جامعة نايف العربية للعلوم الأمنية
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Arab Journal of Forensic Sciences & Forensic Medicine
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المجمعة العربية لعلوم الأدلة الجنائية والطب الشرعي
Arab Society for Forensic Sciences and Forensic Medicine

Original Article

Determination of Sex from Footprint Dimensions in Contemporary Indian Bengali Population: A Pilot Study

تحديد الجنس من أبعاد طبعة القدم في سكان المجتمع الهندي ذي الأصول البنغالية المعاصر: دراسة استطلاعية

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Received 14 Feb. 2018; Accepted12 Apr. 2018; Available Online 03 Jun. 2018

Abstract

Footprint dimensions are vital evidences obtained from scenes of crime. Forensic scientists use this information to help identify the offender. Footprints have also been used to build the biological profile of an unknown individual for identification. The measurements are specific for race and sex. The objectives of the present study are to examine the sexual dimorphism of footprint dimensions in adults of an Indian Bengali sample and determine the sex from those measurements.

The study was done on 100 adult volunteers of ethnic Bengali origin of West Bengal. Footprints were taken on glossy paper with blue stamp pad ink, and then measurements were taken to the nearest mm. Discriminant function analysis was conducted using several linear measurements, and discriminant function was obtained. Sex determination was successful in 82.0% of the samples.

This study provides useful baseline morphometric data of footprints of the Indian Bengali population, which will aid in forensic investigations.

Keywords: *Forensic Sciences, Forensic Anthropology, Sexual Dimporphism, Footprint, Indian Bengali, Discriminant Function Analysis.*

المستخلص

تعتبر أبعاد طبعة القدم هي أدلة حيوية يتم الحصول عليها من مسرح الجريمة. في كثير من الأحيان يستخدم علماء الطب الشرعي هذه المعلومات للمساعدة في التعرف على الجاني باستخدام السمات الشخصية. وتستخدم آثار الأقدام لبناء المظهر البيولوجي لفرد مجهول لتحديد الهوية وتعد القياسات محددة للعرق والجنس. تهدف الدراسة الحالية إلى فحص الفروقات بين الجنسين من خلال شكل طبعات القدم لدى البالغين في عينة من سكان المجتمع الهندي ذي الأصول البنغالية وتحديد الجنس بواسطة قياسات طبعات القدم.

أجريت الدراسة على 100 متطوع هندي من أصل بنغالي من منطقة غرب البنغال. أخذت آثار أقدام على ورق لامع بعد طبع القدم بحبر أزرق موجود على لبادة ختم، وبعد ذلك تم أخذ القياسات إلى أقرب ملليمتر. وأجري تحليل التمييز الخطي باستخدام عدة قياسات خطية. وقد تم الحصول على وظيفة تمييزية، والتي عند تطبيقها تمكنت من تحديد الجنس بشكل صحيح بنسبة 82.0 ٪.

توفر هذه الدراسة بيانات مورفومترية أساسية مفيدة من آثار أقدام السكان الهنود ذوي الأصول البنغالية والتي تساعد في التحقيقات الجنائية.

الكلمات المفتاحية: علوم الأدلة الجنائية، الأنثروبولوجيا الجنائية، الفروقات بين الجنسين، طبعة القدم ، الهنود ذوي الأصول البنغالية، تحليل التمييز الخطي

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doi: 10.26735/16586794.2018.009

1. Introduction

A footprint is the impression left by a foot after being placed on a surface. The nature of the impression is dependent on various functional, morphological and structural aspects of the foot. The pressure distribution depends on the angle of the step and arch of the foot. It is also attributed to the weight of an individual and any anatomical deformation they might have e.g. cavus foot type, hallux valgus, and toe deformities. In addition, some medical conditions like diabetic foot affect pressure distribution. All these factors may differ in males and females and thus produce relative differences in footprint dimensions. Several studies clearly indicate the existence of sexual dimorphism in footprint morphology and morphometry [1-13]. Determination of stature [2-4, 14-16] and sex [17-19] from footprints have been investigated in different populations. Studies have indicated that predicting sex is an important component of the process of establishing the identity of an individual [5, 6]. Often, the sex of the offender can be determined from the dimensions of a footprint that is found at the scene of a crime. Forensic scientists and anthropologists have shown considerable interest in studying footprint dimensions for aiding criminal investigation agencies. Forensic podiatry is "the application of sound and researched podiatry knowledge and experience in forensic investigations, to show the association (or disassociation) of an individual with a scene of crime, or to answer any other legal question concerned with the foot or footwear that requires knowledge of the functioning foot" [4]. Pioneering work and extensive research in forensic podiatry has been done by Burrow [5-8] in the recent past.

The objectives of the present study are to examine the sexual dimorphism of footprint dimensions in adults of an Indian Bengali sample and determine the sex from those measurements by discriminant function analysis (DFA).

2. Materials and Methods

The study was done on 100 adult volunteers of ethnic Bengali origin of West Bengal, India. After obtaining informed consent, their static weight-bearing [9,10] footprints were taken on white A4 size glossy printing quality paper with blue stamp pad ink. Firstly, the feet were cleaned and wiped dry. The volunteers were then asked to smear blue ink on the plantar aspect of the foot. Footprints were then taken on white paper, marked and preserved for measurement. Foot measurements were taken using a standard technical quality stainless-steel scale to the nearest mm. One observer took the measurements twice at a gap of seven days and the mean was recorded. Prior to this, a paired t-test was conducted to test intra-observer-agreement. Furthermore, 20 random cases were measured by two authors and inter-observer agreement was tested by Cohens Kappa test. This was done for all the variables to ensure repeatability of the measurements. Bilateral measurements were also taken but only the left side was used in the analysis according to the principle of "non-dominant" foot. This approach was adopted after reviewing the literature on bilateral asymmetry of feet and issues in selection of feet for barefoot print analysis [5-8,10]. The following measurements were used in the present study (Figure-1):

a. F1- Length from the pternion (A) to B the most anterior point of toe 1.

b. F2- Length from the pternion (A) to C the most anterior point of toe 2.

c. F3- Length from the pternion (A) to D the most anterior point of toe 3.

d. F4- Length from the pternion (A) to E the most ante-

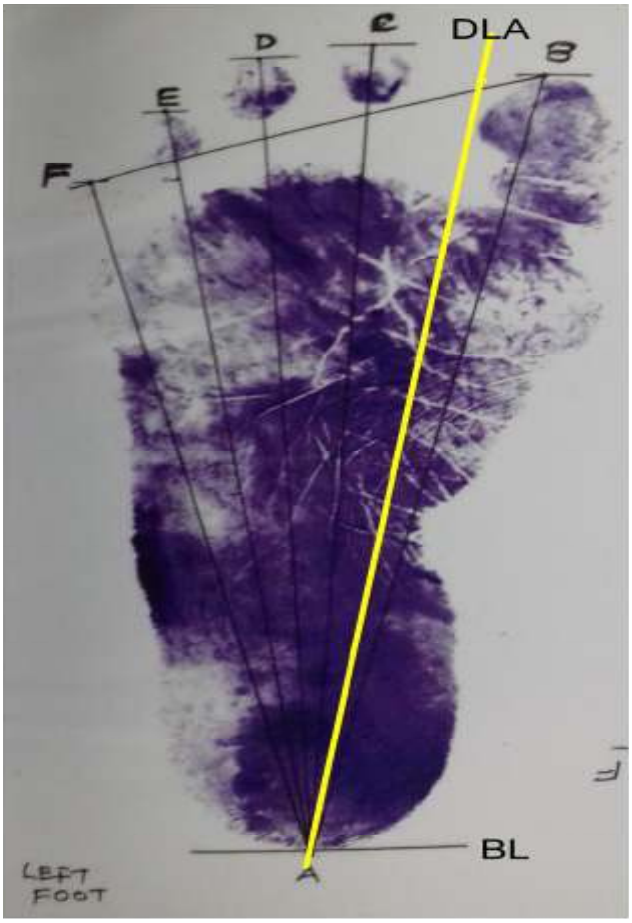

Figure 1- *Linear measurements of footprint used in the study.*

rior point of toe 4.

e. F5- Length from the pternion (A) to F the most anterior point of toe 5.

The Longitudinal Axis was drawn as a straight line from the pternion (i.e. the most posterior point of the rear heel margin, A) to the lateral side of the first toe pad margin. Base line (BL) was drawn perpendicular to the Designated Longitudinal Axis at the rear edge of the footprint. The axes were drawn to correct the axial orientation during measurement according to the proposed methodology of Robbins [11].

Descriptive statistics, ROC curve analysis, comparison of mean and test of normality (by one sample K S test) was done prior to the discriminant function analysis. For hypothesis testing, a *p* value of less than 0.05 was considered significant. Discriminant functional analysis was performed to predict sex from a combination of the above linear measurements. The discriminant function was obtained and a cut-off score was used to allocate sex. Statistical analysis was done using SPSS 17 for windows.

3. Results

In the present study, a sample of 100 adult footprints, 47 male and 53 female, were analyzed. The summary of univariate and multivariate analysis is shown in Table-1.

It was observed that the footprints were larger in males regarding all the five variables used in the study. Table-2 shows the result of test of equality of means.

Discriminant function analysis was performed using five variables (F1, F2, F3, F4, and F5) as predictors of sex. All the variables were entered together. The predictors were the linear dimensions of the foot, namely F1 through F5. The classification groups were male and female. One discriminant function, calculated with Wilks' Lambda was equal to 0.46, chi square ($\chi 2$) equal to 73.536, degree of freedom 5 and p-value of.000. Because p-value was less than 0.05, we could say that the model was a good fit for the data (Table-3).

The following Discriminant Function (DF) was obtained:

DF = 0.85*F1 +0.22*F2 + 0.39 *F3 – 0.35* F4+0.23 *F5 -20.81

The standardized canonical coefficients and the structure weights revealed that all of the five variables contributed to the multivariate effect (Table-2). The best predictor for distinguishing between male and female footprints was the length from the pternion to the farthest point of the first toe F1. The group centroid showed the unstandardized canonical discriminant functions evaluated at group means by using the mean values of the variables for the given sex. In this case, using mean values for males we got

Table 1- *Descriptive statistics for univariate and multivariate analysis of the variables among Indian-Bengali volunteer (n=100).*

	Minimum	Maximum	Mean	Std. Deviation
Age (Years)	17.00	52.00	25.6720	8.80604
F1 (cm)	20.50	27.50	23.4450	1.64608
F2 (cm)	20.50	27.50	23.1094	1.57453
F3 (cm)	19.00	26.40	22.3014	1.54593
F4 (cm)	18.00	24.60	21.0635	1.44931
F5 (cm)	16.30	22.80	19.5241	1.31615

F1, Length from the pternion (A) to B the most anterior point of toe 1; F2, Length from the pternion (A) to C the most anterior point of toe 2; F3, Length from the pternion (A) to D the most anterior point of toe 3; F4, Length from the pternion (A) to E the most anterior point of toe 4; F5, Length from the pternion (A) to F the most anterior point of toe 5.

Table 2- *Group statistics: mean value of variables among male and female volunteers.*

Group Statistics

	Sex	*n*	Mean	Std. Deviation	Std. Error Mean
Age (Years)	Male	47	26.6851	9.54939	1.39292
	Female	53	24.7736	8.07570	1.10928
F1 (cm)	Male	47	24.7128	1.29994	.18962
	Female	53	22.3208	.96064	.13195
F2 (cm)	Male	47	24.2583	1.32809	.19372
	Female	53	22.0906	.95319	.13093
F3 (cm)	Male	47	23.4264	1.26482	.18449
	Female	53	21.3038	.98819	.13574
F4 (cm)	Male	47	22.0819	1.16569	.17003
	Female	53	20.1604	1.01401	.13928
F5 (cm)	Male	47	20.4662	1.03940	.15161
	Female	53	18.6887	.91034	.12504

F1, Length from the pternion (A) to B the most anterior point of toe 1; F2, Length from the pternion (A) to C the most anterior point of toe 2; F3, Length from the pternion (A) to D the most anterior point of toe 3; F4, Length from the pternion (A) to E the most anterior point of toe 4; F5, Length from the pternion (A) to F the most anterior point of toe 5.

Table 3- *Wilk's lambda of the discriminant function.*

Wilks' Lambda

Test of Function(s)	Wilks' Lambda	Chi-square	dF	Sig.
1	0.463	73.536	5	0.000

a DF score of 1.132 for males and -1. 004 for females. The cut-off score or the sectioning point is the arithmetic mean of the values at group centroid. The cut-off score was 0.06 [calculated from group centroid (Table-4) by obtaining the arithmetic mean of the values]. In cases where the DF score was less than 0.06, the bone was female. For values of discriminant score above 0.06, the bone was male.

Out of 47 males, 35 were correctly classified while 47 out of 53 females were correctly classified. Thus, (35 plus 47) 82.0% of the sample was correctly classified into their group by this model. At the individual group level, 88.7% of females and 74.5% of males were correctly classified. Cross-validated results showed 82.0% of the cases correctly classified by this five variable model (Table-5).

Table 4- *Functions at group centroids.*

Functions at Group Centroids	
Test of Function(s)	**Wilks' Lambda**
	Function
Sex	1
Male	1.132
Female	-1.004

Unstandardized canonical discriminant functions evaluated at group means

Table 5- *Summary table of classification results.*

Classification Results [b,c]					
		Sex	**Predicted Group Membership**		**Total**
			Male	**Female**	
Original	Count	Male	35	12	47
		Female	6	47	53
	%	Male	74.5	25.5	100.0
		Female	11.3	88.7	100.0
Cross-validated[a]	Count	Male	35	12	47
		Female	6	47	53
	%	male	74.5	25.5	100.0
		Female	11.3	88.7	100.0

[a] *Cross validation was done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.*

[b] *82.0% of original grouped cases correctly classified.*

[c] *82.0% of cross-validated grouped cases correctly classified.*

4. Discussion

Footprint dimensions are vital evidences obtained from the scene of a crime. Forensic scientists use this information to help identify the offender using various attributes of the person. Footprints have also been used to build the biological profile of an unknown individual for identification. The measurements are specific for race and sex.

DFA is a statistical method wherein a combination of several continuous variables is used to differentiate between two or more natural groups. This helps in building a classification model to predict the outcome from a set of independent variables. In the present investigation, the foot dimensions were used to predict the sex of the individual. Discriminant functions are race and population specific. DFA have been used earlier to successfully determine sex from skeletal remains in the Indian Bengali population, primarily from the sternum [20], hyoid [21], clavicle and fragmentary hip bones [22-24]. Recent studies on Western Australians [17] and Turks [18] reported that using DFA, 79.5%–89.5% and 66.7%-82.4% of individuals could be respectively classified using their footprint dimensions. The footprint dimension that yielded the highest accuracy of sex discrimination varied from the longest toe [19] to the third toe (T3) [19] in different populations. Another recent work from Ghana [19] revealed that stepwise DFA correctly classified 80.3% and 77% of cases into their sex groups using left and right footprints, respectively. The present investigation showed 82% correct classification of sex from footprints in an Indian Bengali population. The results are similar to earlier works on other populations.

All the dimensions of feet were larger in males than in females, as seen in the present series. This difference in linear measurements was statistically significant. This is also in concurrence with reports from earlier works, [17-19].

A study on a Ghanaian population reiterated that the most accurate discriminant functions were produced by T5 and breadth at heel using left and right footprints, respectively. Our results showing F1 as the best predictor is, however, different from previous studies.

Furthermore, an automated model has been proposed [28] for analyzing the sex of an individual from his/her broken/incomplete footprint impressions based on morphological features alone. The study reported that in comparison to a system for sex prediction from complete footprint impressions (82.2%), the automated system developed on incomplete foot impressions recorded an accuracy level of 83.47%. The results with complete footprints are almost similar to our observation of 82% correct prediction. This supports our contention that discriminant functions are race specific and are reliable predicting models for forensic application. Unlike earlier works from India [26,27] where indices like heel ball index were used to determine sex, the present study took up only the five linear measurements.

The present investigation, however, has some limitations that need to be addressed in future studies. Firstly, the sample size comprised only 100 adult subjects. Secondly, only linear measurements were taken along the longitudinal axis and the width, but heel dimensions were excluded. The angle of step and the pressure distribution of the plantar surface was not considered in the present investigation. As the anatomy of the foot is complex, more variables are needed to be investigated in later broad-based studies to

get more precise results. Our present work can be considered as a pilot study indicating the positive application of DFA in predicting sex from footprints in the Indian Bengali population. This is perhaps the only study of sex prediction on Indian Bengali footprints to date. Further researches can be done with geometric morphometrics [25] wherein the curves of a footprint in soft material can be used to determine the sex of a person. Similarly, the depth of a footprint might help in weight estimation. This will have wide forensic as well as anthropological applications.

5. Conclusion

Population specific discriminant functions are appropriate for the determination of sex from footprint dimensions. The present study contends that DFA can be successfully used to predict sex from linear measurements of footprints in the Indian Bengali population. In the present study, 82.0% of the cases could be correctly classified into their proper sex from the five foot measurements taken from footprints. This will have extensive forensic and anthropological use when applied to a particular population.

Conflict of Interest

None.

Source of Funding

None.

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