Foot morphological variations between different ethnicities and sex: a systematic review
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**Abstract**

Foot morphology varies between individuals of different sex and ethnicities across the world. Most commonly measured are foot length and breadth which have practical implications in shoe design and forensics. This review aims to identify relevant papers on the topic of foot morphological variation, and compare results. Searches were carried out on PubMed, Scopus and Web of Science until January 2020. Live human subjects age 16 and over were included the study. Included studies were analysed using the Anatomical Quality Assurance (AQUA) Checklist (Tomaszewski et al., 2017) to determine the quality and reporting from the studies. Any study using cadavers, paediatric participants and those with any underlying condition that affected foot shape were excluded. This review included 17 studies involving 15,235 participants from across the globe. Evidence suggests that foot morphology differs among ethnicities and sex. Most significant differences were found between the Asian population when compared to Australian and Pacific Islanders. Females had smaller foot morphological measurements across all studies with the exception of lateral talocalcaneal angle and calcaneal pitch in two African studies which indicate the higher arch profile of females in this ethnic group. This review highlights the differences in foot morphology that exist between individuals of the same and different ethnicities and sex. Foot length is most commonly used for stature estimation and sex prediction and is more accurate for prediction than foot breadth. Results highlight the need for global shoe and orthotic manufacturers to broaden fit of footwear for worldwide inclusion and continued research with greater sample size and ethnicities to be studied.

Key terms: Nationality, gender, feet, shape, characteristic

**Introduction**

Globally, there are hundreds of ethnic groups which have different biological characteristics. Anthropometric measures between individuals of the same ethnicity varies and even more so when compared with individuals of different ethnicities across the world (Vergara, 2019). One of these distinguishable features is foot characteristics which are based and variant upon an individual’s origin (Shariff et al., 2019). Previous research has shown variation in foot morphology between different ethnicities (Castro-Aragon et al., 2009; Dahiru et al., 2013; Dunn et al., 2004; Gurney et al., 2009). However, global anthropometric studies based on a large variation of ethnicities studied is sparse (Ahmed et al., 2014).

Foot morphological measures reported in the literature vary but commonly reported measures are foot length and breadth (Hyer et al., 2004; Shariff et al., 2019; Shu et al., 2015). A full morphological description of the foot has been suggested to comprise 26 anthropometric measurements (Agić et al., 2006), though these are not consistently carried out in current literature. The complex dynamic nature of the foot must also be considered when discussing foot function and morphology (Agić et al., 2006; Gurney et al., 2009). Within each ethnicity, foot morphology differences also exist between sexes. Examples for these variations include metatarsal characteristics (Griffin & Richmond, 2005), metatarsal base thickness (Hyer et al., 2004), calcaneal angle (Igbigbi & Mutesasira, 2003) and foot length (Choi et al., 2014), to name a few.

Understanding in foot morphology between sexes and ethnicities have multiple purposes but is especially needed for consideration in footwear designing and manufacturing (Gurney et al., 2009). Indications from the literature suggest the importance for worldwide brands to offer a wide range of fitting footwear for both males and females. Overall, research on foot morphology is commonly limited to cover a small number of ethnic groups or nationalities. Findings from these studies have not been collectively evaluated in an attempt to synthesize clinical recommendations and measurements for global use. Therefore, the final aim of this study is to conceptualise how ethnicity/nationality and sex affect foot anthropometry and how these measures have been performed in research.

**Methods**

This systematic review adhered to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines (Page et al., 2021) . It was ensured that this systematic review was not in the International Prospective Register of Systematic Reviews by searching our title on the website (Page et al., 2018) and searching Google Scholar.

Search strategy

Potentially eligible studies were identified through a systematic search in electronic databases (PubMed (1996-2021), Scopus (1996-2021) and Web of Science (1950-2021)) from inception to January 23rd 2020. The search terms (foot OR feet OR forefoot OR midfoot OR rearfoot OR heel OR calcaneus OR cuboid\* or cuneiform\* OR ankle\* OR talus OR tarsal\* OR phalange\* OR hallux\*OR toe) AND (morpholog\* OR size\* OR shape\* OR length\* OR anatom\*) AND (ethnic\* OR racial\* OR race\*) AND (sex OR gender) were used. The generation of search terms was generated in accordance with the PICO framework (Huang et al., 2006).

We used two extra search approaches to identify any potentially eligible articles that could have been missed in the electronic database search. Additional searches were performed using initially included studies. A citing reference search was done using Google Scholar up to February 2020. Hand searching of the reference lists of eligible papers was also carried out to ensure no papers that could have been included in the systematic review were missed.

Literature screening

All articles to be reviewed following the literature search were uploaded to Mendeley (Version 1.19.4, Mendeley Ltd, London, UK) and duplicates were removed. Following this, articles were uploaded to Rayyan (Ouzzani et al., 2016) to facilitate blinded abstract and title screening by two of the three reviewers (CH, AU, RJ). This ensured a non-biased screening process. Titles and abstracts were screened through the inclusion and exclusion criteria to identify potentially relevant articles. Disagreements were resolved by a fourth reviewer (KK).

Inclusion and exclusion criteria

Inclusion:

* Sex – *the term sex was used as it is biological whereas gender is not defined*
* Ethnicity – *Only studies which defined the population based on their ethnic origin or nationality and/or specified the sex of their subjects were included.*
* Human population of which are alive – *Cadaver studies were not included in this review as bone studies results from deceased humans differ when compared to human subjects* (Nester, 2009)*.*
* Adults (aged 15 or older) – *Children’s feet stop growing around the age of 15* (Walther et al., 2008) *and therefore the age of 16 and above was decided on as a group.*
* Healthy BMI – *BMI out of the normal range can influence foot posture*
* Healthy population – *conditions such as diabetes can alter foot shape,* *therefore a healthy sample group will be more representative of the populations foot morphology*
* Non-injured – *foot injuries may also modify normal foot shape*
* English speaking
* Published literature - *original peer-reviewed articles only and no reviews to be included. If multiple publications reported on the same study, we prioritised the article originally written to avoid reporting on the same participants twice* (Khan & Nataraja Moorthy, 2015)

Exclusion:

* Deceased participant or dry bone studies
* Diagnosis of foot altering condition such as diabetes or any neurological condition. Underweight (BMI <18.5) or overweight (BMI >30).
* Duplicate publications on the same cohort of participants
* Those in a foreign language.

Quality assessment

The authors CH and AW blindly scored the reporting quality of each study using the Anatomical Quality Assurance (AQUA) checklist (Tomaszewski et al., 2017). Any discrepancies were resolved by a third reviewer (KK). Due to the nature of the studies included in this review a checklist was selected for specificity. The AQUA checklist contains 8 sections with a total of 29 items. However, one item was excluded to modify the checklist as it was not applicable in this review. This made the maximum score of 28. The item excluded from the AQUA checklist was item number 27, ‘Acknowledge individual(s), institution(s), or third parties who significantly contributed to the study’. This was excluded from the checklist as it does not reflect the quality of a paper and it is an optional element for authors to consider.

Due to the heterogenous nature of the data and the lack of effect of a variable being measured a meta-analysis was not necessary to be carried out in this review.

Data extraction and summary measures

Data from all included articles were extracted by three reviewers (KK, AW, CH). The information extracted from the studies included:

* Size of the population being studied
* Demographics (i.e. age, sex, ethnicity/nationality, height, mass)
* Outcome measures
* Methods and equipment used to collect outcome measures
* Findings of outcome measures

The main outcome measures of interest in this review were foot length and breadth. The data will be separated into male and female sections. The highest and lowest mean values for each foot measurement in males, females and between ethnicities will be determined from the data collected. Geographical mapping was also used and created on Excel to give a visual representation of ethnical involvement from around the world (Figure 2).

**Results**

***Study selection***

The literature search yielded 9,315 results (Figure 1). After duplicates were removed 5,943 remained. Of these, 5,893 were excluded during the initial screening stage. This left 50 for eligibility and full reading, of which 17 studies met the inclusion criteria (Figure 1). The reasons for excluding articles after screening were foreign language (N=6), wrong outcome (N=8), inclusion of a systemic disorder in participants that would affect foot morphology such as Gurney et al (Gurney et al., 2012) who included diabetic patients as one half of the population being studied (N=4), merged sex or ethnicity data (N=6), cadaver bone studies (N=4), data extracted from a separate study (N=3) infants included in one study and incorrect species (N=2). No additional studies were gained from reference list screening or via author citation searches (Figure 1).

**Figure 1.** PRISMA flow chart (Page et al., 2021).

\*\*\*\* Figure 1 near here\*\*\*\*

***Quality assessment:***

All 17 studies were cross-sectional in design. The highest scoring studies achieved a score of 21/28 (Hemy et al., 2013; Shu et al., 2015), and the lowest scoring studies received a score of 7/28 (Dezhen, 1989). Majority of studies failed to disclose firstly, how their sample size was reached and second, identifying any potential sources of bias (Table 1).

**Table 1**. AQUA Checklist scores

\*\*\*\* Table 1 near here\*\*\*\*

***Participant characteristics***

The 17 studies included 15,235 individual participants subdivided to 8,972 males and 6,263 females (Table 2a and 2b). The smallest sample size was 18 female participants (Dahiru et al., 2013) and the largest sample size was 2,750 participants (Kim et al., 2018) Age ranged from 16-84 (Table 2a and 2b). Ethnical groups included South Korean (Kim et al., 2018), Taiwanese (Y.-C. Lee & Wang, 2015) Japanese (Baba, 1974), Indian (Nataraja Moorthy et al., 2014; Sen et al., 2011a), Malaysian (Khan & Nataraja Moorthy, 2015; Nataraja Moorthy & Hairunnisa Bt Mohd, 2016b, 2016c, 2016a)Turkish (Ozaslan et al., 2012), Spanish (Rodríguez et al., 2013), Croatian (Agić et al., 2006), Western Australia (Hemy et al., 2013), Nigerian (Dahiru et al., 2013), Masaii (Choi et al., 2014), and Ugandan (Igbigbi & Mutesasira, 2003). As a continent Asia was the most represented geographical region (Figure 2; Table 2a and 2b).

\*\*\*\* Table 2a and 2b near here\*\*\*\*

\*\*\*\* Figure 2 near here\*\*\*\*

**Figure 2**. Participant numbers included in review illustrated by shading map of the world (***a***) females and males, (***b***) females and (***c***) males

***Measurements performed***

Measurements for morphological data extraction used most commonly were foot length (female N=10, male N=13) followed by width (female N=7, male N=7; Figure 3 and 4). A wide variety of other foot measures were also performed, however the maximum of studies looking at the same measure was 2 studies (Table 3). The studies additionally utilised a variety of measuring styles varying in body position when measure being taken, equipment used, and definition of measure taken (Table 4). Measurement equipment used in the studies varied between the use of sliding callipers (Baba, 1974; Ozaslan et al., 2012; Sen et al., 2011a), tape measures (Agnihotri et al., 2007; Baba, 1974), rulers (Hemy et al., 2013) and more advanced methods such as 3-D scanning (Y.-C. Lee & Wang, 2015; Shu et al., 2015) or digital techniques (Hemy et al., 2013). Importantly, some studies failed to disclose the equipment used and majority of studies did not present the validity and reliability of the used equipment. (Table 3).

***Variations in measures - Foot length***

Foot length for women has been assessed in a single African group, six Asian groups, one European group, one North American group and one group from Oceania (Figure 3). Results varied among the different ethnicities with East Malaysian Iban women recording the lowest mean length of 21.3±1.0 cm (Nataraja Moorthy & Hairunnisa Bt Mohd, 2016a), whilst the longest mean foot length was recorded for Western Australian women (24.6±1.2 cm; Figure 3) (Hemy et al., 2013). Foot length for men has been assessed in a single African group, eight Asian groups, two European groups, one North American group and one group from Oceania (Figure 3). Results also varied among the different ethnicities with East Malaysian Iban men also having the lowest recorded mean length of 23.1±1.1 cm (Nataraja Moorthy & Hairunnisa Bt Mohd, 2016a), whilst the longest mean foot length was also recorded for Western Australian men (27.4±1.4cm ; Figure 3**;**(Hemy et al., 2013).

 \*\*\*\* Figure 3 near here\*\*\*\*

**Figure 3.** Mean foot length for female and males expressed by ethnicity

***Variations in measures - Foot width***

Foot length for women has been assessed in five Asian groups, one European groups, and one group from Oceania (Figure 4). Results varied among the different ethnicities with Turkish women recording the lowest mean width of 8.6±0.6 cm (ratio 0.38) (Ozaslan et al., 2012), whilst the largest mean foot width was recorded for Western Australian women (9.4±0.5; ratio 0.40; Figure 4**;** (Hemy et al., 2013). Foot length for men has been assessed in five Asian groups, one European groups, and one group from Oceania (Figure 4). Results also varied among the different ethnicities with Turkish men also having the lowest recorded mean width of 9.4±0.7 cm (ratio 0.37**;** (Ozaslan et al., 2012), whilst the largest mean foot width was recorded for Taiwanese men (10.4±0.6; ratio 0.4; Figure 4**;** (Y.-C. Lee & Wang, 2015).

\*\*\*\* Figure 4 near here\*\*\*\*

**Figure 4.** Foot width for females and males expressed by ethnicity as mean and ratio to foot length

***Variations in measures - Other foot measures***

An additional 17 foot shape measures were assessed in the literature (Table 3) in addition to ten additional foot length measures not targeting the maximum distance (Table 3). Of the 17 measures, 14 were only assessed in a single study, such as ball of the foot length or ball girth (Table 3). When more than one measure was published, variations were seen in measure description and equipment used (Table 3).

**Discussion:**

This systematic review is the first to provide a synthesis of evidence on foot morphology and how it differs between different sex and ethnicities. Understanding foot morphology based on sex and ethnicity is essential for global shoe manufacturing, orthotic design and forensic work (Wunderlich & Cavanagh, 2001). Not only does this systematic review highlight the importance of understanding foot morphology, it also unfortunately highlights the disparity between researchers and countries on what is required to adequately measure a human foot.

***Limitations of the current literature***

Seventeen studies were included in this systematic review, however multiple limitations to interpretation of the information were recognised by the authors of this paper. (i) The overall quality of the papers gathered, with only two achieving 75% on a quality assessment checklist (Hemy et al., 2013; Shu et al., 2015). (ii) The measures conducted were limited. The two main morphological features measures were foot length (N=13) and foot breadth (N=7). Other measurements included forefoot circumference, arch height (N=1), calcaneal angle (N=1), calcaneal pitch (N=1), lateral talocalcaneal angle, (N=1) length of the first metatarsal (N=1), and hallux angle (N=1). Other studies presented measurements with less morphological importance such as the minimal distance from the hallux to the second toe (Shu et al., 2015).

(iii) Poor measures procedure clarity. Older studies applied sliding callipers (Baba, 1974; Ozaslan et al., 2012; Sen et al., 2011b), tape measures (Agnihotri et al., 2007; Baba, 1974) and rulers (Hemy et al., 2013). Two studies utilised 3-D scanning (Y.-C. Lee & Wang, 2015; Shu et al., 2015), which has been proven to give more accurate and precise data when compared to traditional measurement methods with a mean absolute difference between all measurement methods of only 3mm (Y. C. Lee et al., 2014). As long as equipment reliability and validity are acknowledged, these are only minor concerns to raise. Another more prominent measurement issue encountered was the lack of measures procedure disclosure such as anatomical locations used which further complicated our ability to compare outcomes between studies. Various measurement conditions were used including those standing, fully weight bearing (Y.-C. Lee & Wang, 2015), single leg weight bearing (Moorthy & Khan, 2015; Nataraja Moorthy et al., 2014) and some were measured under ‘No Load’ conditions (Agić et al., 2006). (iv) Varying sample sizes throughout the review also meant global comparisons between ethnicities were difficult to make. Asia was most heavily researched with majority of participants studied being Japanese (N=1934)(Baba, 1974), Taiwanese (N=3000)(Y.-C. Lee & Wang, 2015), and South Korean (N=2750)(Kim et al., 2018). Given the absence of high-quality studies and their essential limitations to methodology transparency definitive conclusions were difficult to make regarding foot morphological differences and how to accurately carry out measurements.

***Expectations from future research***

Given the disparities in studies, we cannot currently describe variabilities in foot morphology between sexes or ethnicities. Precise anatomical measurement procedures must be clarified for future research to be accurate, comparable and, hence meaningful. Lee et al (Y. C. Lee et al., 2014) demonstrated this well how this could be obtained by using six defined measurements of foot length, ball of foot length, outside ball of foot length, foot breadth diagonal, foot breadth horizontal and heel breadth. Each measurement was described using an exact definition. This extent of clarity of measurement must be given in all future research.

For precise future research the ISO 20685-1:2018 document should be adhered to (Agić et al., 2006; Kouchi & Mochimaru, 2011; Y. C. Lee et al., 2014). Telfer and Woodburn reported the ISO has been produced ‘with the aim of ensuring that measurements taken using 3D scanning systems are comparable with those taken using traditional methods and can be sued in anthropometric databases’ (Shu et al., 2015; Telfer & Woodburn, 2010). Indeed a more accessible document to future researchers would be the IEEE paper written by a Footwear Subgroup which includes a modern compilation of foot measurement definitions (IEEE, 2014).

Another element future research must consider is the measuring conditions of the subject. All measurements should be taken at the same time of day, morning ideally to avoid foot deformation with potential swelling (Burrow, 2016). The dominant foot should be selected, and the subject should be fully weightbearing with a normal posture.

Although 3D scanning is not without intra and inter-observer errors (Kouchi & Mochimaru, 2011), it should be used when collecting foot morphological data in future research. 3D scanning is more reliable, accurate and has a reduced incidence of human error (Y. C. Lee et al., 2014; Telfer & Woodburn, 2010). Future studies should aim to report their inter/intra-rater reliability and equipment accuracy level and validity when carrying out measurements of the foot and indeed the entire body.

***Are there morphological differences between ethnicities and sexes?***

Finally, future studies should aim to involve a varied population from across the globe. Differences between ethnicities were certainly seen in this review. Foot breadth differences were seen in the male population with Taiwanese males demonstrating the widest foot (10.4 +/-0.6) (Y.-C. Lee & Wang, 2015). Interestingly in the study by Agnihotri et al (Agnihotri et al., 2007) females exhibited a wider foot than males in the same Indo-Mauritian population. From the studies included in this review that studied foot length, large variation was seen when comparing the Asian (Nataraja Moorthy & Hairunnisa Bt Mohd, 2016a) and Australian population (Hemy et al., 2013) who have significantly larger feet. This is potentially due to the shorter stature of Asian participants although, without demographic data on the subjects this cannot be concluded. These findings were similar to those of Jurca et al who analysed 1.2 million foot scans, however they did not distinguish between ethnicities and therefore was not included in this study, albeit the largest data pool of foot scans studied to date (Jurca et al., 2019). In the male population, foot length values were similar amongst the Western Australian and Croatian population (Agić et al., 2006; Hemy et al., 2013). Unfortunately, there were no females included in this Croatian study so no comparison of sexes could be made. Overall, the number of subjects studied in each paper varied greatly and thus highlights the need to larger and more diversity in the populations to be studied.

***Strength and limitation***

This review is not without its limitations. Studies written in the English language only were included in this review as it was the only language of all authors. Only three databases were used in this review, however, the PRISMA guidelines were followed for best practice when conducting systematic reviews. We are limited in our systematic review that paper can or may be missed during the search process despite strict follow of methodology. This review did not include any participants under the age of 16. This was to avoid including participants who were still in a growth phase. Grey literature was also excluded from this review as by definition may include data which is not controlled by commercial publishing organisations (Adams et al., 2016).

**Conclusion**

Based on the findings of this study it is clear foot morphology differs between ethnicities and sex. This was most evidently seen when comparing the Australian and Asian populations. This review also founds males to have a longer and wider foot than females with the exception of one Indo-Mauritian population where the female’s feet studied were wider. However, the small number of ethnicities included in this review are a vast underrepresentation of the global population and it is therefore difficult to conclusively state findings.

The studies included in this review varied in quality with several limitations such as sample size and poor methodological design. However, these limitations could be overcome as outlined above for future research. The findings of this study may be used to inform orthotic design and shoe manufacturing as to the variation that exists in foot morphology between individuals of different ethnicities and sex.

**References:**

Adams, J., Hillier-Brown, F. C., Moore, H. J., Lake, A. A., Araujo-Soares, V., White, M., & Summerbell, C. (2016). Searching and synthesising ‘grey literature’ and ‘grey information’ in public health: Critical reflections on three case studies. *Systematic Reviews*, *5*(1), 1–11. https://doi.org/10.1186/s13643-016-0337-y

Agić, A., Nikolić, V., & Mijović, B. (2006). Foot anthropometry and morphology phenomena. *Collegium Antropologicum*, *30*(4), 815–821.

Agnihotri, A. K., Purwar, B., Googoolye, K., Agnihotri, S., & Jeebun, N. (2007). Estimation of stature by foot length. *Journal of Forensic and Legal Medicine*, *14*(5), 279–283. https://doi.org/10.1016/j.jcfm.2006.10.014

Ahmed, S., Akhter, A. B., Anwar, S., Begum, A. A., Rahman, K., & Saha, N. C. (2014). Comparison of the Foot Height, Length, Breadth and Types between Santhals and Bangalees of Pirganj, Rangpur. *Bangladesh Journal of Anatomy*, *11*(1), 30–33. https://doi.org/10.3329/bja.v11i1.20506

Baba, K. (1974). Foot measurement for shoe construction with reference to the relationship between foot length, foot breadth, and ball girth. *Journal of Human Ergology*, *3*(2), 149–156. https://doi.org/10.1016/0003-6870(76)90175-7

Burrow, J. G. (2016). Is Diurnal Variation a Factor in Bare Footprint Formation? *Journal of Forensic Identification*, *66*(2), 107–117.

Castro-Aragon, O., Vallurupalli, S., Warner, M., Panchbhavi, V., & Trevino, S. (2009). Ethnic radiographic foot differences. *Foot and Ankle International*, *30*(1), 57–61. https://doi.org/10.3113/FAI.2009.0057

Choi, J. Y., Suh, J. S., & Seo, L. (2014). Salient features of the Maasai foot: Analysis of 1,096 Maasai subjects. *Clinics in Orthopedic Surgery*, *6*(4), 410–419. https://doi.org/10.4055/cios.2014.6.4.410

Dahiru, A. U., Ojo, S. A., Hamidu, A. U., & Danborno, B. (2013). Calcaneal Pitch and Lateral Talocalcaneal Angle among Nigerians. *International Journal of Morphology*, *31*(2), 528–532. https://doi.org/10.4067/s0717-95022013000200028

Dezhen, C. C. (1989). Regression analysis of four physical characteristics-stature, length of thigh, length of leg and length of foot of the male population in Sichuan Province. *International Journal of Anthropology*, *4*(4), 287–294. https://doi.org/10.1007/BF02444644

Dunn, J. E., Link, C. L., Felson, D. T., Crincoli, M. G., Keysor, J. J., & McKinlay, J. B. (2004). Prevalence of Food and Ankle Conditions in a Multiethnic Community Sample of Older Adults. *American Journal of Epidemiology*, *159*(5), 491–498. https://doi.org/10.1093/aje/kwh071

Griffin, N. L., & Richmond, B. G. (2005). Cross-sectional geometry of the human forefoot. *Bone*, *37*(2), 253–260. https://doi.org/10.1016/j.bone.2005.04.019

Gurney, J. K., Kersting, U. G., & Rosenbaum, D. (2009). Dynamic foot function and morphology in elite rugby league athletes of different ethnicity. *Applied Ergonomics*, *40*(3), 554–559. https://doi.org/10.1016/j.apergo.2008.11.001

Gurney, J. K., Kuch, C., Rosenbaum, D., & Kersting, U. G. (2012). The Māori foot exhibits differences in plantar loading and midfoot morphology to the Caucasian foot. *Gait and Posture*, *36*(1), 157–159. https://doi.org/10.1016/j.gaitpost.2012.01.013

Hemy, N., Flavel, A., Ishak, N.-I., & Franklin, D. (2013). Sex estimation using anthropometry of feet and footprints in a Western Australian population. *Forensic Science International*, *231*(1–3), 402.e1-402.e6. https://doi.org/10.1016/j.forsciint.2013.05.029

Huang, X., Lin, J., & Demner-Fushman, D. (2006). Evaluation of PICO as a knowledge representation for clinical questions. *AMIA ... Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, 359–363.

Hyer, C. F., Philbin, T. M., Berlet, G. C., & Lee, T. H. (2004). The obliquity of the first metatarsal base. *Foot and Ankle International*, *25*(10), 728–732. https://doi.org/10.1177/107110070402501006

IEEE. (2014). Comprehensive Review of Foot Measurements Terminology in Use. *Danish Medical Journal*, *61*(9), 1–23.

Igbigbi, P. S., & Mutesasira, A. N. (2003). Calcaneal angle in Ugandans. *Clinical Anatomy*, *16*(4), 328–330. https://doi.org/10.1002/ca.10104

Jurca, A., Žabkar, J., & Džeroski, S. (2019). Analysis of 1.2 million foot scans from North America, Europe and Asia. *Scientific Reports*, *9*(1), 1–10. https://doi.org/10.1038/s41598-019-55432-z

Khan, H. B. M. A., & Nataraja Moorthy, T. (2015). Stature estimation from the anthropometric measurements of footprints among Melanaus: An indigenous population of Malaysian Borneo. *Canadian Society of Forensic Science Journal*, *48*(2), 68–84. https://doi.org/10.1080/00085030.2015.1019225

Kim, W., Kim, Y. M., & Yun, M. H. (2018). Estimation of stature from hand and foot dimensions in a Korean population. *Journal of Forensic and Legal Medicine*, *55*(January), 87–92. https://doi.org/10.1016/j.jflm.2018.02.011

Kouchi, M., & Mochimaru, M. (2011). Errors in landmarking and the evaluation of the accuracy of traditional and 3D anthropometry. *Applied Ergonomics*, *42*(3), 518–527. https://doi.org/10.1016/j.apergo.2010.09.011

Lee, Y. C., Lin, G., & Wang, M. J. J. (2014). Comparing 3D foot scanning with conventional measurement methods. *Journal of Foot and Ankle Research*, *7*(1). https://doi.org/10.1186/s13047-014-0044-7

Lee, Y.-C., & Wang, M.-J. (2015). Taiwanese adult foot shape classification using 3D scanning data. *Ergonomics*, *58*(3), 513–523. https://doi.org/10.1080/00140139.2014.974683

Moorthy, T. N., & Khan, H. B. M. A. (2015). Estimation of Stature from Footprint Anthropometry Using Regression Analysis: A Study on the Bidayuh Population of East Malaysia. *Arab Journal of Forensic Sciences and Forensic Medicine*, *1*(1), 114–122. https://doi.org/10.12816/0011255

Nataraja Moorthy, T., & Hairunnisa Bt Mohd, A. K. (2016a). Body weight estimation from various footprint length measurements among Ibans of East Malaysia. *Malaysian Applied Biology*, *45*(2), 113–118.

Nataraja Moorthy, T., & Hairunnisa Bt Mohd, A. K. (2016b). Estimation of body weight from foot outline length measurements in Melanau population of East Malaysia. *Malaysian Applied Biology*, *45*(2), 125–130.

Nataraja Moorthy, T., & Hairunnisa Bt Mohd, A. K. (2016c). Stature estimation from anthropometric measurements of footprints in Lun Bawang, an indigenous ethnic groups of East Malaysia by linear regression analysis. *Malaysian Applied Biology*, *45*(2), 69–74.

Nataraja Moorthy, T., Mostapa, A. M. Bin, Boominathan, R., & Raman, N. (2014). Stature estimation from footprint measurements in Indian Tamils by regression analysis. *Egyptian Journal of Forensic Sciences*, *4*(1), 7–16. https://doi.org/10.1016/j.ejfs.2013.10.002

Nester, C. J. (2009). Lessons from dynamic cadaver and invasive bone pin studies: Do we know how the foot really moves during gait? *Journal of Foot and Ankle Research*, *2*(1), 1–7. https://doi.org/10.1186/1757-1146-2-18

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan-a web and mobile app for systematic reviews. *Systematic Reviews*, *5*(1), 1–10. https://doi.org/10.1186/s13643-016-0384-4

Ozaslan, A., Karadayi, B., Kolusayin, M. O., & Kaya, A. (2012). *Predictive role of hand and foot dimensions in stature estimation*. 41–46. https://doi.org/10.4323/rjlm.2012.41

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., & Moher, D. (2021). Updating guidance for reporting systematic reviews: Development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology*, *134*, 103–112. https://doi.org/10.1016/j.jclinepi.2021.02.003

Page, M. J., Shamseer, L., & Tricco, A. C. (2018). Registration of systematic reviews in PROSPERO: 30,000 records and counting. *Systematic Reviews*, *7*(1), 1–9. https://doi.org/10.1186/s13643-018-0699-4

Rodríguez, S., Miguéns, X., Rodríguez-Calvo, M. S., Febrero-Bande, M., & Muñoz-Barús, J. I. (2013). Estimating adult stature from radiographically determined metatarsal length in a Spanish population. *Forensic Science International*, *226*(1–3), 297.e1-297.e4. https://doi.org/10.1016/j.forsciint.2012.12.006

Sen, J., Kanchan, T., & Ghosh, S. (2011a). Sex Estimation from Foot Dimensions in an Indigenous Indian Population. *Journal of Forensic Sciences*, *56*(SUPPL. 1), 148–153. https://doi.org/10.1111/j.1556-4029.2010.01578.x

Sen, J., Kanchan, T., & Ghosh, S. (2011b). Sex Estimation from Foot Dimensions in an Indigenous Indian Population. *Journal of Forensic Sciences*, *56*(SUPPL. 1), 148–153. https://doi.org/10.1111/j.1556-4029.2010.01578.x

Shariff, S. M., Merican, A. F., & Shariff, A. A. (2019). Development of new shoe-sizing system for Malaysian women using 3D foot scanning technology. *Measurement: Journal of the International Measurement Confederation*, *140*, 182–184. https://doi.org/10.1016/j.measurement.2019.03.057

Shu, Y., Mei, Q., Fernandez, J., Li, Z., Feng, N., & Gu, Y. (2015). Foot morphological difference between habitually shod and unshod runners. *PLoS ONE*, *10*(7), 1–13. https://doi.org/10.1371/journal.pone.0131385

Telfer, S., & Woodburn, J. (2010). The use of 3D surface scanning for the measurement and assessment of the human foot. *Journal of Foot and Ankle Research*, *3*(1), 1–9. https://doi.org/10.1186/1757-1146-3-19

Tomaszewski, K. A., Henry, B. M., Kumar Ramakrishnan, P., Roy, J., Vikse, J., Loukas, M., Tubbs, R. S., & Walocha, J. A. (2017). Development of the Anatomical Quality Assurance (AQUA) checklist: Guidelines for reporting original anatomical studies. *Clinical Anatomy*, *30*(1), 14–20. https://doi.org/10.1002/ca.22800

Vergara, E. S. (2019). *NORMAL AND PATHOLOGICAL FOOT BONES VARIABILITY IN HISTORICAL AND MODERN SERIES*.

Walther, M., Herold, D., Sinderhauf, A., & Morrison, R. (2008). Children sport shoes-A systematic review of current literature. *Foot and Ankle Surgery*, *14*(4), 180–189. https://doi.org/10.1016/j.fas.2008.04.001

Wunderlich, R. E., & Cavanagh, P. R. (2001). Gender differences in adult foot shape: Implications for shoe design. *Medicine and Science in Sports and Exercise*, *33*(4), 605–611. https://doi.org/10.1097/00005768-200104000-00015