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Fingerprint White Line Counts: An Upcoming Forensic Tool for Sex Determination



تعداد الخطوط البيضاء في بصمات الأصابع: طريقة قادمة في تحديد الجنس.

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Abstract

Fingerprints are one of the common forensic tools used in personal identification. However, the associated secondary epidermal creases of fingerprints, fingerprint white line count (FWLC), has received less attention within the forensic community. This study was conducted with an aim to determine the potential of FWLC in sex inference among adult Nigerians.

A cross sectional study was carried out with 150 males and 150 females with age range of 18-30 and 18-33 years, respectively. Live scanner (Digita persona, China) was used to capture the plain fingerprint for FWLC. Mann Whitney, Kruskal Wallis and logistic regression analyses were employed for determination of digit variation (based on side and type), sexual dimorphism and prediction models, respectively. Likelihood ratio and posterior probability were used to determine the favour odd for sex inference from FWLC.

A significant higher mean value of FWLC was observed in females (2.24 ± 2.03) compared to males (0.85 ± 1.29). Absence of white line was indicative of male origin in all the digits except for left index digit (favor odd of 0.72 for females and 0.29 for males). However, FWLC from 5 to 11 were more likely to be of female origin. The best discriminator of sex was the left FWLC with a percentage accuracy of discrimination of 72%. The percentage contribution of the left FWLC in the discrimination of the sexes was observed to range from 23.0 to 30.20%.

The FWLC was found to be a potential predictor of sex among adult Nigerians of Hausa ethnic origin.

Keywords: Forensic Science, Identification, Fingerprint, White Line Counts, Sex Inference.



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المستخلص

تعد بصمات الأصابع إحدى أدوات الطب الشرعي الشائعة المستخدمة في تحديد الهوية الشخصية. ومع ذلك فإن التجاعيد الجلدية الثانوية المرتبطة ببصمات الأصابع وتعداد الخطوط البيضاء في بصمات الأصابع (FWLC) لاقت اهتماماً أقل من قبل أخصائيي الأدلة الجنائية.

وأجريت الدراسة بهدف تحديد إمكانات (FWLC) في الاستدلال على الجنس بين النيجيريين الكبار. بنيت الدراسة على استقصاء مقطعي تضمن 150 من المتطوعين الذكور و150 من المتطوعات الإناث، ممن تتراوح أعمارهم بين 18-30 سنة و18-33 سنة على التوالي. واستخدم المسح الضوئي المباشر (Digita persona، الصين) لالتقاط بصمة واضحة لإجراء (FWLC). وتم استخدام كل من التحاليل الإحصائية مان ويتي، كروسكال واليس والانحدار اللوجستي لتحديد اختلاف الأصابع (على أساس الجانب والنوع)، والاختلاف بين الجنسين، ونماذج التنبؤ على التوالي. استخدمت نسبة الاحتمالات والاحتمال البعدي لتحديد نسبة الترجيح للاستدلال على الجنس من FWLC.

لوحظت قيمة متوسطة أعلى من FWLC عند الإناث (2.24 ± 2.03) مقارنة بالذكور (0.85 ± 1.29). وكان غياب الخط الأبيض يدل على الأصل الذكوري في جميع الأصابع باستثناء الإصبع القياسي الأيسر (نسبة الترجيح بقيمة 0.72 عند الإناث و0.29 عند الذكور). ومع ذلك، فإنه من المرجح أن تدل قيم FWLC من 5 إلى 11 على الأصل النسائي للإصبع. وكان أفضل تمييز بين الجنسين يعتمد على قيم FWLC الأيسر مع دقة نسبة تمييز بقيمة 72%. ولوحظ أن النسبة المئوية لمساهمة FWLC في التمييز بين الجنسين تراوحت بين 23.0 و30.20%.

وقد خلصت الورقة إلى أن قيم FWLC يمكن أن تكون مؤشراً محتملاً لتقدير الجنس بين البالغين النيجيريين من أصل الهوسا.

الكلمات المفتاحية: علوم الأدلة الجنائية، تحديد الهوية، بصمة الأصابع، تعداد الخط الأبيض، الاستدلال الجنسي.

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1. Introduction

The fingerprint epidermal ridge pattern depends on the cornified layer of epidermis and dermis configuration. The main events that lead to establishment of the epidermal ridge pattern occur during the 10th to 16th week of intra uterine life. Embryonal volar skin is made up of two main structures, the superficial layered epidermis and deep amorphous fibrous dermis [1, 2, 3]. The basal layer consisting of columnar epithelium becomes undulated. This results in the formation of the folds of the epidermis into dermis called primary ridges, which establish the future surface fingerprint patterns [1, 4, 5]. The primary features of the fingerprint resulting from the epidermal ridge configuration include ridge pattern (basically arches, whorls and loops), ridge density, ridge pores, minutiae, ridge contour and shape which are all of forensic interest. In some instances, after formation of the fingerprint, the associated ridges undergo ridge hypoplasia, resulting in a decrease in their height, giving them a “worn-off” appearance. These areas of worn off ridges are also covered with number of fine secondary creases that become visible, producing an additional feature “called white lines” [6, 7, 8].

The potential of features like ridge density has already gained popularity for sex inference since the introduction of quantitative mean of ridge count per unit area by Acree [9]. This fingerprint feature found at the scene of a crime has been proven to be a useful indicator of the sex of the perpetrator. This helps the forensic experts to minimize the time and effort spent on each case by directing the investigation process toward the suspects belonging to the most likely sex [10]. To reinforce the above claim, studies on African populations such as Nigerians [11], Sudanese [12], Egyptians [13], Asian populations such as Chinese and Malaysians [14], and South Indian populations have been conducted [15]. Other studies have concentrated on Indo-Mauritian populations [16], and central Indian (Marathi) populations [17], European populations, Spanish Caucasians [10], Latin American populations, and Argentinean populations [18].

Despite the wide application of fingerprints in the forensic community in personal identification and the wide population data in the ridge density, the associated second-

ary epidermal creases of fingerprints, the fingerprint white lines, have received less attention in the literature. This study provides an in-depth analysis of FWLC to fill in the gap in the literature, especially among the Hausa ethnic group. There are ongoing global efforts to discover more predictors of human identity. This justifies the need for the present effort of providing reference data on FWLC among the Hausa ethnic group for sex discrimination and personal identification. Furthermore, there is a need to recognize biological traits which can provide additional information about individuality. The present study aimed to determine the potential of FWLC in sex inference among adult Nigerians of Hausa ethnic background through three objectives as follows: (i) to determine the level of sexual dimorphism in FWLC (ii) to determine the probability of sex inference of each FWLC per unit area of plain fingerprint and (iii) to provide models and prediction accuracy of FWLC in sex inference among adult Nigerians of Hausa ethnic origin.

2. Materials and Methods

2.1 Study Area and Population

The study was conducted at Bayero University Kano and Maitama Sule University, Kano. Using simple random sampling, a total of 300 students (150 males and 150 females) were selected for the study. The mean ages of male and female participants were 21.94 ± 2.31 years (18 -30 years) and 20.13 ± 2.33 years (18-33 years), respectively. The inclusion criteria included any participant without any physical deformity in the tip of the fingers who belongs to the Hausa ethnic group. The study was conducted following the ethical guidelines of the Helsinki Declaration. The protocol involved in the study was approved by the Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Science, Bayero University Kano. Informed consent was also obtained from the participants.

2.2 Collection of Biodata and Fingerprints

The study was cross-sectional which involved the collection of the bio-data (sex, age and ethnicity) using proforma. The plain fingerprints were captured using live scanner (Digita Persona, China) in accordance with Adamu et al. [11].



2.3 Fingerprint White-Line Counts

The white lines were determined according to the previous method [19] as skin folds in the friction ridges that appear as white lines in a fingerprint (Figure-1). The white lines were considered when more than one epidermal ridge is crossed by the white lines. This was irrespective of the orientation and direction of the white line. Fingerprint pores (formed by sweat glands) associated with ridges were not included in the counts. The number of white lines per unit fingerprints gives the white line count.

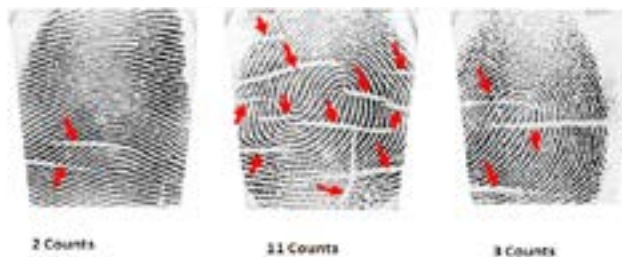


Figure 1- Plain fingerprint and method of FWLC observed in arches, whorls and loop patterns.

2.4 Measurement Error

The Cronbach's Alpha of the white line counts of the ten digits range from 0.98-1.00. Repeated measurement was carried out on 30 selected participants. According to Shrout and Fleiss [20], Cronbach's Alpha of 0.6 to < 0.8 represents "substantial reliability", and 1 represents "almost perfect reliability".

2.5 Calculation of Likelihood Ratio (LR), Posterior Probability (PP) and Favour Odd (FO)

The calculated LR gives the strength of support for one of the hypotheses: C or C'. Posterior probabilities $P(C/FWLC)$ and $P(C'/FWLC)$ were calculated using Bayes' theorem [21]. Favored odds for support of the most likely hypothesis for a given FWLC $P(FWLC/C)$ and $P(FWLC/C')$ were obtained from information of both LR computations and posterior probabilities. The likelihood ratio (LR) was calculated using relative frequency of FWLC.

Relative FWLC = (Frequency of a given FWLC) / (Total frequency of all FWLC)

The likelihood ratio (LR) was calculated as;

LR = (probability of observing a given FWLC if the donor was male (C) / (probability of observing a given

FWLC if the donor was female (C')) = $P(FWLC/C) / P(FWLC/C')$, where C is the male donor, and C' is the female donor, and assuming the equal probability between the sexes $P(C) = P(C') = 0.5$.

The FWLC with likelihood ratio of > 1 is more likely to be of male origin, and < 1 is likely to be of female origin. The favor odd (FO) was calculated as $FO = P(FWLC/C) / P(FWLC/C) + P(FWLC/C')$

Frequencies for different types of patterns and mean ridge density were also determined.

2.6 Statistical Analysis

The data were expressed in mean \pm SD, frequency and percentages. The data were not normally distributed (Shapiro Wilk test, $p < 0.05$), which indicate the need for non-parametric tests. Mann-Whitney and Kruskal Wallis tests [Dunn's pair-wise multiple comparisons with Benferoni correction (adjusted significance)] were used to compare differences in FWLC. Step-wise multiple logistic regression analyses were used to generate a model for sex inference and accuracy of prediction. SPSS version 20 (IBM Corporation, for Windows) was employed for analysis of data. $p < 0.05$ was set as the level of significance.

3. Results

Table-1 shows variation of fingerprint white lines counts across digits and sides among the Hausa ethnic group of adult Nigerians. In males, the thumb had significantly higher FWLC compared to all other digits in both left and right sides of the hand. In females, a significant difference was observed in only FWLC of the index and ring fingers in both sides, and between the thumb and index finger in the right hand. The ring and thumb digits had higher FWLC compared to index digits.

Figure-2 shows sexual dimorphism in FWLC among the Hausa ethnic group of Nigeria. It was observed that females tend to have significantly ($p < 0.001$) higher mean values compared to males. In both sides of the hand, males had higher FWLC in the thumb compared to other digits. However, in females, the higher count was observed in the ring digits.

Table-2 shows the predictive potential of FWLC in sex inference among the Hausa ethnic group of Nigerian



Table 1- Variation of fingerprint white line counts across digits and sides among the Hausa ethnic group of adult Nigerians.

Sex	Side	DIGITS					Kruskal Wallis Test		
		Thumb	Index	Middle	Ring	Little	χ^2	P Value	
Male	Right	Mean \pm SD	1.03 \pm 1.13 ^{a,b,c,d}	0.47 \pm 0.92 ^a	0.56 \pm 0.94 ^b	0.58 \pm 1.22 ^c	0.49 \pm 1.20 ^d	44.02	<0.001
		Mean \pm SD	1.24 \pm 1.29 ^{a,b,c,d}	0.85 \pm 1.29 ^a	0.92 \pm 1.38 ^b	0.93 \pm 1.47 ^c	0.66 \pm 1.15 ^d	27.80	<0.001
	Mann-Whitney test	Z Value	-1.32	-2.86	-2.07	-2.16	-1.60		
		P Value	0.188	0.004	0.039	0.031	0.110		
	Female	Right	Mean \pm SD	2.13 \pm 1.66 ^a	1.43 \pm 1.78 ^{a,b}	1.87 \pm 2.06	2.35 \pm 2.81 ^b	2.03 \pm 2.40	18.61
Mean \pm SD			2.71 \pm 1.90	2.24 \pm 2.03 ^a	2.53 \pm 2.54	3.31 \pm 2.99 ^a	2.77 \pm 2.89	12.86	0.012
Mann-Whitney test		Z Value	-2.81	-4.08	-2.46	-3.40	-2.35		
		P Value	0.005	<0.001	0.014	0.001	0.019		

Similar superscript letters indicate significant difference along the raw using Dunn's pair-wise multiple comparisons with Benferoni correction (adjusted significance).

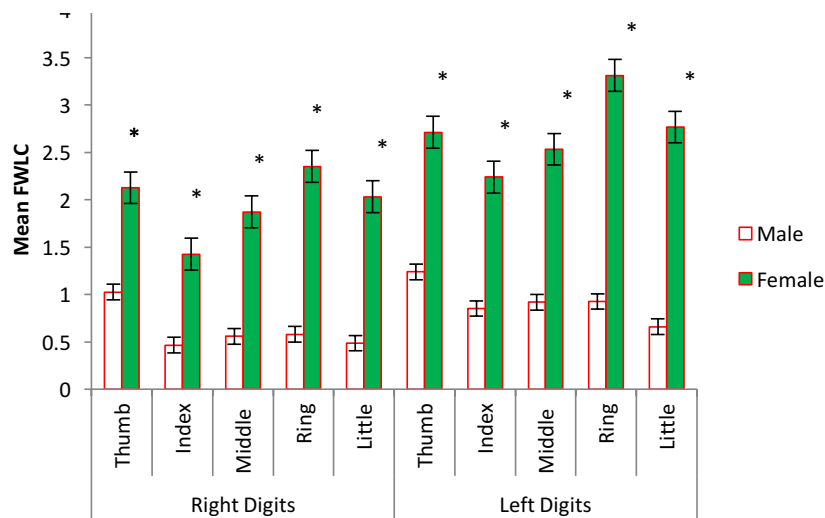
**Figure 2-** Sexual dimorphism in FWLC among the Hausa ethnic group of Nigeria (* $p < 0.001$).

Table 2- Predictive potential of FWLC in sex inference among the Hausa ethnic group of adult Nigerians.

Models	FWLC	B	OMT	Exp(B)	Accuracy	Cox & Snell R ²	Nagelkerke R ²
Step 1	Left ring	0.55	78.34*	1.73	72.00	0.23	0.31
	Constant	-1.00		0.37			
Step 2	Left ring	0.41	87.55*	1.51	71.00	0.25	0.34
	Left Thumb	0.33		1.39			
	Constant	-1.35		0.26			
Step 3	Left Little	0.28	93.82*	1.32	71.00	0.27	0.36
	Left Ring	0.25		1.29			
	Left Thumb	0.29		1.34			
	Constant	-1.38		0.25			

* $p < 0.01$, OMT; omnibus test of coefficients of the regression models

adults. Using step wise binary logistic regression, FWLC from three digits were significant predictors of sex. It was observed that the best sex predictor was the left ring finger FWLC followed by the left thumb FWLC and then the left little finger FWLC. The percentage accuracy obtained for the best predictor significantly inferred sex higher than sex inference by chance (50%). The variance of sex inference explained by this predictor ranged from 23% to 31%, which was significant at the level of $p < 0.01$.

Tables-3, 4, 5 show the probability of sex inference of each FWLC per unit area of plain fingerprint using the three significant predictors. In all the three digits, absence of FWLC was indicative of male origin. The FWLC greater than seven in the left ring digits was an absolute (probability =1) indication of female origin (Table-3). For left thumb and left little digits, the FWLC greater than five were an absolute (probability =1) indication of female origin (Table-4 & 5). Any increase in FWLC was more indicative of female than male gender in all the ten digits.

4. Discussion

Fingerprints are a valued forensic tool and one of the commonly encountered evidences at crime scenes which prove to be useful in identification of the suspect [22]. The widely used features include pattern type, pattern intensity index, ridge counts/density/thickness, and minutiae [23].

However, other characteristic features including FWLC have received less attention in the literature. The current study explored the potential of white line counts as a possible additional feature of forensic significance.

The higher FWLC observed in females compared to males in the present study is in keeping with previous studies among different populations [19, 24]. The increase in the FWLC in females may be explained by the fact that females tend to have more ridge density compared to males. Thus, more FWLC are accommodated by higher ridge density digits. This may also suggest the influence of sex hormones, especially testosterone, in the sex differences observed in the FWLC. This is more so since previous studies documented that in human populations dermatoglyphics asymmetry is affected by the level of prenatal hormone [25]. It has been documented that a high level of testosterone in adult males was associated with more pronounced dermatoglyphics asymmetry [26].

The relatively higher percentage accuracy of sex inference from FWLC may also portray significance of the variable as an isolative entity in sex prediction without considering other features like ridge density. Thus, additional variables such as ridge density and finger anthropometry, which are also reported to have sex discriminating potential [11, 27] when combined with FWLC, will for sure in-



Table 3- Probability of sex inference of each FWLC per unit area of plain fingerprint using left ring digit among adult Nigerians.

FWLC	Frequency		Relative FWLCD		Posterior Probability		Likelihood/0.5			Favour odd	
	Male	Female	Male	Female	Male	Female	Male	Female	Sum of PP	Male	Female
0	90	29	0.60	0.19	1.20	0.39	3.10	0.32	1.59	0.76	0.24
1	22	17	0.15	0.11	0.29	0.23	1.29	0.77	0.52	0.56	0.44
2	15	22	0.10	0.15	0.20	0.29	0.68	1.47	0.49	0.41	0.59
3	15	23	0.10	0.15	0.20	0.31	0.65	1.53	0.51	0.39	0.61
4	4	19	0.03	0.13	0.05	0.25	0.21	4.75	0.31	0.17	0.83
5	-	9	0.00	0.06	0.00	0.12	0.00		0.12	0.00	1.00
6	2	11	0.01	0.07	0.03	0.15	0.18	5.50	0.17	0.15	0.85
7	2	6	0.01	0.04	0.03	0.08	0.33	3.00	0.11	0.25	0.75
8	-	5	0.00	0.03	0.00	0.07	0.00	-	0.07	0.00	1.00
9	-	4	0.00	0.03	0.00	0.05	0.00	-	0.05	0.00	1.00
10	-	1	0.00	0.01	0.00	0.01	0.00	-	0.01	0.00	1.00
11	-	2	0.00	0.01	0.00	0.03	0.00	-	0.03	0.00	1.00
13	-	1	0.00	0.01	0.00	0.01	0.00	-	0.01	0.00	1.00
17	-	1	0.00	0.01	0.00	0.01	0.00	-	0.01	0.00	1.00

PP; posterior probability

Table 4- Probability of sex inference of each FWLC per unit area of plain fingerprint using left thumb digit among adult Nigerians.

FWLC	Frequency		Relative FWLCD		Posterior Probability		Likelihood/0.5			Favour odd	
	Male	Female	Male	Female	Male	Female	Male	Female	Sum of PP	Male	Female
0	52	13	0.35	0.09	0.69	0.17	4.00	0.25	0.87	0.80	0.20
1	47	26	0.31	0.17	0.63	0.35	1.81	0.55	0.97	0.64	0.36
2	30	40	0.20	0.27	0.40	0.53	0.75	1.33	0.93	0.43	0.57
3	10	30	0.07	0.20	0.13	0.40	0.33	3.00	0.53	0.25	0.75
4	6	19	0.04	0.13	0.08	0.25	0.32	3.17	0.33	0.24	0.76
5	5	11	0.03	0.07	0.07	0.15	0.45	2.20	0.21	0.31	0.69
6	-	2	0.00	0.01	0.00	0.03	0.00	-	0.03	0.00	1.00
7	-	8	0.00	0.05	0.00	0.11	0.00	-	0.11	0.00	1.00
12	-	1	0.00	0.01	0.00	0.01	0.00	-	0.01	0.00	1.00

PP; posterior probability



Table 5- Probability of sex inference of each FWLC per unit area of plain fingerprint using left little digit among adult Nigerians.

FWLC	Frequency		Relative FWLCD			Posterior Probability			Likelihood/0.5		Favour odd	
	Male	Female	Male	Female	Male	Female	Male	Female	Sum of PP	Male	Female	
0	102	40	0.68	0.27	1.36	0.53	2.55	0.39	1.89	0.72	0.28	
1	19	24	0.13	0.16	0.25	0.32	0.79	1.26	0.57	0.44	0.56	
2	14	20	0.09	0.13	0.19	0.27	0.70	1.43	0.45	0.41	0.59	
3	10	17	0.07	0.11	0.13	0.23	0.59	1.70	0.36	0.37	0.63	
4	3	18	0.02	0.12	0.04	0.24	0.17	6.00	0.28	0.14	0.86	
5	2	11	0.01	0.07	0.03	0.15	0.18	5.50	0.17	0.15	0.85	
6	-	3	0.00	0.02	0.00	0.04	0.00	-	0.04	0.00	1.00	
7	-	3	0.00	0.02	0.00	0.04	0.00	-	0.04	0.00	1.00	
8	-	6	0.00	0.04	0.00	0.08	0.00	-	0.08	0.00	1.00	
9	-	1	0.00	0.01	0.00	0.01	0.00	-	0.01	0.00	1.00	
10	-	2	0.00	0.01	0.00	0.03	0.00	-	0.03	0.00	1.00	
11	-	3	0.00	0.02	0.00	0.04	0.00	-	0.04	0.00	1.00	
12	-	2	0.00	0.01	0.00	0.03	0.00	-	0.03	0.00	1.00	

PP; posterior probability

crease the accuracy of the sex inference as well as reduce the chances of error that may occur when a single variable is considered.

Population based comparison showed that the absence of FWLC is indicative of male origin and is preserved across different ethnic groups [19, 24]. However, the defined frequency that infers actual sex varies. This may further support the genetic influence on the associated FWLC feature. This suggests that in addition to sex inference, the FWLC may be an important tool for ethnic differentiation. The possible heritability of FWLC, just like other fingerprint features, may also need to be investigated as this may reveal the probable role of genetics in the embryogenesis and formation of FWLC.

Despite the promising results of sex inference from FWLC, earlier studies suggested that this feature increases in frequency with advancement in age and also with significant positive alteration in subcutaneous body fat [6, 7]. This report needs to be investigated further, since a reliable and

valid forensic tool should always be a unique and constant feature throughout life. Although a previous study suggested alterations of FWLC [7], the study designed was not longitudinal; as such, the claim of the alteration of FWLC may be due to possible variation of FWLC across different age groups. However, a longitudinal and retrospective study conducted by Vieira Silva et al. [28] demonstrated significant increase in white line count among the elderly population. If this is the case, the stability of FWLC as forensic tool will be at stake. It was suggested that aging decreases skin moisture, oils, vascularization and cellular proliferation, leading to a low turn of elastin proteins of the extracellular matrix and consequent degradation of elastic fibers [29]. Cumulatively, these changes decrease the elasticity and support of the tissue and lead to a subsequent increase in brittleness and probable appearance of lesions and spots, due to mitochondrial and nuclear DNA repair mechanisms impairment in the aging process [30]. Additionally, it was further suggested that the increase in white



lines may be due to the loss of resilience of the skin, which is the property by which it regains its normal shape after being subjected to the process of elastic deformation [28]. It should also be noted that other features of the fingerprint like ridge thickness and density changes with age advancement [31] as a continuum of body development in general. But these change in the fingerprint features do not alter the uniqueness and consistency of fingerprints. Also, females tend to have more accumulated fat compared with their male counterparts. This may support the hypothetical positive relationship between the FWLC and subcutaneous fat. It is hoped that the mechanism that influenced the formation of the fingerprint features incorporate FWLC among the associated features of fingerprints.

In the context of forensic sciences, the present study could be useful, as FWLC offers a potential sex discrimination tool for sex inference in conditions such as aviation disasters, murder-mutilation, forensic scenes and natural disasters where other body parts that could aid sex identification are mutilated beyond identification.

In conclusion, FWLC was found to be a sex predictor among adults of Hausa ethnic origin in Nigeria. Females had a significantly higher mean value of FWLC compared to males.

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Conflict of Interest

None

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References

1. Babler WJ. Embryological development of epidermal ridges and their configuration. In: Plato CC, Garuto RM, Shaumann BA. Eds. *Dermatoglyphics: Science in transition*. 2nd Ed. New York: Wiley liss; 1991; 27: 95-112.
2. Hale A. Morphogenesis of volar skin in the human fetus. *Am J Anat*. 1951; 91: 147-180. <https://doi.org/10.1002/aja.1000910105>
3. Penrose L, O'Hara P. The development of epidermal ridge. *J Med Gen*. 1973; 10: 201-208. <https://doi.org/10.1136/jmg.10.3.201>
4. Okajima M. Development of dermal ridges in the fetus. *J Med Gen*. 1975; 12: 234-250. <https://doi.org/10.1136/jmg.12.3.243>
5. Kucken M, Newell AC. A model of fingerprints formation. *Euro Phy Latt*. 2004; 68(1). 141-146. <https://doi.org/10.1209/epl/i2004-10161-2>
6. Ashbaugh DR. *Quantitative-qualitative friction ridge analysis: an introduction to basic and advanced ridgeology*. CRCPress LLC, Boca Raton, FL, 1999. <https://doi.org/10.1201/9781420048810>
7. Cummins H, Midlo C. *Finger Prints, Palms and Soles: An Introduction to Dermatoglyphics*. Dover Publishing, New York, 1943.
8. D'Adamo PJ. *Dermatoglyphic in: fundamentals of generative medicine, vol. 1*. Drum Hill Books, Wilton CT, USA, 2010.
9. Acree MA. Is there a gender difference in fingerprint ridge density? *Forensic Sci Int*. 1999; 102:35-44. [https://doi.org/10.1016/S0379-0738\(99\)00037-7](https://doi.org/10.1016/S0379-0738(99)00037-7)
10. Gutierrez-Redomero E, Alonso C, Romero E, Galera V. Variability of fingerprint ridge density in a sample of Spanish Caucasians and its application to sex determination. *Forensic Sci Int*. 2008;180:17-22. <https://doi.org/10.1016/j.forsciint.2008.06.014>
11. Adamu LH, Ojo SA, Danborno B, Adebisi SS, Taura MG. Sex prediction using ridge density and thickness among the Hausa ethnic group of Kano state, Nigeria. *Aust J Forensic Sci*. 2018; 50(5): 455-471. <https://doi.org/10.1080/00450618.2016.1264477>
12. Ahmed AA, Osman S. Topological variability and sex differences in fingerprint ridge density in a sample of the Sudanese population. *J Forensic Leg Med*. 2016; 42:25-32. <https://doi.org/10.1016/j.jflm.2016.05.005>
13. Eshak GA, Zaher JF, Hasan EI, El-Azeem Ewis AA. Sex identification from fingertip features in Egyptian



- population. *J Forensic Leg Med.* 2013; 20:46–50. <https://doi.org/10.1016/j.jflm.2012.04.038>
14. Nayak VC, Rastogi P, Kanchan T, Yoganarasimha K, Kumar GP, Menezes RG. Sex differences from fingerprint ridge density in Chinese and Malaysian population. *Forensic Sci Int.* 2010; 197:67–69. <https://doi.org/10.1016/j.forsciint.2009.12.055>
15. Nithin MD, Manjunatha B, Preethi DS, Balaraj BM. Gender differentiation by finger ridge count in South Indian population. *J Forensic Leg Med.* 2011;18(2):79–81. <https://doi.org/10.1016/j.jflm.2011.01.006>
16. Agnihotri AK, Jowaheer V, Allock A. An analysis of fingerprint ridge density in the Indo-Mauritian population and its application to gender determination. *Med Sci Law.* 2012; 52(3):143–147. <https://doi.org/10.1258/msl.2012.011093>
17. Kapoor N, Badiye A. Sex differences in thumbprint ridge density in a central Indian population Egyptian. *J Forensic Sci.* 2015; 5(1):23–29.
18. Rivalderia N, Sanchez-Andres A, Alonso-Rodriguez C, Dipierri JE, Gutierrez-Redomero E. Fingerprint ridge density in the Argentinean population and its application to sex inference: a comparative study. *HOMO J Comp Hum Biol.* 2016;67:65–84. <https://doi.org/10.1016/j.jchb.2015.09.004>
19. Tadorana RJO, Tadeo AKV, Nadine, Escalona AC, Townsend GC. Sex determination from fingerprint ridge density and white line counts in Filipinos. *HOMO - J Comp Hum Biol.* 2016; 67: 163–171. <https://doi.org/10.1016/j.jchb.2015.11.001>
20. Shrout P, Fleiss J. Intraclass correlations: Uses in assessing rater reliability. *Psychol Bull.* 1979; 86: 420–428. <https://doi.org/10.1037/0033-2909.86.2.420>
21. Grieve MC, Dunlop J. A practical aspect of the Bayesian interpretation of fibre evidence, *J Forensic Sci Soc.* 1992; 32: 169–175. [https://doi.org/10.1016/S0015-7368\(92\)73066-7](https://doi.org/10.1016/S0015-7368(92)73066-7)
22. Champod C, Lennard PA, Stoilovic MM. Fingerprints and other ridge skin impressions, 2nd ed. CRC Press, Washington, 2004. <https://doi.org/10.1201/9780203485040>
23. Gutiérrez-Redomero E, Alonso C, Romero E, Galera V. Variability of fingerprint ridge density in a sample of Spanish Caucasians and its application to sex determination. *Forensic Sci Int.* 2008; 180: 17–22. <https://doi.org/10.1016/j.forsciint.2008.06.014>
24. Badawi A, Mahfouz M, Tadross R, Jantz R. Fingerprint based gender classification. In: the International Conference on Image Processing, Computer Vision, and Pattern Recognition, CSREA Press, Las Vegas, NV, 2006.
25. Jamison CS, Meier RJ, Campbell BC. Dermatoglyphic asymmetry and testosterone level in normal males. *Am J Phys Anthropol.* 1993; 90 :185–198. <https://doi.org/10.1002/ajpa.1330900205>
26. Gasparov AS, Pshenichinkova T. Clinicodermatoglyphic correlations in patients with hyperandrogenia. *Akush Kinekol (MOSK).* 1989;2: 46–9.
27. Kralik M, Novotny V. Epidermal ridge breadth: an indicator of age and sex in paleodermatoglyphics. *Variabil Evol.* 2003;11:5–30.
28. Vieira Silva LR, Mizokami LL, Vieira PR, Souka Kuckelhaus SA. Longitudinal and retrospective study has demonstrated morphometric variations in the fingerprints of elderly individuals. *Forensic Sci Int.* 2016; 259: 41–46. <https://doi.org/10.1016/j.forsciint.2015.11.019>
29. Farage MA, Miller KW, Elsner P, Maibach HI. Characteristics of the aging skin, *Adv. Wound Care (New Rochelle)* 2013; 2: 5–10. <https://doi.org/10.1089/wound.2011.0356>
30. Makrantonaki E, Zouboulis CC. German National Genome Research Network 2, The skin as a mirror of the aging process in the human organism—state of the art and results of the aging research in the German National Genome Research Network 2 (NGFN-2), *Exp. Gerontol.* 2007; 42:879–886. <https://doi.org/10.1016/j.exger.2007.07.002>
31. Sánchez-Andrés A, Barea JA, Rivaldería N, Alonso-Rodríguez C, Gutiérrez-Redomero E. Impact of aging on fingerprint ridge density: Anthropometry and forensic implications in sex inference. *Sci Justice,* 2018. <https://doi.org/10.1016/j.scijus.2018.05.001>

