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A Study of Morphological Features of Footprints in Egyptian and Malaysian Population



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دراسة الخصائص الشكلية لبصمات القدم في المجتمع المصري والماليزي

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Abstract

Determination of sex and ethnicity is one of the main tasks in building the biological profile of individuals. Keen examination of footprints that may be found at the crime scene can give valuable clues in forensic identification. The current work aimed to study the footprint morphological features and their relation to sex and population difference.

The study was conducted on 200 adult volunteers. They were divided into two equal racial groups: Malaysians and Egyptians. The collected footprints were classified into four types based on relative morphological toes lengths. Toes inter-distance, phalangeal marks position and number, humps count and Chippaux-Smirak index (CSI) were examined. The frequency of these characteristics was analyzed statistically using regression analysis.

Among the studied morphological features, it was found that t3-t4 inter-distance, phalangeal marks number, humps count and CSI differed significantly between males and females.

As regards ethnicity, all footprints characteristics differed significantly between Egyptians and Malaysians except CSI.

المستخلص

يعد تحديد الجنس والعرق أحد المهام الرئيسية في بناء الشخصية البيولوجية للأفراد. الفحص الدقيق لبصمة القدم التي يمكن العثور عليها في مسرح الجريمة قد يعطي أدلة قيمة في تحديد الهوية.

كان الهدف من هذا البحث دراسة الخصائص الشكلية لبصمة القدم وعلاقتها بالجنس والفرق السكاني.

أجريت الدراسة على مائتي متطوع بالغ. تم تقسيمهم إلى مجموعتين عرقيتين متساويتين: الماليزيين والمصريين. و تم جمع بصمات القدم وتصنيف القدم إلى أربعة أنواع بناء على الأطوال النسبية لأصابع القدم. تم فحص المسافات بين أصابع القدم، علامات السلاميات، عدد الحذب ومؤشر CSI، و تم تحليل هذه الخصائص إحصائياً باستخدام تحليل الانحدار.

من بين السمات الشكلية التي تمت دراستها، تبين أن المسافة بين أصابع القدم الثالث والرابع، عدد علامات السلاميات والحذب ومؤشر CSI تختلف بشكل ذو دلالة إحصائية بين الذكور والإناث. وفيما يتعلق بالعرق اختلفت جميع خصائص بصمات القدم بشكل ذو دلالة إحصائية بين المصريين والماليزيين باستثناء مؤشر CSI.

Keywords: Forensic Science, Identification, Footprints, Morphological Characteristics, Ethnicity.

الكلمات المفتاحية: علوم الأدلة الجنائية، تحديد الهوية، بصمة القدم، الخصائص الشكلية، العرق.



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The study showed that foot has unique morphological characteristics that differ by sex and population difference and would help in establishing the personal identity.

أوضحت الدراسة أن للقدم خصائص شكلية فريدة تختلف باختلاف الجنس وفرق السكان، وقد تساعد دراستها في تحديد الهوية الشخصية.

1. Introduction

Determination of sex and ethnicity is one of the crucial tasks of forensic investigations. Fingerprints and DNA are probably the most common techniques used to establish the biological profile of individuals. However, since they cannot always be used, it is necessary sometimes to apply different techniques such as footprints [1,2].

It is not possible to find a crime scene without a footprint or shoeprint, but meticulous observation is required to trace these prints. The frequency of finding footprints and shoeprints is more or less the same as that of finding fingerprints at a crime scene [3].

Shoe prints are found in many crime scenes; however, a bare footprint still can be founded in sexual assaults, homicides and scuffle cases. Moreover, the shoes may be left at the crime scene; and they may contain the impression of the plantar surface of foot. [3].

So, footprint forms valuable evidence that can be found and collected from almost all crime scenes. Moreover, in mass disasters, the forensic expert may sometimes be confronted with only a foot to build the biological profile of a victim [4,5].

The foot morphology shows variations due to the effects of heredity and environmental factors, so footprints are unique and have individual characteristics that are capable of providing positive identification. Footprints differ not only between individuals but also between the right and left foot of the same individual; even in identical twins [6-8].

In identification from footprints, podiatrists firstly describe the footprints under consideration and then compare suspects and crime scene footprints together [9-11].

Recently, the human foot has gained popularity in the field of identification and despite its medico-legal role; it is still underestimated as a probable tool for identification. Few researches have been conducted to assess the importance of barefoot morphology and individual characteristics for establishing the biological profile [7,9,12]. Hence the present research was designed to study the morphological features of footprint in Egyptian and Malaysian sample and its relation to sex and population differences.

2. Materials and Methods

2.1 Subjects

The present cross-sectional study was conducted in the Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine, Alexandria University, Egypt. The study was conducted on two hundred adult volunteers. They were divided into two racial groups; one hundred adult Egyptians (50 males and 50 females) and one hundred adult Malaysians (50 males and 50 females). After approval of the Ethics Committee of Alexandria, Faculty of Medicine (IRB number: 00012098, approval serial number: 0201044, dated 27/12/2017), informed consent was obtained from all participants.

All subjects with apparent symptomatic deformity of the feet and spine, history of lower extremity injuries, foot or ankle surgery, lower limb edema, and also pregnant females were excluded from the present research.

2.2 Materials

The materials used in this research included: Inkless shoe print kit (Carolina. USA), pencil and ruler.

2.3 Methods

For each research subject, the following was fulfilled:

1) Demographic data: age, sex, and nationality.

2) Static barefoot prints collection: After cleaning soles, the footprints were obtained from each research subject using an inkless shoe print kit. Each subject was requested to place one foot on an inkless shoe print pad with a little pressure and then to step on shoe print white paper (included in the kit) on a flat surface, bearing equal weight on both feet while standing. Left and right footprints were recorded one by one. A serial number was given to each print.

2.4 Analysis of footprints:

The obtained footprints were classified into four types depending on the relative morphological lengths of the first, second and third toes (**Figure-1**) [13].

These types are described in the current study (**Figure-2**) as follows:

- Tibularis type (T-type) when the $T1 > T2$.
- Fibularis type (F-type) when the $T2 > T1$.
- Intermediate type (O-type) when the $T1 = T2$.



d. Medularis type (M-type) when the $T3 > T1$ and $T2$.

On the other hand, after marking the outlines of toes on prints, the toes inter-distance was measured as the least distance between two adjacent toes, and then was classified into three types (Figure-3) [12] :

- a. Narrow: when the toes inter-distance is equal or less than 0.50 cm.
- b. Medium: when the toes inter-distance is between 0.51 and 1.50 cm
- c. Wide: when the toes inter-distance is more than 1.5 cm.

In the present study, during the development process of footprints, some toes inter-distance could not be measured. This is because some toes inter-distance couldnt be measured in these cases due to missing impression which is clarified in Table-2. So toes impressions were missed in these cases.

Number and position of phalangeal marks, which are the marks created by the phalanges of toes and imprinted in a form of toe stem, were examined carefully as shown in Figure-4.

At the same time, humps which are defined as protruding curvatures in the ball line [12] were examined and counted carefully as shown in Figure-5.

The Chippaux-Smirak index (CSI) was calculated in each footprint. The CSI is the ratio of the narrowest distance of mid-foot (line A) to the widest distance of fore-foot (line B) multiplied by 100 [14]. Forefoot breadth was measured at right angle of footprint length as the straight distance between two tangents drawn on both sides of the forefoot outline [15]. For this index, the reference values were: high (0%), normal (0.1–29.9%), intermediary (30–39.9%), low (40–44.9%) and flat ($\geq 45\%$) [14] (Figure-6).

2.5 Statistical analysis

Data were collected, tabulated and analyzed using SPSS software (IBM SPSS Statistics for Windows; Version 26.0. Armonk, NY: IBM Corp).

Qualitative data were summarized using the number and percentages. In the present study, the effects of predictors such as sex, race, and side was tested using different models for different outcomes, ordinal regression model with ordinal outcomes (CSI and toes inter-distances), Poisson regression model with count outcomes (counts of humps and number of phalangeal marks), and nominal logistic regression model was used with nominal outcome (foot type).

Interaction terms were used to test whether the effect

of one predictor depends on another. The effects of different predictors were expressed using $\text{Exp}(B)$, which represents the odds ratio from logistic regression, proportional odds ratio from ordinal regression, and incident rate ratio from Poisson regression. In all the models, generalized estimating equations were used to adjust for the correlations among observations from both feet of same person.

Significance test results were quoted as two-tailed probabilities and judged at the 5% level.

3. Results

3.1 Demographic Data

The present study included two hundred adult volunteers in the age of 18-30 years. The participants were divided into two racial groups: one hundred adult Egyptians (50 males with mean age of 22.28 ± 3.95 and 50 females with mean age of 22.14 ± 4.11) and one hundred adult Malaysians (50 males with mean age of 21.76 ± 2.05 and 50 females with mean age of 21.98 ± 1.48). There were no significant differences as regards age between males and females in the same population or between the two populations.

3.2. Foot Type

Table-1 shows that among Egyptian population, the most frequent type in males was F-type (right 52%, left 50%) followed by T-type (right 34%, left 36%), while in females the most frequent type in right foot was T-type (48%) followed by F-type (34%), and in the left foot, F-type was the most frequent (46%) followed by T-type (30%).

In Malaysian population, the frequency of F-type was the highest in males (right 64%, left 68%) followed by O-type in right foot (22%) and F-type in left foot (20%), while in females, F-type was the most frequent (right 64%, left 72%) followed by O-type in right foot (20%) and followed by O-type and T-type in left foot with the same frequency (14%).

3.3. Toes Inter-Distance:

Table-2 shows that the distance between toe 1 and toe 2, the percentage of medium inter-distance was found to be comparatively higher in both sexes of the two populations in both left and right feet.

The distance between toe-2 and toe-3 showed that



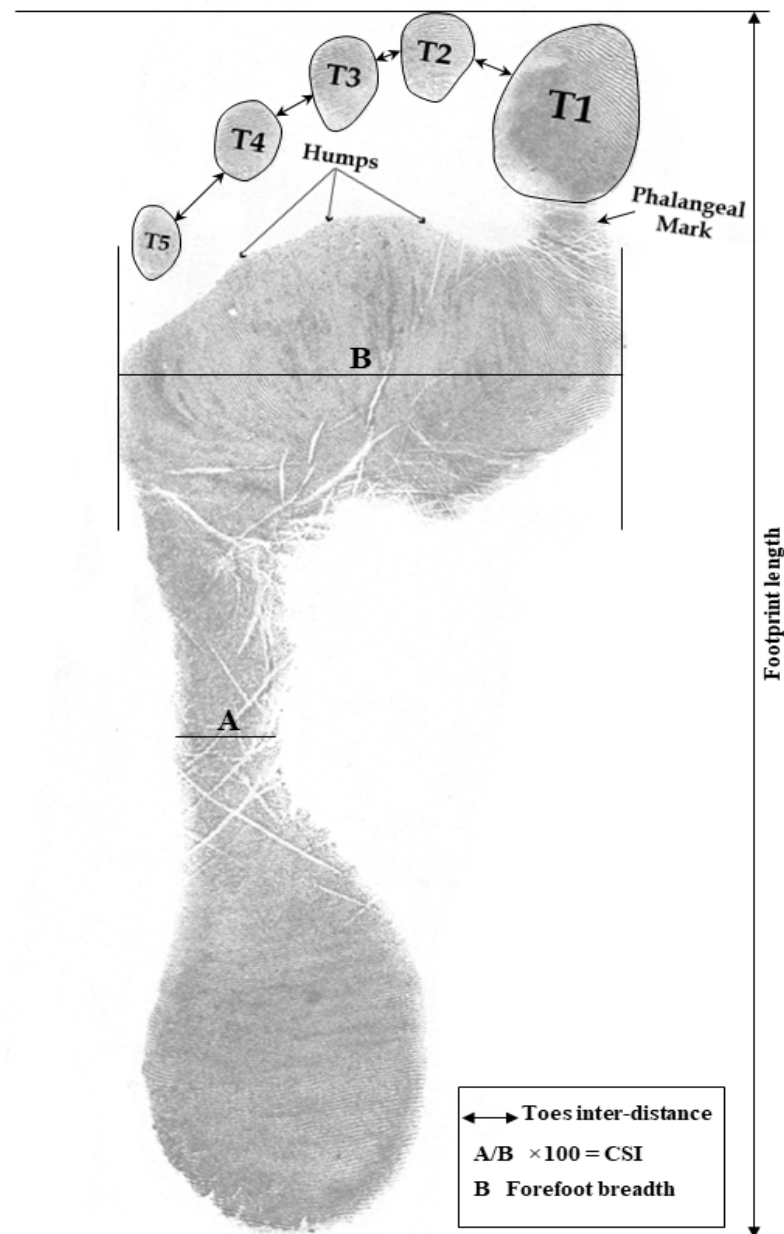


Figure 1- Illustrative figure showing the studied morphological features of footprint.

narrow inter-distance was the most prevalent one, followed by medium inter-distance in Egyptian and Malaysian populations in both sexes in both feet.

The distance between toe-3 and toe-4 was narrow and occurred most frequent followed by medium inter-distance in Egyptian population. While in Malaysian population, the medium inter-distance was the most frequent.

On the other hand, medium inter-distance between toe-4 and toe-5 predominates in all groups.

3.4. Phalangeal Marks

As shown in Table-3, the phalangeal marks which are created only by one toe was the most frequent finding in Egyptian males (right 68%, left 72%) and females (right 66%, left 68%), and also in Malaysian males (right-70% left 60%) and females (right 50% left 48%).

According to phalangeal marks created by different toes, as shown in Table-4, in most of the footprints, the phalangeal marks are created by toe 1, (right 90% left

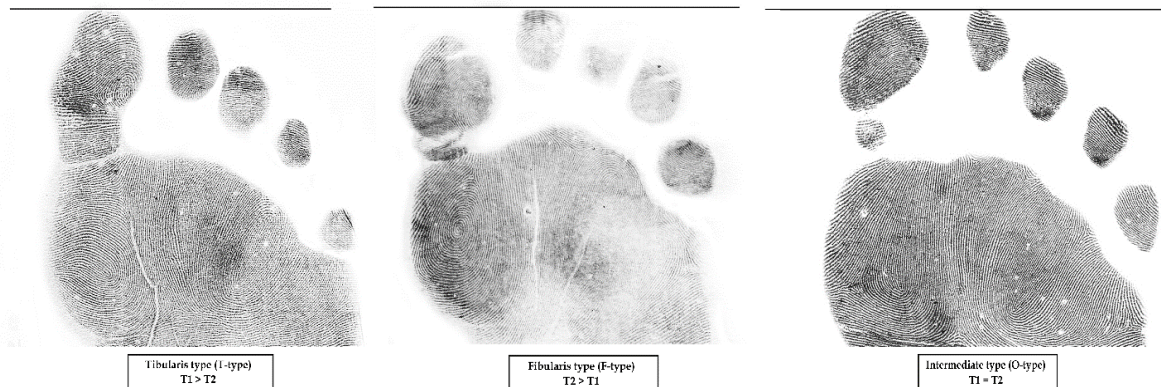


Figure 2- Illustrative figure showing types of footprint according to the relative toe lengths of the first, second and third toes.

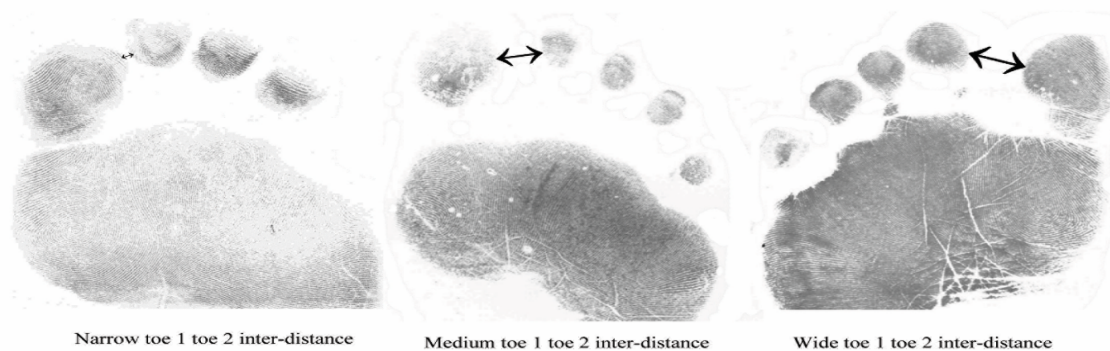


Figure 3- Illustrative figure showing toes inter-distance measured in the footprints.

88%) in Egyptian males, (right 82%, left 84%) in Egyptian females, (right 88% left 84%) in Malaysian males, (right 84%, left 88%) in Malaysian females, and phalangeal marks by toe-5 was the second most frequent finding found in both sexes of the two studied populations.

3.5. Number of Humps

Table-5 shows that in Egyptian population, feet of males with three humps were found more often (right 52 %, left 62%), followed by feet with two humps (right 42%, left 30%), while in females, two humps were most frequent finding (right 60%, left 56%) followed by three humps (right 34%, left 40%). On the other hand, in the Malaysian sample, the results of males showed that feet with two humps were found more often (right 54%, left 56%), followed by three humps (right 44%, left 44%).

But in female footprints, the sequence differed, three humps finding was found more often (right 56%, left 58%), followed by two humps.

3.6. CSI

In Egyptian males, the most frequent variant was intermediary (right 36%, left 50%) followed by low (right 30%, left 22%). In females, intermediary variant was also the predominant one (right 54%, left 34%) followed by normal (right 26%, left 38%). As regards flatfoot, its frequency was higher in males (right 14%, left 18%) than in females (right 12%, left 14%).

In Malaysian population, intermediary variant was the most frequent one in males (right 42%, left 42%) and in females (right 42%, left 50%) followed by normal variant in males (right 22%, left 28%) and females (right

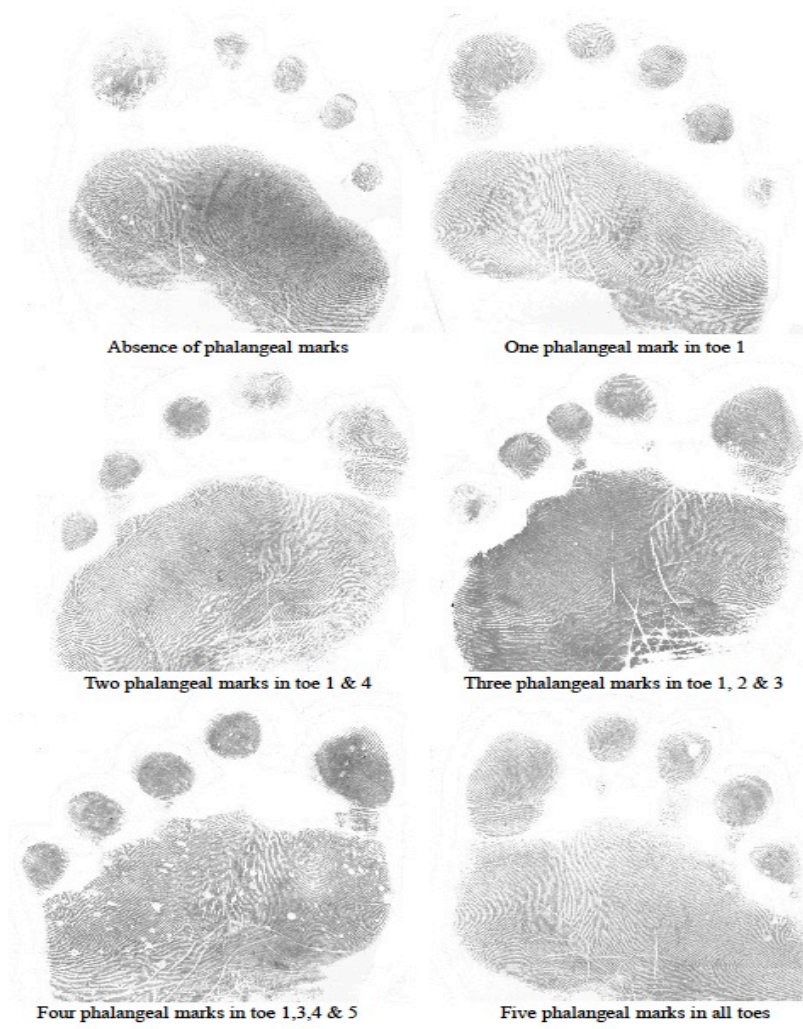


Figure 4- Illustrative figure showing different numbers and position of phalangeal marks.

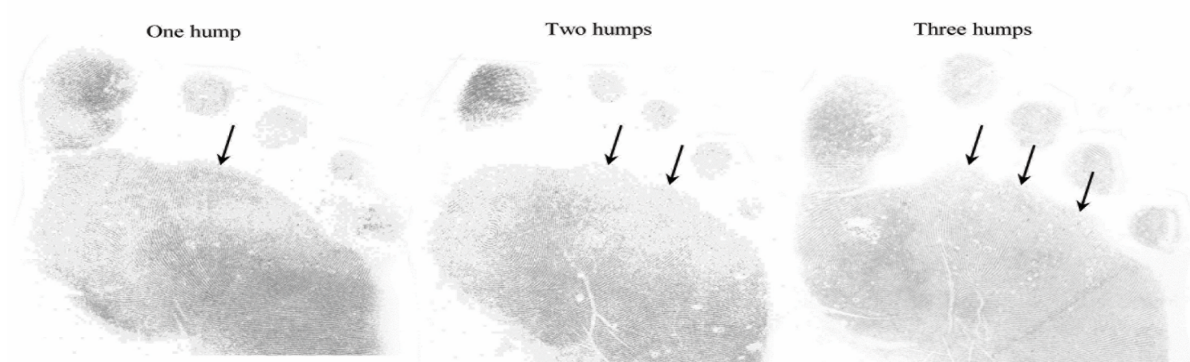


Figure 5- Illustrative figure showing different numbers of humps.



Figure 6- Illustrative examples for different variants of Chippaux-Smirak index (CSI).

36%, left 28%). The frequency of flat foot was higher in males (right 20%, left 20%) than in females (right 14%, left 8%) as shown in Table-6.

3.7. Table-7 shows the differences between morphological features of footprints by sex, ethnicity, and side using regression analysis:

It was found that among morphological features of footprints, the t3-t4 inter-distance, the number of phalangeal marks, the number of humps as well as CSI differed between males and females.

Males tended to have lower t3-t4 inter-distance (Prop OR=0.54, 95% CI: 0.34, 0.88) and higher CSI (Prop OR=1.94, 95% CI: 1.23, 3.07). This observation was consistently shown among both races and both sides.

On the other hand, the relation between the number of humps or phalangeal marks and sex were not consistent among Egyptians and Malaysians.

- Among Egyptians, being a male was associated with a 14% increase in the number of humps (95% CI: 6% to 23%). Among Malaysians, this association was not observed. The number of humps among Malaysian males was equal or less than these observed among Malaysian females.

(IRR=0.93, 95% CI: 0.86 to 1).

- While Malaysian males tend to have significantly fewer phalangeal marks compared to Malaysian females (IRR=0.69, 95%:0.55 to 0.88), no significant difference was observed among Egyptians.

As regards ethnicity, it is apparent from Table-7 that, apart from CSI, all footprints characteristics differed between Egyptians and Malaysians. Overall, toes inter-distance measures were wider among Malaysians. This observation was considerably evident across t1-t2 inter-distance, t2-t3 inter-distance, and t3-t4 inter-distance, but less evident in t4-t5 inter-distance ($p=0.057$).

The relation between the number of humps or pharyngeal marks and ethnicity was not consistent among males and females. Malaysian females tend to have significantly more humps and phalangeal marks compared to Egyptian females (IRR= 1.14; 95%CI: 1.06, 1.24, $p=0.001$ and IRR=1.58; 95%CI: 1.23 to 2.02, $p<0.001$ respectively). By contrast, among males, Malaysians tend to show relatively fewer humps than Egyptians (IRR 0.93, 95%CI: 0.87 to 0.99; $p=0.034$) and insignificantly different number of phalangeal marks ($p=0.415$).

As regards the difference between right and left feet, the present study revealed that among Malaysian and Egyptian males and females, the right and left feet were overall comparable. Only t2-t3 inter-distance and count of humps differed by side. With adjustment for ethnicity and sex, left foot tend to have smaller t2-t3 (OR_{prop}=0.67; 95%: 0.45 to 0.93, $p=0.017$). Moreover, compared to right side, left foot showed more humps among Egyptians only (IRR=1.07; 95%; 1.01 to 1.13, $p=0.021$) with no statistically significant difference observed among Malaysians ($p=0.873$).

4. Discussion

Although it can be used effectively for personal identification, some crime scene investigators underestimate footprint as important physical evidence in many incidents. It was reported that a footprint can give information even more than a fingerprint [16-18].

The evidence may be recovered as a partial or complete footprints in the crime scene or mutilated remains of feet in mass disasters. Forensic podiatrists collect any evidence related to the foot that may be useful in determining the identity [19].

It has been a well-observed fact that the foot is unique to each individual. Environmental and conditions like habitual barefoot walking and wearing of a particular type of footwear may affect the foot structure and result in anatomical and morphological variations. [20, 21].

Table 1- Distribution of study participants according to the relative morphological length of the first, second and third toe in the footprints (number of prints=400).

Foot type	Egyptian								Malaysian							
	Male				Female				Male				Female			
	Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
T*	17	34.0	18	36.0	24	48.0	15	30.0	7	14.0	10	20.0	8	16.0	7	14.0
F†	26	52.0	25	50.0	17	34.0	23	46.0	32	64.0	34	68.0	32	64.0	36	72.0
O‡	7	14.0	7	14.0	9	18.0	12	24.0	11	22.0	6	12.0	10	20.0	7	14.0
M§	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Tibularis type; †Fibularis type; ‡Intermediate type; §Medularis type.

Table 2- Distribution of study participants according to toes inter-distances in the footprints (number of prints=400).

Toes inter-distance	Egyptian								Malaysian							
	Male				Female				Male				Female			
	Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
t1-t2*																
Narrow (≤ 0.5 cm)	14	28.0	13	26.0	17	34.0	12	24.0	6	12.0	7	14.0	6	12.0	10	20.0
Medium (0.51-1.5 cm)	34	68.0	37	74.0	29	58.0	37	74.0	39	78.0	37	74.0	41	82.0	36	72.0
Wide (≥ 1.5 cm)	2	4.0	0	0.0	4	8.0	1	2.0	5	10.0	6	12.0	3	6.0	4	8.0
t2-t3†	(n = 49)		(n = 50)													
Narrow (≤ 0.5 cm)	39	79.0	43	86.0	31	62.0	36	72.0	26	52.0	32	64.0	25	50.0	28	56.0
Medium (0.51-1.5 cm)	10	20.4	7	14.0	19	38.0	13	26.0	24	48.0	18	36.0	25	50.0	22	44.0
Wide (≥ 1.5 cm)	0	0.0	0	0.0	0	0.0	1	2.0	0	0.0	0	0.0	0	0.0	0	0.0
t3-t4‡	(n = 49)		(n = 50)													
Narrow (≤ 0.5 cm)	33	67.3	37	74.0	27	54.0	32	64.0	23	46.0	24	48.0	19	38.0	11	22.0
Medium (0.51-1.5 cm)	16	32.6	13	26.0	23	46.0	18	36.0	27	54.0	25	50.0	31	62.0	39	78.0
Wide (≥ 1.5 cm)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	2.0	0	0.0	0	0.0
t4-t5 §	(n = 49)		(n = 49)		(n = 49)		(n = 49)		(n = 49)		(n = 49)		(n = 49)		(n = 49)	
Narrow (≤ 0.5 cm)	12	24.0	8	16.3	12	26.08	8	17.8	3	6.25	4	8.3	9	19.1	10	21.7
Medium (0.51-1.5 cm)	37	74.0	40	81.6	34	73.9	36	80.0	43	89.5	40	83.3	37	78.7	35	76.1
Wide (≥ 1.5 cm)	1	2.0	1	2.04	0	0.0	1	2.2	2	4.2	4	8.3	1	2.1	1	2.2

*inter-distance between first & second toe; †inter-distance between second & third toe; ‡ inter-distance between third & fourth toe; §inter-distance between fourth & fifth toe.



Table 3- Distribution of study participants according to number of phalangeal marks created by toes in the footprints (number of prints=400)

Number of PMS*	Egyptian								Malaysian							
	Male				Female				Male				Female			
	Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Absence of PMS*	4	8.0	3	6.0	9	18.0	7	14.0	5	10.0	7	14.0	5	10.0	6	12.0
PM* in one toe.	34	68.0	36	72.0	33	66.0	34	68.0	35	70.0	30	60.0	25	50.0	24	48.0
PMS* in two toes	10	20.0	8	16.0	7	14.0	6	12.0	8	16.0	12	24.0	9	18.0	11	22.0
PMS* in three toes	0	0.0	0	0.0	1	2.0	2	4.0	1	2.0	1	2.0	6	12.0	4	8.0
PMS* in four toes	1	2.0	3	6.0	0	0.0	1	2.0	0	0.0	0	0.0	2	4.0	0	0.0
PMS* in five toes	1	2.0	0	0.0	0	0.0	0	0.0	1	2.0	0	0.0	3	6.0	5	10.0

*PMS; phalangeal marks

Table 4- Distribution of study participants according to phalangeal marks created by different toes in the footprints (number of prints=400).

PMS* created by various toes	Egyptian								Malaysian							
	Male				Female				Male				Female			
	Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
PMS* by toe 1	45	90.0	44	88.0	41	82.0	42	84.0	44	88.0	42	84.0	42	84.0	44	88.0
PMS* by toe 2	6	12.0	5	10.0	3	6.0	5	10.0	1	2.0	1	2.0	9	18.0	10	20.0
PMS* by toe 3	2	4.0	3	6.0	1	2.0	1	2.0	2	4.0	2	4.0	13	26.0	10	20.0
PMS* by toe 4	1	2.0	2	4.0	1	2.0	2	4.0	2	4.0	1	2.0	6	12.0	5	10.0
PMS* by toe 5	9	18.0	10	20.0	4	8.0	6	12.0	10	20.0	11	22.0	14	28.0	14	28.0

*PMS; phalangeal marks

• Percentages are not mutually exclusive



Table 5- Distribution of study participants according to number of humps in the footprints (number of prints=400).

No. of Humps	Egyptian								Malaysian							
	Male				Female				Male				Female			
	Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	2	4.0	0	0.0	3	6.0	2	4.0	0	0.0	0	0.0	2	4.0	2	4.0
2	21	42.0	15	30.0	30	60.0	28	56.0	27	54.0	28	56.0	17	34.0	16	32.0
3	26	52.0	31	62.0	17	34.0	20	40.0	22	44.0	22	44.0	28	56.0	29	58.0
4	1	2.0	4	8.0	0	0.0	0	0.0	1	2.0	0	0.0	3	6.0	3	6.0

Table 6- Distribution of study participants according to Chippaux Smirak index variants of footprints (number of prints=400).

CSI Variants	Egyptian								Malaysian							
	Male				Female				Male				Female			
	Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)		Right (n = 50)		Left (n = 50)	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Normal	10	20.0	5	10.0	13	26.0	19	38.0	11	22.0	14	28.0	18	36.0	14	28.0
Intermediary	18	36.0	25	50.0	27	54.0	17	34.0	21	42.0	21	42.0	21	42.0	25	50.0
Low	15	30.0	11	22.0	4	8.0	7	14.0	8	16.0	5	10.0	4	8.0	7	14.0
Flat	7	14.0	9	18.0	6	12.0	7	14.0	10	20.0	10	20.0	7	14.0	4	8.0

Chippaux Smirak index

There have been very limited number of similar publications that have considered the morphological characteristics of footprints [7, 9, 12, 22]. However, those studies did not apply statistical tests to assess the significance of their results.

The present study highlighted some of the morphological characteristics of footprints in Egyptian and Malaysian populations and it aimed to determine whether sex and population differences affects the range of foot morphology parameters.

In the present study, footprints were collected using

the inkless shoe print kit. This method was chosen because it is simple, easy to use, yields clear prints and is relatively inexpensive. At the same time, it was reported that it caused no allergies and no issues concerning hygiene or cross-infection [23].

The age of the subjects who participated in the present study ranged from 18-30 years. This age range was chosen to ensure that the average adult length of the foot is attained and to avoid age-related changes such as wrinkles that may be reflected in the feet of elderly persons [19, 24].



Table 7- Differences in morphological features by gender, ethnicity and side.

Foot type ^a	Male vs Female		Malaysian vs Egyptian		Lt side vs Rt side	
	Exp (B) [95%CI]	(p-value)	Exp (B) [95%CI]	(p-value)	Exp (B) [95%CI]	(p-value)
O vs T	0.8 [0.39,1.64]	(0.538)	2.29 [1.1,4.75]	(0.027)	1 [0.6,1.66]	(0.987)
F vs T	1.16 [0.64,2.11]	(0.617)	3.41 [1.86,6.26]	(<.001)	1.2 [0.86,1.67]	(0.276)
Toes (t) Inter-distance^b						
t1- t2b	1.16 [0.68,1.99]	(0.588)	2.38 [1.37,4.14]	(0.002)	0.98 [0.72,1.34]	(0.918)
t2-t3b	0.61 [0.37,1.02]	(0.058)	2.41 [1.45,4.01]	(0.001)	0.67 [0.49,0.93]	(0.017)
t3-t4b	0.54 [0.34,0.88]	(0.012)	3.03 [1.89,4.86]	(0.000)	0.98 [0.7,1.38]	(0.922)
t4-t5b	1.79 [0.99,3.27]	(0.056)	1.81 [0.98,3.35]	(0.057)	1.3 [0.88,1.92]	(0.191)
Phalangeal marks number^c						
	0.69 [0.55,0.88] M	(0.003)	1.58 [1.23,2.02] Female	(<.001)	1.02 [0.92,1.12]	(0.755)
	1.2 [0.95,1.51] E	(0.123)	0.91 [0.73,1.14] Male	(0.415)		
Humps count^c						
	0.93 [0.86,1]M	(0.056)	1.14 [1.06,1.24] Female	(0.001)	1 [0.95,1.04] M	(0.873)
	1.14 [1.06,1.23]E	(<.001)	0.93 [0.87,0.99] Male	(0.034)	1.07 [1.01,1.13] E	(0.021)
CSI ^b	1.94 [1.23,3.07]	(0.004)	0.84 [0.54,1.31]	(0.435)	0.97 [0.76,1.24]	(0.805)

Exp(B) stands for adjusted proportional odds ratio in case of adjusted odds ratio from logistic regression (a), ordinal logistic regression (b), adjusted incident rate ratio from Poisson regression (c). M, E, Male, Female stands for Exp(B) calculated among Malaysians, Egyptians, males and females respectively.

CSI, Chippaux-Smirak index; O, intermediate foot type; T, tibularis type; F, fibularis type; t1-t2, inter-distance between first & second toe; t2-t3, inter-distance between second & third toe; t3-t4, inter-distance between third & fourth toe; t4-t5, inter-distance between fourth & fifth toe.



On the other hand, footprints were taken from both feet of each participant in the present study. Many earlier studies suggested that individuals demonstrated high asymmetry between left and right feet because most of the individuals have dominant foot. The dominant foot supports the body to a greater extent, so the bones of the this foot are subjected to stronger stress forces like weight-bearing pressures than are the bones of the other foot. This, in turn, results in enlargement of bones of the dominant foot and therefore, produces footprints with different dimensions and morphology [18, 25, 26].

Based on the relative morphological lengths of the first, second and third toe, the footprints are classified into four types: T-type (Tibialis-type), F-type (Fibularis-type), M-type (Midularis-type) and O-type (Intermediate-type) [13].

In the current study, the most frequent foot type in Egyptian males was F-type, while in females T-type and F-type were the most prevalent types in right and left foot, respectively, In Malaysian population, F-type was the most frequent in both sexes. These findings were in accordance with the findings reported by Tharmar [9] and Moorthy & Sulaiman [12] on Malaysian population. On the contrary, Krishan [7] found that T-type was the predominant one in North Indian males.

One of the variations of footprints in the toe region is the toes inter-distance, which shows characteristic features as no two footprints have identical toes inter-distances even between the left and right footprints of the same individual. Jasuja et al [27] studied the different forms of toe inter-spaces and reported that a difference has been observed in occurrence of toe inter-spaces and also in various toe positions.

In the present study, the percentages of medium and narrow inter-distance were the predominant and wide toes inter-distance was the least finding in all groups. This result coincided with Tharmar [9] and Moorthy & Sulaiman [12].

Within the studied footprints in the current work, missing toe prints were sometimes apparent. This finding may be related to actual missing toes, contracted/retracted toes or the foot function itself that could have led to an absence of ground contact at the site of the apparently missing toe [28].

The ball region of the footprint represents the major weight-bearing area of the plantar surface of the foot. Furthermore, its morphological contours and features are

well defined. General appearance of the ball region, relative placement of the first metatarsal joint to that of the fifth metatarsal may be straight, oblique or horizontal, so it forms morphological features of the region and ball line may have one or several humps [19].

Egyptian population sample showed that in male, three humps was the most frequent finding, while in females, the prints with two humps were found more often.

In Malaysian population, the presence of two humps was the most predominant finding in males, while the frequency of three humps was the highest in females. This was in accordance with the findings reported by Tharmar [9], Moorthy and Sulaiman [12] and Krishan [7]. The results of their studies showed variability of the number of humps from no humps in the ball line to five humps.

Another identifying characteristic feature in footprint is the phalangeal mark which is created by the phalanges of the toes and is imprinted in the form of toe stems. The presence, position, and number of the phalangeal marks are also of great evidentiary value in criminal investigations and can be used as a method of comparison [7].

As regards the position of phalangeal marks, the present study revealed that the phalangeal marks of both populations were not only created by toe one, but also by other toes with varying frequencies in both sexes. This finding was in agreement with Tharmar [9], who demonstrated that the phalangeal marks created by first toe took the highest percentage followed by fifth toe, third, and second toe and those created by fourth toe were the least in Malaysian Chinese population. In the study of Moorthy and Sulaiman [12], the Malaysian Malay population had also followed almost the similar order observed in the current study in both sexes. This may be due to the fact that both studies conducted on a sample of Malaysian population.

However, Krishan [7] reported that phalangeal marks of the toes 2–5 were not found in most of the footprints among Indian Gujjar males.

Another finding in the present study is the presence of multiple phalangeal marks in some samples and some other prints showed no phalangeal marks at all. This finding was consistent with Tharmar [9] and Moorthy and Sulaiman [12].

On the other hand, many different measures and indices have been used to describe foot shape based mainly on the geometry of the medial longitudinal arch. [20].



In the present study, the Chippaux- Smirak index (CSI) was the chosen parameter used in footprint evaluation. Chen KC et al. [29] concluded that the CSI had a high predictive probability in screening for flatfoot.

The frequency of intermediary variant was the commonest in the entire sample participated in the current study, while low and flat foot were the least common variants in both populations.

The frequency of flat foot was higher in males than in females. This finding was in accordance with Tharmar [9] and Moorthy and Sulaiman [12].

In the present study, males tended to have higher CSI than females. This difference between both sexes could be explained by the fact that larger foot tends to have a lower-arched foot [19].

At the same time, this finding was contradictory to the results showed by Didia [30] in Nigerian population in which the frequency of flatfoot was found to be higher in females than in males.

The frequencies of CSI variants were different between the Egyptian and Malaysian populations studied in the current work and that can be explained by different environmental conditions and the different habitual use of footwear that may influence the overall shape and planter pressure variables [31].

For forensic anthropological methods of identification to be more accepted and applicable, research using statistical methods such as regression analysis is needed. According to the available knowledge, none of the previous studies conducted to show the importance of footprints morphological characteristics in determination of personality, used regression analysis to assess the statistical significance of their results.

Using regression analysis, the current study revealed that among the studied morphological features of footprints, the t3-t4 inter-distance, number of phalangeal marks, and count of humps as well as CSI were the best to use in assessment of sex from footprints morphology.

For sex determination in Egyptian population, the present study showed that it was more accurate to use count of humps rather than using the number of phalangeal marks as males tended to have 14% increase in number of humps. While in Malaysian population, it was better to use the phalangeal marks as males tended to have a significantly fewer number of marks.

On the other hand, apart from CSI, all foot morphological characteristics could be used in determining of

population difference. Malaysians tended to have O or F foot type rather than T-type. Moreover, the comparative analysis of humps showed that overall toes inter-distance measures were wider among Malaysians.

As regards determination of population difference using count of humps and number of phalangeal marks, Malaysian females tended to have significantly more humps and phalangeal marks compared to Egyptian females. On the contrary, among males, Malaysians tended to show relatively fewer humps than Egyptians and insignificantly different number of marks.

5. Conclusion

From the current study, it could be concluded that foot has unique morphological characteristics that would help in building the biological profile of individuals and may be useful in inclusion and exclusion process of suspects. There are many incidences that only a small portion of footprint found at a crime scene may be sufficient for building the biological profile of individuals. Therefore, the present study encourages conducting more research on different populations to confirm the current findings.

6. Recommendations

To yield more reliable results that could be replicated in forensic practices; the following recommendations are proposed:

- Studies on larger sample size and on different populations to confirm the current findings
- Similar studies are to be undertaken if morphological features vary considerably between static and dynamic footprints, or vary if studied on different types of surfaces.

Authors' Contribution

MA Conducted practical part of research and helped in writing. SM, AE, HA designed the study, interpreted the data, assisted in writing and were in charge of overall direction and planning. GA performed the statistical analysis.

Conflict of Interest

None

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