Characteristics of Musculoskeletal Imaging of the Foot in Healthy Subjects Analyzed by Photogrammetry: A Non-invasive Methodology in Medical Examination.

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Abstract: This study aimed to determine the characteristics of the musculoskeletal imaging of the foot in healthy subjects analyzed by photogrammetry. This study was exploratory and descriptive and was carried out on a group of healthy subjects from Trujillo (Peru) using a prototype of cameras around a podoscope and imaging analysis software called ImageJ. The parameters of photographic imaging to characterize the measurements were the length of the foot, the width of the foot, and dorsal height. The parameters of photographic imaging to characterize normal or variant was the measurements of angles of the hallux and 5th foot for forefoot, the arch index for the midfoot, and positional angle of the rearfoot. The 30 healthy subjects evaluated had an average age of 25.06+/-11.95 years, the women predominated with 53.3%, the photographic imaging was found only variants of the forefoot in 20% and a total length of the foot, meta-tarsal width, and instep height average for the right side in 226. 55±36.49mm, 98.99±22.71 mm, and 36.32±4.07 mm respectively; and for the left side at 229.81±42.25 mm, 104.49±16.84, and 36.31±3.32 respectively. In conclusion, the characterization of the musculoskeletal imaging presented the only variant in the forefoot, and their measurements mentioned were lower than other studies. This methodology is useful in non-invasive medical examinations to determine deformity.

Keywords: Foot, Photogrammetry, Musculoskeletal.

I. INTRODUCTION (*HEADING 1*)

The incidence of diabetes mellitus has quadrupled in the last two decades worldwide [1]. Foot deformity is a major component of the diabetic foot [2].

The normality of the musculoskeletal system is based on anatomical and physio-logical criteria regarding a common pattern of measurement and its variability [3]. Anatomical variability is defined as a modification of the usual presentation of a body part that does not require treatment [4]. The musculoskeletal anatomy of the foot is evaluated with measurements of length, width, height, angulations of its different parts concerning the standing position in the longitudinal, coronal, and axial planes [5].

The most important non-invasive anatomical musculoskeletal assessment methods of the foot are photogrammetry and B-mode ultrasound [6]. Photogrammetry allows precise information to be obtained about the surface structure of an object in a particular environment using photography or another method [7].

Some previous studies using photogrammetry have considered the total length, total width, and dorsal height of foot as the most important linear measurements and other measurements such as internal length, external length, metatarsal width, heel width, hallux height, and instep height [8,9]. The most important angular measurements and indexes of the foot considered by some studies that have managed to validate them using photogrammetry were the index of the plantar arch for the midfoot and the postural angle for the hindfoot [10,11]. Other angular measurements have been validated using digital radiography such as the intermetatarsal angle of the 1st and 2nd rays for the hallux and the intermetatarsal angle of the 4th and 5th rays for the 5th toe [12,13].

The use of a non-invasive medical optical methodology to identify the measurements and state of normality of the foot and extrapolate it in the pathology of foot deformity has justified the objective to identify the characteristics of the musculoskeletal images of the foot in a group of healthy subjects using photogrammetry based on longitudinal, angular and index measurements.

II. MATERIALS AND METHODS

A. Design and Variables

The design of this study was descriptive and exploratory. The characteristics of the musculoskeletal images considered as a variable were the linear measurement of the foot that was evaluated in length, width, and back height in millimeters, Yadav et al in 2015 [8]. On the other hand, the variable angular measurement and index of the plantar arch were evaluated in the forefoot (hallux and fifth toe), the midfoot and the rearfoot.

The hallux was evaluated in the anterior foot, which was categorized as normal when the intermetatarsal angle of the 1st and 2nd bone rays was + 12 degrees to - 5 degrees in the horizontal plane [12]. The fifth toe was categorized as normal when the intermetatarsal angle of the 4 and 5 bone rays was +3 to +9 degrees [13].

Midfoot was evaluated in the whole plantar zone, it was categorized as normal when the arch index presented values between 0.21 and 0.26 in the horizontal plane [14]. The arch

index is the area of the midfoot divided by the sum of forefoot, mid-foot, and rearfoot area.

Rearfoot was evaluated in the posterior area of the foot; this was categorized as normal when the angle of the rearfoot was +5 degrees to - 5 degrees in the longitudinal plane [11].

Forefoot, midfoot, and rearfoot with measurements different from those mentioned above were considered as variants.

B. Population, Sample, and Sampling

The study population was healthy subjects over 18 and under 40 years of age and both sexes. The excluded subjects were pregnant women, amputees of lower limbs, psychomotor disabilities, congenital and/or acquired deformities of the spine and lower limbs. The proposed sample was of 30 subjects who have the inclusion and exclusion criteria, chosen by non-probability sampling for expert convenience. The unit of analysis was the right and left foot of each subject evaluated.

C. Collection Technique

The data collection techniques were the measurement made on the two-dimensional images using hardware and software. The hardware for the musculoskeletal evaluation was transparent, green-light, gridded podoscope with two Logitech Webcam model C310 HD Webcam (5-megapixel optical sensor and fixed image stabilizer).

The first camera placed on a tripod with an adaptation for circular sliding in the horizontal plane was initially located 30 cm in front from front to back along the line between both malleoli of the subject's ankle, sliding to the same point from back to front and finally sliding to the right and left sides focused on the midpoint of the internal plantar arch of the foot. The second camera without a tripod was located inside a podoscope 30 cm below the methacrylate platform and was directed at a point equidistant from both internal plantar arches. The software was free software for image processing called ImageJ for Microsoft Windows 10. The images obtained in this study were in JPEG format that can be analyzed by the mentioned software. The linear and arch index measurements were previously calibrated to the real size and then processed in millimeters. Calibration was not necessary for the angular measurements.

The data collection consists of demographic data, clinical examination, and measurements; the measurement data were validated by previous studies mentioned in the introduction to this article.

D. Procedure

The evaluation site was a diabetic foot clinic unit in the city of Trujillo located on the northern coast of Peru.

The subject of study was positioned in a standing position with a square bottom (each square had 2cm of side), mobile for the lateral, frontal, and under the methacrylate approaches being the region of interest the foot and the ankle in all its magnitude. The posterior photograph was obtained by the posterior approach and the lateral photographs were right and left by turning the subject on the methacrylate platform. The inferior photograph was obtained below the transparent methacrylate. The photographs of the region of interest were in JPG format to be processed by the ImageJ software. The photographs were performed by a trained technician and the images were analyzed by an expert in the software. The categorization of normal or variant concerning angular and arch index measurements was decided for the expert researcher. The details of the linear measurements were shown in figure 1 and angular and arch index measurements were shown in Figure 2.

E. Statistical Analysis and Ethical Aspects

Descriptive statistics were made using the SSPP 25 software to calculate frequencies, averages, and standard deviation. The study was approved by the ethics committee of the University César Vallejo in 2019. The informed consent was performed to all subjects and the confidentiality of the data was protected.

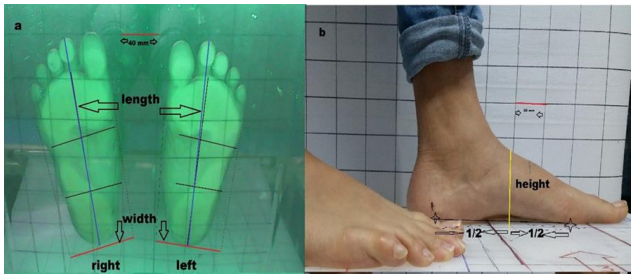

Figure 1. Linear measurements on photographic images considered for evaluation on healthy subjects by ImageJ.

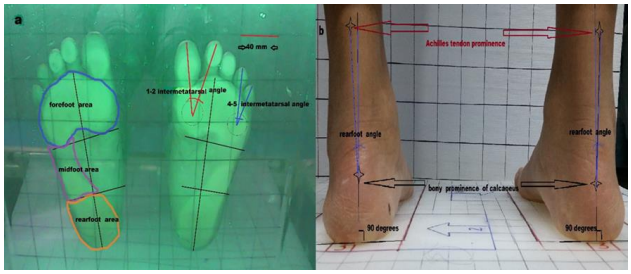

Figure 2. Angular and arch index measurements on photographic images considered for evaluation in healthy subjects by ImageJ.

III. RESULTS

The 30 health subjects had an average age of 25.06 ±11.95 years, predominated women in 53.3%, and predominated athletic physical constitutions by 50%. The average shoe size was 39.35±2.67 and overweight according to body mass index was 50%. The averages and standard deviation of linear measurements of the 30 healthy subjects corresponding to length, width, and dorsal foot in millimeter are shown in Table 1. The angle measurements in degree are shown in Table 2, and the right and left arch index measurements were 0.23±0.2 and 0.22±0.1 respectively. The categorization of the normal foot for the forefoot, midfoot, and rearfoot was 80%, 100%, and 100% respectively. The variant of the foot was located in the forefoot and they corresponded to 3 subjects in the hallux, 2 subjects in the 5th toe, and 1 subject in both.

Table 1. Linear measurements of musculoskeletal images of the foot in 30 healthy subjects using photogrammetry.

Measurement	Right (mm)	Left (mm)
Total length	226.55±36,49	229.81±42,25
Total width	98.99±22.71	104.49±16.84
Dorsal Height	36.32±4.07	36.31±3.32

Table 2 Angular measurements of the musculoskeletal images of the foot in 30 healthy subjects using photogrammetry**.**

Measurement	Right (°)	Left (°)
1-2 intermetatarsal angle	11.2±3.47	10.8±3.41
4-5 intermetatarsal angle	6.4±2.82	6.2±3.34
Rearfoot angle	2.13±1.43	2.09±1.56

IV. DISCUSSION

This study focused on the musculoskeletal anatomy of the foot using linear measurements and categorization of normal or variant using angular and arch index measurements.

Clinical examination of the foot is performed by a specialized physician on palpation or clinic tools and this procedure is systematic, operator-dependent, and requires training [15]. Traditional examination of the foot requires the operator to use instruments such as caliper and goniometer for linear and angular measurements respectively and calculation of the arch index is performed by a conventional plantigrade and podoscope [16,17,18]. Therefore, the traditional exploration alone shows limitations that are improved by the digital podoscope that was used in this study and which were analyzed by software. The proposed digital podoscope of this study was similar to that, O'Meara et al in 2010 [9].

The linear measurements of the foot found in this study were lower than two mentioned studies [8,9]; these lower length and dorsal height were explained because the mentioned studies were performed in European subjects whose height is greater and the predominance of the male gender explained by the dimorphism of the foot [19,20]. The linear measurement of the width of the foot in our study was slightly higher than the studies mentioned above due to the presence of variability in the forefoot that influences the metatarsal area and their predominance in women who have more the presence of hallux valgus and tailor's bunion [21,22]. This study could not be compared with another because that other studies didn't consider linear, angular, and arch index measurements together.

The measurements of the foot in this study presented variants only in the forefoot which was not considered pathological because there was no presence of pain or corns [23]. This study presented variants that can cause a deformity in healthy subjects over decades [24].

One limitation of this study was to categorize as normal or variant only for one evaluator and the other was that the angular measurements of the forefoot were extrapolated from radiographic studies. The strength of this study was the use of hardware and software validated in other studies.

V. CONCLUSION

This exploratory descriptive study on the characteristics of the musculoskeletal images of the foot in a group of healthy subjects using linear measurements was smaller than other studies and the categorization of angular and arch index measurements had a low frequency of variants which were located in the forefoot. The use of this photographic image methodology can be extrapolated to ergonometric and clinical practice for measuring feet and identifying deformity respectively.

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