Taura et al. Egyptian Journal of Forensic Sciences (2019) 9:63
https://doi.org/10.1186/s41935-019-0169-8

Egyptian Journal of
Forensic Sciences

ORIGINAL ARTICLE Open Access

# Adjacent digit fingerprint white line count differences: a pointer to sexual dimorphism for forensic application

Magaji Garba Taura[1,2], Lawan Hassan Adamu[2*], Abdullahi Yusuf Asuku[2], Kabiru Bilkisu Umar[3] and Musa Abubakar[2]

## Abstract

**Background:** Sex determination is one of the leading criterion in identification and verification of an individual. However, the potential roles of differences in adjacent fingerprint white line count (FWLC) in sex inference are not well elucidated in the literature especially among Hausa population. The study was conducted to determine sexual dimorphism and predict sex using adjacent digit FWLC difference (adj. DFWLCD) among Hausa population of Kano state, Nigeria.

**Methods:** The study population involved 300 participants. FWLC was determined from a plain fingerprint captured using live scanner. The formula for adj. DFWLCD of thumb and fifth digit is dR15 for right hand. The same applied for possible combination in cephalocaudal direction. Mann-Whitney and *t* tests were used for comparison of variables between sexes. Binary logistic regression analyses were employed for determination of sex.

**Results:** We observed a significantly larger adj. DFWLCD in males compared with females in most of the digit combination. A significant sexual dimorphism was observed in most of the adj. DFWLCD involving ring digit in both right (dR14, dR24, and dR34) and left (dL14, dL24, and dL34). The best discrimination was observed in adjacent FWLC difference of second and fourth digits in both right and left digits (dR24 and dL24). This was further supported by stepwise logistic regression analyses.

**Conclusion:** The adj. DFWLCD exhibits sexual dimorphism. The best prediction potentials were found to be dR24 and dL24 for right and left hands respectively.

**Keywords:** Forensic sciences, Fingerprint white line, Sex determination, Hausa population

## Introduction

Fingerprint is one of the widely used biometrics for the purpose of human identification. Its uniqueness, consistency, and inexpensiveness give room for its application in the distinction between individuals at different stages of human life (Zugibe and Costello, 1986; Yager and Amin, 2004; Gutierrez et al., 2007; Kahana et al., 2001; Franca, 2011; Vanrell, 2012). The fingerprint ridge configuration formed by epidermal ridges during 12th–19th gestational weeks remains fixed and permanent throughout the life of an individual (Mulvihill and Smith, 1969; Babler, 1979). The epidermal ridges are explained at different levels; these include pattern configuration, minutiae, ridge characteristic such as ridge flow, shape, contour, etc. (Hong et al., 1998; Jain et al., 2007). The epidermal ridges are often associated with surface wrinkling on gross examination of fingertip called fingerprint white lines.

Fingerprint white lines (FWL) correspond to areas of depression on fingerprints that appear white on the fingerprint images and skin deformation on fingertip that may be linked to loss of the elements of skin tissues (Cummins and Midlo, 1943; Ashbaugh, 1999; D'Adamo, 2010; Maceo, 2011). Previous studies suggested that with aging, there is decrease in the strata of the epithelium and an inter digitations between epidermis and dermis

* Correspondence: alhassan.ana@buk.edu.ng
[2]Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Sciences, Bayero University, Kano PMB 3011, Nigeria
Full list of author information is available at the end of the article

of the skin (Makrantonaki and Zouboulis, 2007; Waaijer et al., 2012; Farage, 2013) and reduction of elastin synthesis (Farage, 2013). This leads to decrease in the elasticity and support of the tissue, increase in the brittleness, and impairment of nuclear and mitochondrial DNA repair mechanisms. Hence, the chance for appearance of lesions and spots was exemplified by FWL (Makrantonaki and Zouboulis, 2007). This mechanism is supported by a documented increase in FWL in elderly (Vieira Silva et al., 2016) and increase in frequency of FWL with age or when there is alteration in subcutaneous body fat (Cummins and Midlo, 1943; Ashbaugh, 1999).

It was hypothesized that the size of a fetal fingertip (compared with its neighbor on the same hand) might be influenced by factors that stimulate or inhibit growth along the developmental axis extending from the brain to the lower limbs (Kahn et al., 2001). It is well documented that the growth along developmental axis is sexually dimorphic, with upper to lower body segments proportional difference been higher in males than in females (Bailey and Katch, 1981). However, the potential roles of differences in adjacent FWLC in sex inference are not well elucidated in the literature especially among Hausa population. Only few studies reported the potential role of FWL in sex determination in the other populations (Badawi et al., 2006; Taduran et al., 2016) including the Hausa population (Adamu et al., 2019). Since sex determination is one of the leading criteria in identification and verification of an individual among all the key parameters of identification (Ubelaker, 1996), and determination of sex of human remains has been proven to help forensic experts during analyses of dismembered and fragmentary remains and also in criminal investigation by narrowing the pool of potential suspect matches (Kanchan et al., 2008; Dey and Kapoor, 2015). It is, therefore, plausible to look at the utility of FWL in sex determination. The present study was set to achieve the following objectives: (i) to determine the sexual dimorphism in adj. DFWLCD, (ii) to predict sex from the adj. DFWLCD, and (iii) to determine the best adj. DFWLCD that discriminate the sex, among Hausa population of Kano state, Nigeria.

## Materials and methods

### Study location, design, and participants

The study was carried out at Bayero University Kano (a Federal university) and Maitama Sule University, Kano (a state University). This was a cross sectional study conducted among students of the two selected tertiary institutions in Kano metropolis, Nigeria. We randomly selected sample of 150 males and 150 females to participate in the study based on the study selection criteria. The participants were within the age range of 18–33 years (mean age of 21.94 ± 2.31 and 20.13 ± 2.33 years for male and female respectively). We excluded any participant with physical deformity in the tip of their digit and belonged to other ethnic group. We adopted self-declaration of the ethnicity methods, and only those that belong to Hausa ethnic group up to the level of grand parentage were considered. We obtained an informed consent from the participants before commencement of the study. The study allowed decline of consent by participants at any stage of the data collection (although none of the participants declined his/her consent). We used simple proforma for collection of bio-data (sex, age, and ethnicity) of the participants. The study was conducted following the ethical guidelines of Helsinki Declaration. The protocols involved in the study were approved by the Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Science, Bayero University Kano.

### Fingerprints capturing and white line counts

A live scanner (Digita Persona, China) was used to capture the fingerprint of all the ten digits according to methods described by Adamu et al. (2018). We defined the white line as the skin folds in the friction fingerprint epidermal ridges that appear as white lines in the fingerprint images (Fig. 1). The FWLC for each digit was considered as the number of the observed white lines per unit plain fingerprints (Taduran et al., 2016; Adamu et al., 2019). The reliability and intra observer error in the FWLC were reported elsewhere (Adamu et al., 2019).

### Determination of adjacent digit FWLC differences

It was suggested that each tip of digit is related neurologically to a spinal-cord segment in a range that includes the sixth (C6) through the eighth cervical (C8) levels. The first digit (thumb) is linked to the cephalad (upper) side of C6, and the fifth digit is linked to the caudal (lower) side of C8 (Heimer, 1994). We determined the adj. DFWLCD as per Kahn et al. (2001) methods of determination of adjacent fingerprint ridge count difference. The adj. DFWLCD was therefore determined as the differences in FWLC from the caudal FWLC value subtracted from the cephalad FWLC value (e.g., dR12 is right first digit (thumb) FWLC minus right second digit (index) FWLC, that is the difference in FWLC between thumb and index finger).

### Statistical analyses

The data were expressed using descriptive statistics (mean ± SD, minimum, and maximum), median (interquartile range (25th and 75th percentiles)). The normality test (Shapiro Wilk test, $P < 0.05$) was also carried out. Mann-Whitney and $t$ test were used for comparison of variable between sexes. Binary logistic regression

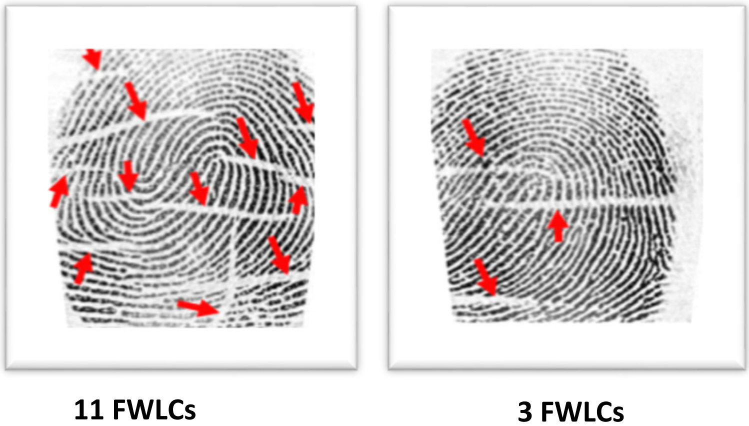


**Fig. 1** Techniques for fingerprints white line counts

analyses were used to generate a model for sex prediction using adj. DFWLCD. Stepwise multiple (forward conditional) binary logistic regression analysis was also conducted to determine the adj. DFWLCD that predict sex. The analyses were carried out using SPSS version 20 (IBM Corporation, for Windows) and 5% ($P < 0.05$) level of error was considered for any statistical inference.

## Results

Table 1 shows the descriptive statistics of the FWLC of the right and left hands digits. The mean FWLC was higher in the females in all the ten digits. Absence of FWLC was observed in both sexes in all the digits as the minimum counts. However, the maximum FWLC was in favor of females, with higher count across the ten digits.

From Table 2, the FWLC on the right digits was found to be higher on the first digit compared with other adjacent digits (second, third, fourth, and fifth) in both sexes except for dR14 in females where fourth digit had higher FWLC compared with the first digit, as indicated by negative mean value (− 0.23 ± 2.18). The second and third digits were observed to have lower FWLC compared with other adjacent digits in both males and females, except for dR35 in males where third digit had higher FWLC compared with the fifth digit, as indicated by positive mean value (0.07 ± 1.02). The mean dR45 was positive in both sexes in the right hand. Similar trend was observed in the left hand except in dL25 in males where the FWLC of the second digit was higher than that of fifth digit, as indicated by positive mean value (0.19 ± 1.27) and dL15 in females where the FWLC of the second digit was lower than the that of fifth digit, as indicated by negative mean value (− 0.05 ± 2.41). There were significantly larger adj. DFWLCD in males compared with females in most of the digit combination. However, few digits indicated higher adjacent digit FWLC difference adj. DFWLCD in females, but none was significant.

Table 3 shows sexual dimorphism in FWLC adjacent digit asymmetry of the right and left digits. A significant

**Table 1** Descriptive statistics of the FWLC of the right and left hands digits

| | | Male | | | Female | | |
|---|---|---|---|---|---|---|---|
| Digits | Designation | Min | Max | Mean ± SD | Min | Max | Mean ± SD |
| Right thumb | R1 | 0 | 6 | 1.03 ± 1.13 | 0 | 8 | 2.13 ± 1.66 |
| Right index | R2 | 0 | 8 | 0.47 ± 0.92 | 0 | 11 | 1.43 ± 1.78 |
| Right middle | R3 | 0 | 5 | 0.56 ± 0.94 | 0 | 9 | 1.87 ± 2.06 |
| Right ring | R4 | 0 | 10 | 0.58 ± 1.22 | 0 | 17 | 2.35 ± 2.81 |
| Right little | R5 | 0 | 10 | 0.49 ± 1.20 | 0 | 11 | 2.03 ± 2.40 |
| Left thumb | L1 | 0 | 5 | 1.24 ± 1.29 | 0 | 12 | 2.71 ± 1.90 |
| Left index | L2 | 0 | 9 | 0.85 ± 1.29 | 0 | 11 | 2.24 ± 2.03 |
| Left middle | L3 | 0 | 7 | 0.92 ± 1.38 | 0 | 15 | 2.53 ± 2.54 |
| Left ring | L4 | 0 | 7 | 0.93 ± 1.47 | 0 | 17 | 3.31 ± 2.99 |
| Left little | L5 | 0 | 5 | 0.66 ± 1.15 | 0 | 12 | 2.77 ± 2.89 |

25th–75th inter quartile range, *min* minimum, *max* maximum, *SD* standard deviation, *d* difference, *R* right, *L* left, 1–5 first to fifth digits

**Table 2** Descriptive statistics adj. DFWLCD and sexual dimorphism in cephalic to caudal growth inhibition in the right and left sides of the hand

| | Male | | | Female | | | | |
|---|---|---|---|---|---|---|---|---|
| Adj. DFWLCD | Mean ± SD | Min | Max | Mean ± SD | Min | Max | Cephalocaudal growth | Comment |
| dR12 | 0.56 ± 1.28 | − 8 | 4 | 0.70 ± 1.69 | − 4 | 5 | > in female | NS |
| dR13 | 0.47 ± 1.03 | − 2 | 4 | 0.25 ± 1.76 | − 8 | 4 | > in males | NS |
| dR14 | 0.45 ± 1.21 | − 4 | 4 | − 0.23 ± 2.18 | − 10 | 4 | > in males | S |
| dR15 | 0.54 ± 1.22 | − 4 | 4 | 0.09 ± 2.13 | − 8 | 4 | > in males | S |
| dR23 | − 0.09 ± 1.09 | − 3 | 8 | − 0.45 ± 1.59 | − 5 | 5 | > in males | S |
| dR24 | − 0.11 ± 1.31 | − 7 | 8 | − 0.93 ± 2.07 | − 11 | 4 | > in males | HS |
| dR25 | − 0.02 ± 1.26 | − 7 | 8 | − 0.61 ± 2.12 | − 8 | 5 | > in males | S |
| dR34 | − 0.02 ± 1.03 | − 5 | 3 | − 0.48 ± 1.97 | − 8 | 7 | > in males | S |
| dR35 | 0.07 ± 1.02 | − 5 | 3 | − 0.16 ± 1.90 | − 6 | 5 | > in males | NS |
| dR45 | 0.09 ± 1.11 | − 4 | 5 | 0.32 ± 1.80 | − 5 | 7 | > in females | NS |
| dL12 | 0.39 ± 1.42 | − 9 | 4 | 0.47 ± 1.80 | − 5 | 5 | > in females | NS |
| dL13 | 0.32 ± 1.40 | − 3 | 5 | 0.18 ± 1.93 | − 6 | 6 | > in males | NS |
| dL14 | 0.31 ± 1.30 | − 4 | 4 | − 0.60 ± 2.33 | − 9 | 6 | > in males | HS |
| dL15 | 0.58 ± 1.24 | − 3 | 4 | − 0.05 ± 2.41 | − 7 | 6 | > in males | S |
| dL23 | − 0.07 ± 1.39 | − 4 | 9 | − 0.29 ± 1.60 | − 5 | 4 | > in males | NS |
| dL24 | − 0.07 ± 1.41 | − 5 | 8 | − 1.07 ± 2.13 | − 10 | 3 | > in males | HS |
| dL25 | 0.19 ± 1.27 | − 4 | 8 | − 0.53 ± 2.35 | − 9 | 5 | > in males | S |
| dL34 | − 0.01 ± 1.17 | − 4 | 5 | − 0.78 ± 2.01 | − 13 | 3 | > in males | HS |
| dL35 | 0.26 ± 1.08 | − 4 | 3 | − 0.23 ± 2.35 | − 8 | 7 | > in males | S |
| dL45 | 0.27 ± 1.08 | − 3 | 5 | 0.55 ± 2.05 | − 5 | 6 | > in females | NS |

*Adj. DFWLCD* adjacent digit fingerprint white line counts difference, 25th–75th inter quartile range, *min* minimum, *max* maximum, *SD* standard deviation, *d* difference, *R* right, *L* left, 1–5 first to fifth digits, *S* significant ($P < 0.05$) *HS* highly significant ($P < 0.001$), *NS* not significant

sexual dimorphism was observed in all the adjacent FWLC differences involving ring digit in both right (dR14, dR24, and dR34) and left (dL14, dL24, and dL34) digits except for dR45. Similarly, dR25 and dL25 exhibited significant sexual dimorphism. The magnitude of the sexual dimorphism was more pronounced in dR24 ($Z = -3.69$, $P < 0.001$) and dL24 ($Z = -4.11$, $P < 0.001$), more in the left that in the right.

A significant sex prediction potential of adj. DFWLCD was observed in dR14, dR15, dR23, dR24, dR25, and dR34. Similar trend was observed in the left digits except for dL23 and addition of dL35. The best discrimination was observed in adj. DFWLCD of second and fourth digits in both right and left digits (dR24 and dL24). This was further supported by stepwise (forward conditional) multiple binary logistic regression analyses. The variance of sex explained by adjacent digit FWLC difference was higher in dL24 (7.4 to 9.9%) compared dR24 (5.6 to 7.4%) as shown in Table 4.

## Discussion

Identification of human remains is an essential element of any medico-legal investigation, and it has been a demanding task for forensic experts and physical anthropologists across the globe (Kanchan et al., 2008). This has led to continuous need to explore different body parts and techniques to determine key identity parameters often collectively described as “the Big Four”; race, sex, age, and stature (Scheuer, 2002; Ahmed and Omer, 2015). Therefore, the goal of the present study was to investigate and provide insight in to the role of adj. DFWLCD as a probable additional forensic tool that might compliment the sex component of “the Big Four.”

The difference in adj. DFWLCD was significantly more pronounced in males compared with females as an indication of larger cephalocaudal growth inhibition in males. This is supported by a previous study, where large fingerprint ridge-count difference between fingers on the same hand (a decline in the cephalocaudal direction) was used to reflect conditions associated with relative inhibition of caudal growth (Kahn et al., 2001). The concept of a more pronounced caudal growth inhibition in males may be explained by the fact that sexual dimorphism in the circumference of the upper limb (averaged 17.9%) was higher compared to that in the lower limb (4.6%), and this exhibited fairly consistent proximal to distal dimorphism in most of the measured body parameters (Bailey and Katch, 1981). It was also suggested that

**Table 3** Sexual dimorphism in FWLC adjacent digit asymmetry of the right and left digits

| | Male | Female | | |
|---|---|---|---|---|
| Adj. DFWLCD | Median (25th–75th) | Median (25th–75th) | *Z* value | *P* value |
| dR12 | 0 (0–1) | 1 (0–2) | − 1.09 | 0.277 |
| dR13 | 0 (0–1) | 0 (− 1–2) | − 0.83 | 0.404 |
| dR14 | 0 (0–1) | 0 (− 1–1) | − 2.55 | 0.011 |
| dR15 | 0 (0–1) | 0 (− 1–2) | − 1.21 | 0.226 |
| dR23 | 0 (− 1–0) | 0 (− 1–0) | − 1.84 | 0.066 |
| dR24 | 0 (0–0) | 0 (− 2–0) | − 3.69 | < 0.001 |
| dR25 | 0 (0–0) | 0 (− 2–1) | − 2.82 | 0.005 |
| dR34 | 0 (0–0) | 0 (− 1–0) | − 2.29 | 0.022 |
| dR35 | 0 (0–0) | 0 (− 1–1) | − 0.90 | 0.367 |
| dR45 | 0 (0–0) | 0 (0–1) | − 1.25 | 0.212 |
| dL12 | 0 (0–1) | 0 (0–2) | − 0.65 | 0.515 |
| dL13 | 0 (0–1) | 0 (− 1–1) | − 0.50 | 0.620 |
| dL14 | 0 (0–1) | 0 (− 2–1) | − 3.40 | 0.001 |
| dL15 | 0 (0–1) | 0 (− 2–2) | − 1.73 | 0.083 |
| dL23 | 0 (− 1–1) | 0 (− 1–1) | − 1.43 | 0.152 |
| dL24 | 0 (− 1–0) | − 1 (− 2–0) | − 4.11 | < 0.001 |
| dL25 | 0 (0–1) | 0 (− 2–1) | − 2.42 | 0.016 |
| dL34 | 0 (0–0) | (− 2–0) | − 3.66 | < 0.001 |
| dL35 | 0 (0–1) | 0 (− 1–1) | − 1.67 | 0.094 |
| dL45 | 0 (0–1) | 0 (− 0.25–2) | − 1.05 | 0.295 |

Adj. DFWLCD adjacent digit fingerprint white line counts difference, 25th–75th inter quartile range, *d* difference, *R* right, *L* left, 1–5 first to fifth digits

growth trends in the limbs are essentially linear through late adolescence but completed earlier in females (Hiernaux, 1968). The adult leg would therefore be less dimorphic than the adult arm (Bailey and Katch, 1981). Also, according to Kahn et al. (2001), developing embryos with higher adjacent digit ridge count difference might accumulate relatively less tissue in the lower body. This might express reduced lower-extremity muscle mass and tissue distribution compared with the upper body. From the foregoing explanations, it is clear that any measurable parameter that serves as an indicator of caudal inhibition, including adj. DFWLCD, will be of interest to forensic experts especially with regard to sex determination.

The significant sexual dimorphism observed in the adj. DFWLCD in the present study; reaffirms the potential of the FWLC in sex prediction as reported in previous studies (Badawi et al., 2006; Taduran et al., 2016; Adamu et al., 2019). The existence of sexual dimorphism in the adj. DFWLCD may be superior to the absolute FWLC in sex prediction especially among the elderly population, since, it was demonstrated that the FWL increases from adult to elderly life cycle. This is linked to the loss of resilience of the skin, which is the property of returning of the skin to its original shape after being subjected to elastic deformation (Vieira Silva et al., 2016). Frequency of FWL was also reported to increase with age or when there is alteration in subcutaneous body fat (Cummins and Midlo, 1943; Ashbaugh, 1999). In addition to FWL changes, the epidermal ridge thickness and inter papillary space were also reported to increase with age as a continuum of increase in body size (Cummins et al., 1994; David, 1981; Babler, 1991; Gutierrez-Redomero et al., 2011; Soanboon et al., 2016; Sánchez-Andrés et al., 2018). But, the adjacent finger ridge count difference (dR45) was suggested to be consistent with aging (Kahn et al., 2001). We therefore extended the same observation, of consistency of finger ridge count difference with aging, to adj. DFWLCD. This may be explained by the fact that, similar to second-to-fourth digit ratio of the hand (2D:4D), the indices do not change with aging and growth in body parts (Manning et al., 2004; Aboul-Hagag et al., 2011). Hence, it was concluded that sexing by indices is more reliable than absolute measurement since the relative growth of body parts are proportional to each other (Gutnik et al., 2015). This may lead to the assumption that adj. DFWLCD might not be altered by age or change in body condition similar to adjacent finger ridge count difference and digit ratios.

**Table 4** Sex prediction using FWLC adjacent difference of the right and left digits among Hausa population

| Adj. DFWLCD | β | *P* value | Constant | Cox & Snell $R^2$ | Nagel kerke $R^2$ | Chi$^2$ | *P* value | Percentage accuracy | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Male | Female |
| dR12 | 0.063 | 0.42 | − 0.039 | 0.002 | 0.003 | 0.66 | 0.418 | 57.30 | 54.00 |
| dR13 | − 0.104 | 0.203 | 0.037 | 0.005 | 0.007 | 1.65 | 0.199 | 44.00 | 54.70 |
| dR14 | − 0.228 | 0.002 | 0.031 | 0.036 | 0.048 | 11.09 | 0.001 | 42.70 | 64.70 |
| dR15 | − 0.152 | 0.029 | 0.050 | 0.017 | 0.022 | 5.01 | 0.025 | 43.30 | 53.30 |
| dR23 | − 0.197 | 0.028 | − 0.054 | 0.017 | 0.023 | 5.12 | 0.024 | 74.00 | 41.30 |
| dR24* | − 0.307 | < 0.001 | − 0.147 | 0.056 | 0.074 | 17.22 | < 0.001 | 78.00 | 44.00 |
| dR25 | − 0.203 | 0.005 | − 0.061 | 0.028 | 0.038 | 8.62 | 0.003 | 84.70 | 43.30 |
| dR34 | − 0.194 | 0.015 | − 0.046 | 0.022 | 0.038 | 6.51 | 0.011 | 80.70 | 40.00 |
| dR35 | − 0.101 | 0.189 | − 0.004 | 0.006 | 0.008 | 1.76 | 0.185 | 86.70 | 32.70 |
| dR45 | 0.103 | 0.192 | − 0.021 | 0.006 | 0.008 | 1.73 | 0.188 | 78.00 | 38.00 |
| dL12 | 0.033 | 0.643 | − 0.014 | 0.001 | 0.001 | 0.22 | 0.643 | 56.00 | 48.70 |
| dL13 | − 0.050 | 0.471 | 0.012 | 0.002 | 0.002 | 0.52 | 0.471 | 43.30 | 60.00 |
| dL14 | − 0.270 | < 0.001 | − 0.030 | 0.057 | 0.076 | 17.58 | < 0.001 | 80.70 | 44.00 |
| dL15 | − 0.177 | 0.006 | 0.049 | 0.027 | 0.036 | 8.21 | 0.004 | 48.70 | 51.30 |
| dL23 | − 0.102 | 0.194 | − 0.019 | 0.006 | 0.008 | 1.73 | 0.189 | 74.70 | 40.70 |
| dL24* | − 0.331 | < 0.001 | − 0.177 | 0.074 | 0.099 | 23.07 | < 0.001 | 74.00 | 54.70 |
| dL25 | − 0.211 | 0.002 | − 0.032 | 0.036 | 0.048 | 10.98 | 0.001 | 81.30 | 44.70 |
| dL34 | − 0.324 | < 0.001 | − 0.117 | 0.056 | 0.075 | 17.39 | < 0.001 | 76.00 | 48.00 |
| dL35 | − 0.153 | 0.023 | 0.004 | 0.018 | 0.024 | 5.52 | 0.019 | 29.30 | 64.00 |
| dL45 | 0.105 | 0.142 | − 0.043 | 0.007 | 0.010 | 2.20 | 0.138 | 72.70 | 42.70 |

Constructed model is sex = β × adjacent FWLC difference + constant, the cut up value is 0.5 (that is predictive probability is for female group membership). Value ≤ 0.5 is indicative of male gender and value > 0.5 is indicative of female gender, *d* difference, *R* right, *L* left, 1–5 first to fifth digits. * This indicates the best adjacent FWLC differences that predict sex (based on stepwise (forward conditional) multiple binary logistic regression analyses). *Adj. DFWLCD* adjacent digit fingerprint white line counts difference

The present quantification method (adj. DFWLCD) of FWLC may not only be superior to absolute quantification of FWLC but also to bilateral asymmetry in FWLC. It was documented that the occurrence of bilateral asymmetry depends on the extent exposure to stress and strain on the dominant side (Gutnik et al., 2015) This implies that the greater the use of the preferred side, the more the hypertrophy and development of the muscles on that side of the limb with consequential increase in asymmetry (Plochocki, 2004; Blackburn, 2011; Krishan, 2011; Krzykala and Leszczynski, 2015). Although, the influence of testosterone is more pronounced on the right hand even among the left handed individuals (Hampson and Sankar, 2012), and not more than 10% of every population are left handed, (Hardyck and Petrinovich, 1977) and 5% among African ages 18 to 33 years (De Agostini et al., 1997). For adj. DFWLCD, the differential influences of hand preference are minimal or absent considering the fact that both digits belong to the same body side.

Interestingly, in both right and left hands, the adj. DFWLCD in second and fourth digits (dR24 and dL24) was the best predictor of sex. This is similar to what was reported for digit ratio, where the 2D:4D exhibited the highest magnitude of sex discrimination especially in the right hand (Kyriakidis and Papaioannidou, 2008; Agnihotri et al., 2015). The 2D:4D is negatively correlated with prenatal testosterone and positively correlated with estrogen (Manning et al., 1998). This relationship between the digit ratio and sex hormones may be extended to other features associated with the digits (second and fourth digits) in a direct or an inverse manner. For the first time, we hypothesized that the dR24 and dL24 of FWLC correlated positively to prenatal testosterone and negatively correlated to estrogen. This may also be extended to other associated features like fingerprint ridge count which has been demonstrated to be an index of caudal growth inhibition (Kahn et al., 2001). Indeed, we also suggested inverse relationship between the adjacent digits associated feature differences and digit ratios, with higher value indicating “masculine feature” and lower value as “feminine feature” and also, more expression of adj. DFWLCD in the left (dL24) than the right (dL24). This is somewhat a paradox when compared with digit ratio, where high and low 2D:4D has been suggested to be a “feminine and masculine features” respectively

(Manning et al., 1998). And also 2D:4D is more sexually dimorphic on the right compared with the left in human hands (Manning et al., 1998; Manning, 2002), the feet of mice (Brown et al., 2002a; Brown et al., 2002), and zebra fishes (Burley and Foster, 2004). Though, further studies are needed to evaluate the direct relationship of adjacent digit associated feature differences with prenatal testosterone and estrogen.

In the present study, we highlighted the significance of adj. DFWLCD with special interest on FWLC as an index for sex discrimination. The pattern of sexual dimorphism exhibited is similar to well established sexually dimorphic digit ratio. This particular finding is a pointer to the need to investigate whether sexual dimorphism in adj. DFWLCD as observed in the present study is a universal phenomenon equally present in populations of different races and ethnicity. Considering the sex prediction potential exhibited by adj. DFWLCD, this study would be useful in any forensic case work since it offers adj. DFWLCD as a new biological characteristic that could compliment other known sex discriminating tools in forensic science. The study may also by extension serve as a source of reference data for forensic anthropologists in the study population. This can be applied in the analyses of cases in situations like mass disasters, acts of violence, bombing, and traffic accidents, which may be associated with dismembered human remains and peripheral parts of the body. It can be applied in assault cases where the victim's body is dismembered to conceal identity. Proper identification of dismembered, mutilated, and fragmentary remains using adj. DFWLCD may be imperative.

## Conclusion

We concluded that adj. DFWLCD exhibited a sexual dimorphism phenomenon that can be used in sex prediction. The best prediction potential was found to be dR24 and dL24 for right and left hands respectively among Hausa population of Kano state, Nigeria. The adj. DFWLCD is an important index for evaluation of caudal growth inhibition along the body axis, a well-established sexually dimorphic phenomenon in human population.

### Abbreviations

1–5: First to fifth digits e.g. dR12: difference between right first and second digit; 2D:4D: Second-to-fourth digit ratio of the hand; Adj. DFWLCD: Adjacent digit fingerprint white line count difference; C6: Sixth cervical; C8: Eighth cervical; d: Difference; FWL: Fingerprint white line; FWLC: Fingerprint white line count; HS: Highly significant; L: Left; Max: Maximum; Min: Minimum; NS: Not significant; R: Right; S: Significant; SD: Standard deviation

### Acknowledgements

We thank all those that participated in the study. The contribution of Sanusi Aminu in the technical aspect of the software development is hereby acknowledged. The assistance provided by Usman Bn Abdallah, Tajudden Lawan Sa'id, and Sadiya Nasir Bala is highly appreciated.

### Authors' contributions

MGT and LHA carried out the concepts, design, definition of intellectual content, editing, and review. AYA, KBU, and MA provided the definition of intellectual content and edited and reviewed the manuscript. LHA helped in the data acquisition and analyses and manuscript preparation. All the authors read and approved the final manuscript.

### Funding

Nil.

### Availability of data and materials

Data sets generated from is available at the Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Sciences, Bayero University or on request to the following email addresses; alhassan.ana@buk.edu.ng/mgtaura.ana@buk.edu.ng.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

### Author details

[1]College of Medicine, University of Bisha, Bisha, Saudi Arabia. [2]Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Sciences, Bayero University, Kano PMB 3011, Nigeria. [3]Department of Human Anatomy, Faculty of Basic Medical Sciences, College of Medicine and Health Sciences, Federal University Dutse, Dutse PMB 7156, Nigeria.

Received: 2 August 2019 Accepted: 24 October 2019
Published online: 07 December 2019

### References

Aboul-Hagag KE, Mohamed SA, Hilal MA, Mohamed EA (2011) Determination of sex from hand dimensions and index/ring finger length ratio in Upper Egyptians. Egypt J Forensic Sci 1(2):80–86

Adamu LH, Asuku AY, Muhd UA, Sa'id TL, Nasir SB, Taura MG (2019) Fingerprint white lines counts: an upcoming tool for sex determination. Arab J Forensic Sci Forensic 1(9):1165–1173

Adamu LH, Ojo SA, Danborno B, Adebisi SS, Taura MG (2018) Sex prediction using ridge density and thickness among the Hausa ethnic group of Kano state, Nigeria. Aust J Forensic Sci 50(5):455–471

Agnihotri AK, Jowaheer AA, Soodeen-Lalloo AK (2015) Sexual dimorphism in finger length ratios and sex determination-a study in Indo-Mauritian population. J Forensic Leg Med 35:45e50

Ahmed AA, Omer N (2015) Estimation of sex from the anthropometric ear measurements of a Sudanese population. Leg Med 17(5):313–319

Ashbaugh DR (1999) Quantitative-qualitative friction ridge analysis: an introduction to basic and advanced ridgeology. CRCPress LLC, Boca Raton, FL

Babler WJ (1979) Quantitative differences in morphogenesis of human epidermal ridges. Birth Defects Origl Artic Ser 15:199–208

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.

Badawi A, Mahfouz M, Tadross R, Jantz R (2006) Fingerprint based gender classification. In: The International Conference on Image Processing, Computer Vision, and Pattern Recognition. CSREA Press, Las Vegas, NV

Bailey SM, Katch VL (1981) The effects of body size on sexual dimorphism in fatness, volume and muscularity. Hum Biol 53(3):337–349

Blackburn A (2011) Bilateral asymmetry of the humerus during growth and development. Am J Phys Anthropol 145(4):639–646

Brown WM, Finn CJ, Breedlove SM (2002a) Sexual dimorphism in digit-length ratios of laboratory mice. Anat Rec 267:231–234

Brown WM, Hines M, Fane BA, Breedlove SM (2002) Masculinized finger length patterns in human males and females with congenitaladrenal hyperplasia. Horm. Behav 42:380–386

Burley NT, Foster VS (2004) Digit ratio varies with sex, egg order and strength of mate preference in zebra finches. Proc. R. Soc. B 271:239–244

Cummins H, Midlo C (1943) Finger prints, palms and soles: an introduction to dermatoglyphics. Dover Publishing, New York

Cummins H, Waits WJ, McQuitty JT (1994) The breadths of epidermal ridges on the finger tips and palms: a study of variations. Am J Anat 68:127–150
D'Adamo PJ (2010) Dermatoglyphic in: Fundamentals of generative medicine, vol 1. Drum Hill Books, Wilton CT, USA
David TJ (1981) Distribution, age and sex variation of the mean epidermal ridge breadth. Hum Hered 31:279–282
De Agostini M, Khamis AH, Ahui AM, Dellatolas G (1997) Environmental influences in hand preference: an African point of view. Brain Cogn 1997 35(2):151–167
Dey S, Kapoor AK (2015) Hand length and hand breadth: a study of correlation statistics among human population. Int J Sci Res 4(4):148–150
Farage MA, Miller KW, Elsner P, Maibach HI (2013) Characteristics of the aging skin. Adv Wound Care (New Rochelle) 2:5–10
Franca GV. Medicina Legal, ninth ed., Guanabara Koogan, Rio de Janeiro, 2011.
Gutierrez E, Galera V, Martınez JM, Alonso C (2007) Biological variability of the minutiae in the fingerprints of a sample of the Spanish population. Forensic SciInt 172:98–105
Gutierrez-Redomero E, Alonso MC, Dipierri JE (2011) Sex differences in fingerprint ridge density in the Mataco-Mataguayo population. HOMO– J Comp Hum Biol 62:487–499
Gutnik B, Skurvydas A, Zuoza A, Zuoziene I, Mickeviciene D, Alekrinskis A et al (2015) Evaluation of bilateral asymmetry between upper Limb masses in right-handed young adults of both sexes. Percept Mot Skills 120(3):804–815
Hampson E, Sankar JS (2012) Hand preference in humans is associated with testosterone levels and androgen receptor gene polymorphism. Neuropsychologia 50(8):2018–2025
Hardyck C, Petrinovich LF (1977) Left-handedness. Psychol Bull 84(3):385–404
Heimer L. The human brain and spinal cord: functional neuroanatomy and dissection guide. 2nd ed. New York, NY: Springer-Verlag, 1994.
Hiernaux J (1968) Variability of sexual dimorphism of stature in sub-Saharan Africa and Europe. In: Anthropology und Humangenetik, Fisher. Springer-Verlag, Stuttgart
Hong Y, Wan A, Jain AK (1998) Fingerprint image enhancement: algorithms and performance evaluation. IEEE Trans Pattern Anal Mach Intell 20:777–789
Jain A, Chen Y, Demirkus M (2007) Pores and pidges: fingerprint matching using level 3 features. Pattern Anal Mach Intell 29:15–27
Kahana T, Grande A, Tancredi DM, Penalver J, Hiss J (2001) Fingerprinting the deceased: traditional and new techniques. J Forensic Sci 46:908–912
Kahn HS, Ravindranath R, Valdez R, KMV N (2001) Fingerprint ridge-count difference between adjacent fingertips (dR45) predicts upper-body tissue distribution: evidence for early gestational programming. Am J Epidemiol 153(4):338–344
Kanchan T, Kumar GP, Menezes RG (2008) Index and ring finger ratio: a new sex determinant in the South-Indian population. Forensic SciInt 181(1):53–e1
Krishan K (2011) Marked limb bilateral asymmetry in an agricultural endogamous population of North India. Am J Hum Biol 23(5):674–685
Krzykala M, Leszczynski P (2015) Asymmetry in body composition in female hockey players. HOMO– J Comp Hum Biol 2015 66(4):379–386
Kyriakidis I, Papaioannidou P (2008) Epidemiologic study of the sexually dimorphic second to fourth digit ratio (2d:4d) and other finger ratios in Greek population. Coll Antropol 32(4):1093–1098
Maceo AV (2011) Anatomy and physiology of adult friction ridge skin. In: Holder EH, Robinson LO, Laub JH (eds) The fingerprint sourcebook. U.S. Department of Justice, Office of Justice Programs, National Institute of Justice, Washington DC, p 16 Available from http://www.nij.gov/pubs-sum/225320.htm
Makrantonaki E, Zouboulis CC (2007) 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). ExpGerontol 42:879–886
Manning JT (2002) Digit ratio: a pointer to fertility, behavior, and health. Rutgers Univ. Press, New Brunswick, NJ
Manning JT, Scutt D, Wilson J, Lewis-Jones DI (1998) The ratio of $2^{nd}$ to 4th digit length: a predictor of sperm numbers and concentrations of testosterone, luteinising hormone and oestrogen. Hum Reprod 13:3000–3004
Manning JT, Stewart A, Bundred PE, Trivers RL (2004) Sex and ethnic differences in 2nd to 4th digit ratio of children. Early Hum Dev 80:161–168
Mulvihill JJ, Smith DW (1969) The genesis of dermatoglyphics. J Pediatr 75:579–589
Plochocki JH (2004) Bilateral variation in limb articular surface dimensions. Am J Hum Biol 16(3):328–333
Sánchez-Andrés A, Barea JA, Rivaldería N, Alonso-Rodríguez C, Gutiérrez-Redomero E (2018) Impact of aging on fingerprint ridge density: anthropometry and forensic implications in sex inference. Sci Justice 58:323–334
Scheuer JL (2002) Application of osteology to forensic medicine. ClinAnat 15: 297–312
Soanboon P, Nanakorn S, Kutanan W (2016) Determination of sex difference from fingerprint ridge density in northeastern Thai teenagers. Egyptian J Forensic Sci 6:185–193
Taduran RJO, Tadeo AKV, Nadine EAC, Townsend GC (2016) Sex determination from fingerprint ridge density and white line counts in Filipinos. HOMO - J Comp Hum Biol 67:163–171
Ubelaker DH (1996) Skeleton testifies: anthropology in forensic science, AAPA Luncheon Address: April 12, 1996. Yearbook Phys Anthropol 39:229–244
Vanrell JP, Odontologia Legal e AntropologiaForense, second ed., Guanabakoogan, Rio de Janeiro, 2012.
Vieira Silva LR, Mizokami LL, Vieira PR, SoukaKuckelhaus SA (2016) Longitudinal and retrospective study has demonstrated morphometric variations in the fingerprints of elderly individuals. Forensic SciInt 259:41–46
Waaijer ME, Gunn DA, Catt SD, van Ginkel M, de Craen AJ, Hudson NM, van Heemst D, Slagboom PE, Westendorp RG, Maier AB (2012) Morphometric skin characteristics dependent on chronological and biological age: the Leiden Longevity Study. Age 34:1543–1552
Yager N, Amin A (2004) Fingerprint verification based on minutiae features: a review. Pattern Anal Appl 7:94–113
Zugibe FT, Costello JT (1986) A new method for softening mummified fingers. J. ForensicSci 31:726–731

## Publisher's Note