ARTICLES

Standardizing Foot-Type Classification Using Arch Index Values

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ABSTRACT

Purpose: The lack of a reliable classification standard for foot type makes drawing conclusions from existing research and clinical decisions difficult, since different foot types may move and respond to treatment differently. The purpose of this study was to determine interrater agreement for foot-type classification based on photo-box-derived arch index values. ***Method:*** For this correlational study with two raters, a sample of 11 healthy volunteers with normal to obese body mass indices was recruited from both a community weight-loss programme and a programme in physical therapy. Arch index was calculated using AutoCAD software from footprint photographs obtained via mirrored photo-box. Classification as high-arched, normal, or low-arched foot type was based on arch index values. Reliability of the arch index was determined with intra-class correlations; agreement on foot-type classification was determined using quadratic weighted kappa (κ_w). ***Results:*** Average arch index was 0.215 for one tester and 0.219 for the second tester, with an overall range of 0.017 to 0.370. Both testers classified 6 feet as low-arched, 9 feet as normal, and 7 feet as high-arched. Interrater reliability for the arch index was ICC = 0.90; interrater agreement for foot-type classification was $\kappa_w = 0.923$. ***Conclusions:*** Classification of foot type based on arch index values derived from plantar footprint photographs obtained via mirrored photo-box showed excellent reliability in people with varying BMI. Foot-type classification may help clinicians and researchers subdivide sample populations to better differentiate mobility, gait, or treatment effects among foot types.

Key Words: foot deformities; photography; dermatoglyphics; reliability of results.

RÉSUMÉ

Objectif : L'absence d'un système fiable pour le classement des types de pieds fait en sorte qu'il est très difficile de parvenir à des conclusions à partir des recherches existantes et de prendre des décisions cliniques, puisque des pieds formés différemment peuvent bouger différemment et réagir de manière différente aux traitements. L'objectif de cette étude était d'en arriver à un consensus entre évaluateurs pour le classement des types de pieds en fonction de valeurs d'indice établies à partir de photos de la cambrure du pied réalisées à l'aide d'une boîte à miroir. ***Méthode :*** Pour cette étude corrélationnelle à deux évaluateurs, un échantillon de 11 bénévoles en bonne santé avec indice de poids corporel variant de normal à obèse a été recruté au sein d'un groupe participant à un programme de perte de poids et parmi des personnes recevant des traitements en physiothérapie. L'indice de la cambrure de leur pied a été calculé à l'aide du logiciel AutoCAD et à partir d'empreintes obtenues à l'aide d'une boîte à miroir pour la prise de photos. Un classement des cambrures selon divers types – cambrure élevée, normale ou faible – a été effectué à partir des valeurs d'indices pour la cambrure du pied. La fiabilité de ces indices a été déterminée à l'aide de corrélations intraclasses; le consensus quant au classement des types de pieds a été obtenu à l'aide d'un indice quadratique kappa pondéré. ***Résultats :*** L'indice moyen des cambrures était de 0,215 pour un évaluateur et de 0,219 pour le deuxième évaluateur, avec une étendue globale de 0,017 à 0,370. Les deux évaluateurs ont classé 6 des pieds de l'étude comme étant peu cambrés; 9 des cambrures ont été jugées normales et 7 pieds présentaient des cambrures prononcées. La fiabilité entre les évaluateurs pour l'indice des cambrures des pieds était CCI = 0,90; le consensus entre évaluateurs pour le classement des types de pieds comportait un kappa pondéré de 0,923. ***Conclusions :*** Le classement du type de pied en fonction de valeurs d'indices de la cambrure obtenues à partir d'empreintes plantaires réalisées à la suite de photos prises avec une boîte à miroir a fait preuve d'une grande fiabilité chez des personnes à IMC variables. Le classement des types de pieds peut aider les cliniciens et les chercheurs à subdiviser les populations échantillons afin de mieux différencier la mobilité, la démarche et les effets des traitements selon les types de pieds.

A "gold standard" method for determining foot type has yet to be established, and clinical observation remains the method most often relied upon.[1] Measures of navicular drop, arch height, dorsal foot height, longitudinal arch angle, and hindfoot angle have demonstrated poor to good reliability in supporting clinical determinations of foot type,[2] but the reliability of these measurements in classifying foot type has not been investigated.

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Arch index values, based on the contact area of the middle section of the plantar footprint, have been used to determine foot type.[3] Arch index values calculated by footprint analysis have been obtained from force plate,[3] carbon footprint paper,[4] and photographs taken with a mirrored glass box.[5,6] The moderate to good correlations between radiographic measures of calcaneal inclination angle and arch index have been shown to be stronger than the correlation between the same radiographic measures and clinical assessment of navicular height.[4] Arch index calculated with AutoCAD software (Autodesk Inc., San Rafael, CA) from scanned footprint photographs has correlated well ($r = 0.841$) with arch index obtained from an inked footprint.[7] Concurrent validity compared to radiographs of photo-box-measured truncated foot length, upon which arch index calculations are based, is similar to caliper measurements.[6] Overall, using digital plantar footprint photographs obtained with mirrored photo-boxes has been shown to be a valid method of estimating arch height,[8] reliable for calculating arch index values,[5] and safe for both individuals of normal weight and those with obesity.[5,6]

A moderate correlation between BMI and occurrence of pes planus exists;[9] differences have been found between children with and without obesity.[10] Arch index also varies with age, falling into the normal adult range by age 5.[11] Whether among obese or non-obese people,[10] school-aged children or adults,[11] or men or women from different countries,[12] arch index values fall into the different ranges of arch index values suggested and used as a potential method to classify high-arched, normal, and low-arched foot types.[12,13] The reliability of classifying foot type by this method has not been investigated, however. Our purpose in this study, therefore, was to determine the interrater reliability of classifying foot type based on photo-box-derived arch index values.

METHODS

Design

This two-tester interrater reliability study was approved by the Institutional Review Boards of Columbia University Medical Center and St. Luke's–Roosevelt Hospital Center Institute for Health Sciences and was conducted at the Columbia University Program in Physical Therapy and the St. Luke's–Roosevelt Hospital Center New York Obesity Research Center.

Participants

A total of 11 volunteers were recruited via announcement from a weight-loss programme and a physical therapy programme. Power analysis suggested that 10 participants were required ($\alpha = 0.05$, power $= 0.80$, $r > 0.7$[14(p.850)]). The 22 feet of 11 subjects were included to increase the likelihood that there would be at least 2 feet of each foot type included in the study.

The participants (7 women, 4 men) were ambulatory community-dwelling adults with a mean (SD) age of 32.4 (14.9) years, body mass index (BMI) of 27.6 (7.0), and average European shoe size of 40.3. Three subjects were classified as obese (BMI $\geq$ 30), three as overweight (BMI $\geq$ 25 but $<$30), and 5 as normal (BMI $<$ 25).

Procedures

All participants gave informed consent, then provided information including age, sex, culture, height, weight, and European shoe size. The two testers varied in terms of their clinical experience: one was a licensed physiotherapist with more than 15 years' experience, the other a student in a Doctor of Physical Therapy programme. Both were newly trained in the study methods, having received 1 hour of training divided between online instruction with a physiotherapist familiar with the methods and independent practice in obtaining arch index values and determining foot type before consensus discussions. Each tester, with no knowledge of the other tester's results, independently analyzed the feet in sequential participant recruitment order.

Foot type was determined by obtaining arch index values using a digital plantar foot photograph taken while the subject stood on the mirrored photo-box. A digital camera (Kodak Easyshare C613; Kodak, Rochester, NY) mounted on a low tripod was aimed at a mirror angled at approximately 45° such that the reflection of the plantar surface of each foot was captured through the transparent top of an otherwise wooden platform. The box was 38 cm tall with a square top (46 cm $\times$ 46 cm) made of 1.2 cm thick tempered glass.

As described elsewhere,[4] two copies of the digital plantar footprint photograph were analyzed with AutoCAD to calculate the arch index: each tester measured footprint length, excluding toes, and mathematically divided this truncated footprint into three equal lengths representing the anterior, middle, and posterior foot.[2,3] Arch index values were calculated by dividing the midfoot area by the total footprint area: arch index $=$ middle / (anterior $+$ middle $+$ posterior).[2,3]

Foot type was classified based on the arch index value. The arch index values of the feet of 107 healthy American men and women aged 30.1 (9.9) years were divided into quartiles and used to define foot types: arch indices $\geq$0.260 were considered low-arched; arch indices between 0.210 and 0.260 were considered normal; and arch indices $\leq$0.210 were considered high-arched.[13]

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 16.0 for Mac (SPSS-UK Ltd., Woking, Surrey, UK). Normality of demographic data was analyzed using the Shapiro–Wilk test ($p < 0.05$). Interrater reliability of arch index values was calculated using intra-class correlation 2-way mixed method for individual scores. Quadratic weighted kappa

(κ_w), a chance-corrected measure of interrater agreement penalizing non-adjacent disagreements (e.g., high- versus low-arched) more than adjacent disagreements (e.g., high-arched vs. normal), was calculated using an online calculator.[15] Interrater agreement >0.80 was considered excellent.[14(p.604)]

RESULTS

The 11 participants' 22 feet were included. Demographic data fell in a normal distribution (Shapiro–Wilk $p > 0.05$), except for age ($p = 0.012$). Mean (SD) arch index was 0.215 (0.101) and 0.219 (0.095) for the two testers and ranged from 0.017 to 0.370. Both testers classified 6 feet as low-arched, 9 feet as normal, and 7 feet as high-arched, although there were two disagreements. Reliability of the arch index values was ICC = 0.990 (95% CI, 0.976–0.996), obtained with individual measures and a 2-way mixed-effects model. The interrater agreement for foot classification was $\kappa_w = 0.923$ (95% CI, 0.755–1.00).

DISCUSSION

Calculation of arch types using a digital photograph obtained via photo-box showed excellent interrater reliability.[14] Although the two novice testers had different levels of clinical experience, our results suggest that the study methods can be learned quickly. Reliability may have been enhanced by using AutoCAD to analyze the digital photographs.

Classification of foot types based on the photo-box arch index values also demonstrated excellent interrater agreement.[14] The high reliability of the arch index values may have aided agreement on classification. Like any classification system based on continuous data, foot-type classification based on arch index led to some disagreements despite similar values. Overall, the two raters classified 20 of 22 feet the same; both disagreements were within 0.003 of a matching classification. Given the continuous classification schema,[3] potentially small disagreements in arch index values may be inevitable, which underscores the importance of using objective measures to classify foot types.

Classification of foot types may lead to more specific understanding of different foot types. Pronated and normal feet classified using the Foot Posture Index, a clinical assessment based on visual observation and ratings of the foot, have demonstrated different midfoot mobility.[16] Clinical judgment based on visual inspection of foot appearance, however, can vary among practitioners, leading to misclassifications.[17,18] A classification system based on verifiable digital photographic arch index values obtained using a photo-box may assist in future research to specify mobility, gait, and foot orthotic effectiveness for different foot types.

Our study had several limitations. Although the participant sample size exceeded the minimum estimated by the power analysis, and participants' data fell within a normal distribution, the sample was small, and our results might have differed with a larger study sample. Although we made an effort to recruit subjects with varying BMIs, ranges of BMI values were not represented evenly, nor were foot types distributed evenly. Although our study examined the testers' reliability in analyzing the footprint photographs, no attempt was made to determine how consistently participants placed their feet on the mirrored photo-box for the photograph. Furthermore, the mirrored box was custom made and was not standardized with mirrored photo boxes used in other research. While arch index has shown moderate correlations with static radiographic and clinical foot measures,[4] we did not compare our classification method with any other foot-type classification system, and its validity remains unknown.

CONCLUSION

Using arch index values obtained from digital photography using a photo-box to classify foot type as high-arched, normal, or low-arched, based on defined ranges, proved to be a reliable method that led to excellent agreement between raters. Classifying feet to subdivide sample populations may help differentiate mobility, gait, or treatment effects among foot types in future research and clinical practice.

KEY MESSAGES

What is already known on this topic

A variety of foot measures, including arch index, have been shown to be reliable and related to other static measures. Yet static measures have not correlated strongly with motion in gait, in part because some study samples have included mixed foot types.

What this study adds

Classification of foot type based on arch index values rather than clinical judgments demonstrated excellent agreement. Standardized foot-type classifications allow sample subdivisions that may further our understanding of different mobility characteristics or treatment effects among high-arched, normal, and low-arched foot types in future research and clinical practice.

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