysis.
Method: 14 individuals (28 feet) with foot deformities were included in this study. We developed a smartphone application called 'ArdAyak' to evaluate the foot deformities remotely. Additionally, we collected pedographic analysis reports of patients by SIDAS custom foot analysis machine in a clinical setting to investigate the correlation with 'ArdAyak' application.
Results: According to pedographic analysis, the percentage of 1st degree pes planus was 36, the percentage of pes cavus was found to be 29. Additionally, the Pearson Correlation Coefficient showed moderate correlation between the pedographic analysis and ArdAyak app (r=.468, 95% confidence interval [CI]= (.07-.86), $p<0.05$).
Conclusion: The smartphone app ''Ardayak'' may have the potential to be a convenient, easy-to-use, and feasible tool for the assessment of foot deformities.

Keywords: Flatfoot, Foot Deformities, Mobile Applications, Smartphone, Talipes Cavus.

INTRODUCTION

The anatomy of the human foot, in its most basic form, permits to walk upright (1). Bones, joints, muscles, tendons, and ligaments make up the foot, and they all work together to maintain everything in place. This allows them to be both flexible and adaptive while being

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sturdy and robust. Foot malformations or misalignments (abnormal bone locations) can develop over time or be present at birth (2). Wearing tight shoes or putting unnatural strain on the foot might be contributing factors. Injuries, inflammations, and being overweight, as well as disorders like osteoarthritis, rheumatoid arthritis, and brain ailments, are all risk factors (3). Genes are generally very important: For example, some people have weak connective tissue, which means the foot's supporting components cannot always keep everything in place. Children's feet might look misshapen at times, but they are perfectly normal (2,3). This is due to the fact that foot deformities are a heterogeneous group of congenital and acquired conditions involving structural abnormalities or muscular imbalances that affect the function of the foot (3,4). The deformities are classified according to clinical appearance. The most recognizable ones are fallen arch/flat/planus and high-arched/cavus feet (4). Flatfoot refers to more severe examples of collapsed arches. Previous studies indicate the prevalence of flatfoot between < 1% and 28% at certain age groups. Weak foot muscles, improper tension on the foot, inappropriate footwear, and joint inflammations are all probable reasons of falling arches. The hollow arch under the foot is flatter than typical in patients with flatfoot (3-5). When standing or walking, the complete sole of the foot becomes flat and fully contacts the ground. After a few years, fallen arches can become uncomfortable, especially when you put your weight on them. These symptoms are rarely inherited (6). On the other hand, as a result of muscular imbalance, the cavus, or high-arched foot can appear in infancy or maturity (7). Pes cavus occurs in about 8-15% of the general population (8). The major causes of adult cavus foot deformity have been recognized as neurologic, traumatic, and idiopathic mechanisms, as well as residual clubfoot (9). The majority of foot abnormalities are apparent at birth and can be identified without the use of imaging. As a result of the formation of a stiff flator cavus or flat feet, imaging is always required to confirm the diagnosis (6). Pes planus and cavus affect gait and cause compensatory changes in other joints. Knee, hip and waist problems can be seen. Foot deformities disrupt the shoe harmony and requires an orthosis. Skin with pressure points ranging from calluses to skin ulcers due to improper pressure causes problems (10,11). These lesions are also associated with infections and they may be complicated with osteomyelitis (5,10,11). For these reasons, it is important to evaluate pes planus and pes cavus. Although there are various imaging methods that evaluate foot deformity, the most commonly used ones are somatometric measurement, radiological evaluation, ultrasonographic, inked or digital footprints (pressure measurements) and photographic techniques (12,13). All these methods are not remote evaluation systems and they require individuals to make expensive clinical visits. In addition, most individuals with these deformities cannot go to the doctor to get diagnosis until being symptomatic. The purpose of this study was to design a remote smartphone application and evaluate the correlation between the smartphone application and pedographic analysis.

METHODS

Study Design

The dependent variable of this study is foot deformity, and the independent variables are gender, age, BMI, and foot pain. This study is registered under clinical trial with NCT04423900 number.

Participants

Volunteer subjects who reported no ankle arthrodesis, acute fractures, or significant acute illnesses were recruited. The sample population included fourteen patients with a total of 28 feet (7 Females / 7 Males; average age: 22.14±2.17). Informed written consent was obtained from all participants. Ethical Standards in the 1946 Declaration of Helsinki, as revised in

2013, were followed, and the University Ethics Board approved the study (approval number; No: 129).

Procedures

After getting consent, pedographic analysis was done using the SIDAS custom station Premium Machine. Additionally, clinical examination was performed by senior orthopedic surgeon to confirm the diagnosis of foot deformity in the clinics. After the diagnosis of individuals with deformities, 'ArdAyak' application entries and measurements were made on the phones of the patients. Details of the application and designed process are given below.

General System Architectures of Smartphone Application

The overall architecture of the prototype system is made up of two major components – the mobile and cloud component. The mobile component are mobile devices running on iOS operating system. The iOS app, implemented as part of this study, is intended to provide two main functionalities; (a) taking pictures of the users' feet and processing them; (b) uploading the collected data to the cloud server platform.

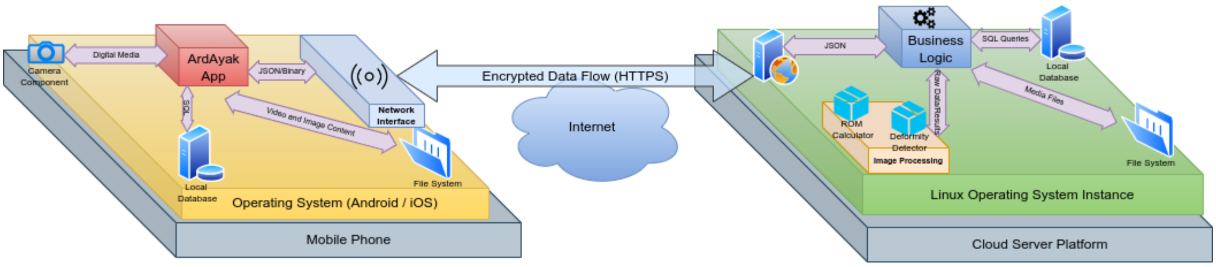

Figure 1. Overall System Architecture of the proposed solution

The cloud component is an online cloud-based platform that processes the uploaded data and keeps the findings and the collected data via the mobile app on a specially designed database. All the processes of the platform are designed as microservices. Hence, by using these services, the mobile app can interact with the cloud-based server platform to upload data and submit feet pictures for analysis. Furthermore, through the same microservices, participants or patients can log on to the system via a web interface and access their data using a browser. Similarly, the platform allows physicians and physiotherapists to log on to the platform using their browsers and access their patient data (Figure 1 &2).

In the backend, the cloud-based server platform is made of five sub-components – namely the (i) web gateway; (ii) business logic; (iii) processing unit; (iv) database; and (v) file system. Accordingly, the web gateway acts as a mediator between the business logic and the mobile app, patient web browsers and the physician web browsers. It is gate keeping and controlling the traffic towards the business logic. On the other hand, the business logic is an orchestration component which receives the user full data and distributes them to the relevant location – i.e. raw user information to the database and images to the file system. Furthermore, it keeps track of the queue for the processing unit. The processing unit receives the data from the business logic, processes them and responds with the calculated resulting data. The main database holds all the information about the patients and the system's users. Last, the file system is used a simple file storage to keep the raw patient feet pictures (Figure 1 &2).

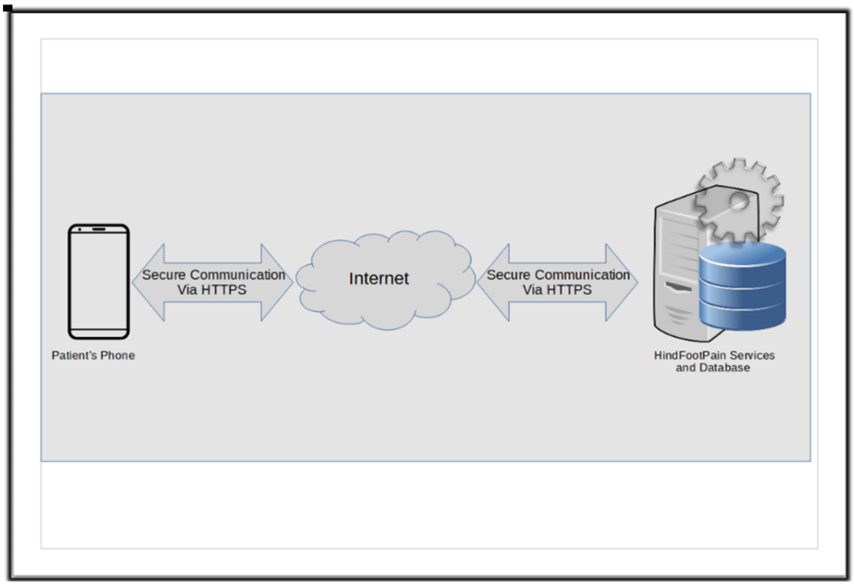

Figure 2. Communication of smartphone application with services and database

ArdAyak Application

During the evaluation phase, initially the ArdAyak app was downloaded from the App Store and installed on the participants iOS phones. As the ArdAyak app was intended towards the local community, the app used primarily native (Turkish) language of the participants. It was set that when it was first executed, it collected socio-demographic and specific information about its users and specific data about their foot and ankle region. Furthermore, a consent page under the privacy policy of the KVK (Turkish Personal Data Protection) was produced before the users could start uploading their data to confirm that they allow the collection and storage of their personal data throughout the study period. Following the data protection confirmation page, the participants were asked to provide information about their sociodemographic characteristics [age, gender, height, weight], dominant side, diabetes mellitus, neurological and internal diseases, the history of the ankle injury, trauma, and surgery by using application. Furthermore, the severity of morning, activity, and night foot and ankle pain were assessed by using a visual analogue scale (VAS) in app. The user interface of the app was designed to be as user-friendly and straightforward as possible so that even the least tech-savvy users could easily use and upload their data (Figure 3).

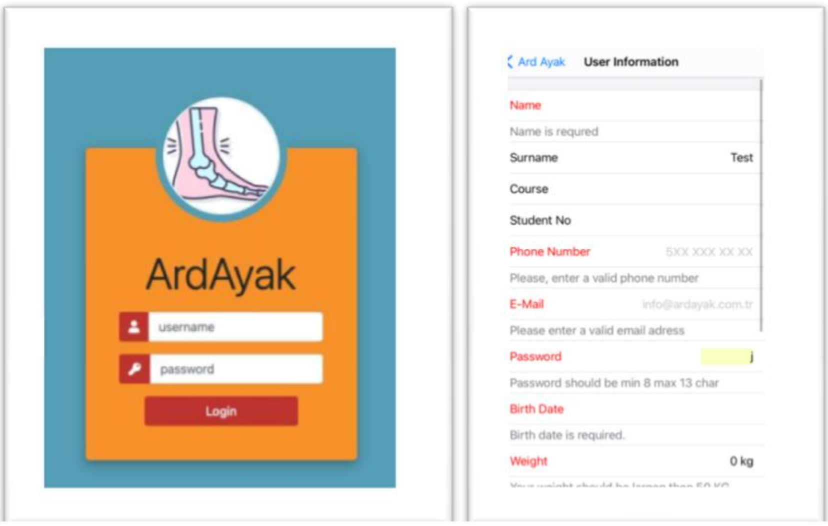

Figure 3. ArdAyak smartphone application

After completing the first stage, the participants were given the ability to take pictures of their leg with the app. During this process, the participants were asked to stand in front of a flat wall and take a picture of their right and left legs. Then, the taken pictures were sent to the cloud component's relevant microservice via a secure network connection (Figure 2). Then, the received images were forwarded to relevant microservice for analysis and categorization of the foot abnormalities. Foot analysis, abnormality detection and categorization services entail image processing and deep learning techniques to obtain the required results. Hence, the uploaded images went through the following phases (1) region of interest (deep learning); (2) Image preparation (detect the contour of the foot's sole- using Sobel edge detection algorithm); (3) image processing (detect foot line detection); (4) sole lining the Arc index is determined based on the extracted foot (Figure 4). During the phases above, the ratio of important points in a foot was also used during these computations. The locations of the points (top, bottom, and metatarsal) were also computed using the foot sole and surface ratio equations.

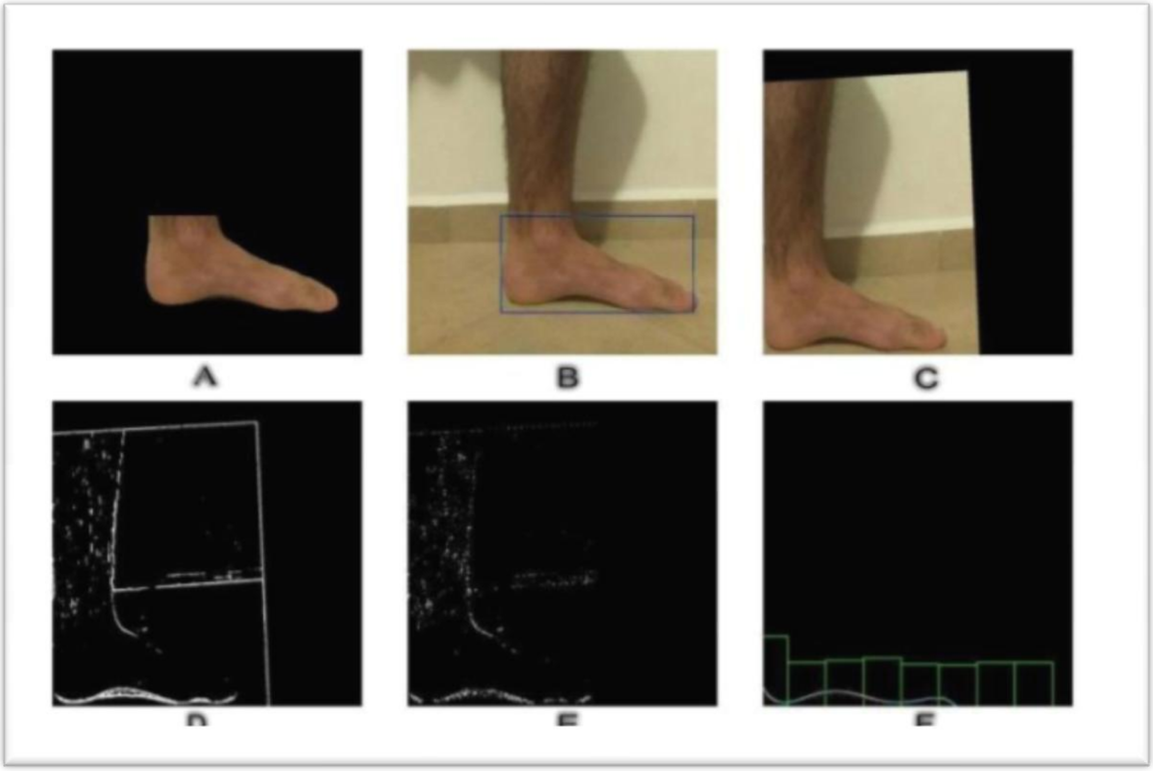

Figure 4. Foot deformity detection with the ArdAyak app

Statistical Analyses

Statistical analyzes were applied by using IBM SPSS Statistics 22 Program. 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

The study participants' descriptive data (age, weight, and height), mean, minimum and maximum values of shoe size, morning, activity and night pain are presented in Table 1.

Table 1. ArdAyak Smartphone Application Participants' Descriptive Data

N=14 participants	Minimum	Maximum	Mean ±SD
Age (years)	21	29	22.14±2.17
Height (cm)	159	191	172.28±11.53
Weight (kg)	50	100	66.85±17.19
ROM (N=28 feet)	**Minimum**	**Maximum**	**Mean ±SD**
Morning Pain	.00	3.00	.17±.66
Activity Pain	.00	5.00	1.03±1.68
Night Pain	.00	.00	.00
Shoe size	36	46	41.07±8.49

The comparison of foot deformity distribution numbers according to pedographic analysis (sidas- custom station premium and ardayak smartphone app) is shown in Table 2. While the percentage of 1st degree pes planus was 36, the percentage of pes cavus was found to be 29 percent.

Table 2. A Comparison of Foot Deformity Distribution Between the Pedographic Analysis and ArdAyak Smartphone Application

Characteristic N=28	Pedographic Analysis (n)	Smartphone App (n)
Pes cavus	8	6
Pes Planus 1	10	11
Pes Planus 2	8	7
Pes Planus 3	2	2
Unknown	0	2

App: Application.

The Pearson correlation coefficient was used to examine concurrent validity, which defines instrument performance, between sidas-custom station premium and the Ardayak smartphone app (r). The Pearson correlation coefficient can range from -1 to 1. There was a strong link between the sidas-custom station premium and Ardayak smartphone app measures (Table 3, p<.05), according to the data. Furthermore, for foot deformity, investigation revealed moderate correlations between the sidas-custom station premium and Ardayak smartphone app, with r values of 0.468. (moderate direct relationship).

Table 3. Pearson Correlation Coefficient Between the Pedographic Analysis and ArdAyak Smartphone Application

N=28	Pearson Correlation	%95 CI	P value
Pedographic Analysis-Smartphone App	.468	(.07-.86)	<.01

CI: confidence interval, App: Application.

DISCUSSION

Clinical examination, somatometric measurement, radiologic, and ultrasonographic evaluations are some of the approaches used to assess foot deformities (pes planus and pes cavus) (13-15). Inked or digital pressure footprints, as well as photographic indirect approaches are discussed in the literature. The radiological examination appears to be the most frequently recognized and used detection approach. Although the greater exposure from radiographic examination prevents it from being extensively utilized, it is universally accepted as the standard approach (12-16).

Chen et al. (17) analyzed the arch index and radiographic findings of 103 people's navicular and talar heights and found that the Chippaux-Smirak index, Clarke's angle, and Staheli arch index have 90.54, 83.89, and 85.43 percent prediction probability in preschool-aged children, respectively ($p<.05$). Pauk et al. (18) also compared Clarke angle and radiography readings of sixty youngsters and discovered a connection ($p<.05$) between radiography and footprint technique. Many studies have also looked at the relationship between radiography and footprint methods. Kanatli et al. (12) conducted radiologic measures and footprint techniques with 38 preschoolers and school-aged children with an average age of 6.4 (ages range from 3.7–11.7) and found a link between arch index, talo–first metatarsal, and talo–horizontal angle ($p<.05$). They discovered that arch index, calcaneal pitch, and lateral talocalcaneal angles had no statistically significant relationship ($p>.05$). Another study analyzed the footprint and radiographic measures of 338 persons, finding a good association between the Staheli index, ChippauxSmirak index, and the Grivas Classification System ($p<.05$). The authors also emphasised a weak correlation between the radiological measurement methods calcaneal pitch and talo-first metatarsal angle and all three foot-print methods (15). In the current study, our proposed smart phone app 'ArdAyak' had a moderate relationship of correlation between the pedographic analysis with r values of 0.468 ($p= .01$).

To the best of our knowledge, this is the first study that can evaluate pes planus and pes cavus foot deformity remotely by a designed smartphone app called 'Ardayak'. It gives to the patient the advantage of monitoring their potential risk factors for secondary complications of the foot and ankle without buying expensive devices. Despite the benefits of using smartphone app, the study has some limitations. Larger sample size would better for the correlation results. Additionally, we designed iOS smartphone app, future studies should focus on developing android smartphone app and investigating their reliability and validity.

CONCLUSIONS

The smartphone app ''Ardayak'' may have the potential to be a convenient, easy-to-use, and feasible tool for the assessment of foot deformities. This motivates the patients for an enthusiastic self-evaluation in their home area. Furthermore, we may say that with this promising smartphone application, it is possible to evaluate the foot deformity, which is a risk factor for many pathologies in the early period, without requiring expensive measurement and analysis devices. Patients, physiotherapists, and physicians may use these apps to remotely assess in-home or clinic area using a personal smartphone.

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Author Contributions

Working Concept / Design	: ETÇ, TŞ, UŞ, FS
Data collecting	: ETÇ, TŞ, SHD
Data Analysis / Interpretation	: SHD, UŞ, FS
Writing Draft	: ETÇ, UŞ, FS
Technical Support / Material Support	: TŞ, SHD
Critical review of content	: ETÇ, UŞ, FS
Literature Review	: ETÇ

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