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Gender Identification from Thumbprint Ridge Thickness Among Hausa Population of Nigeria Using Likelihood Ratio and Posterior Probability Density

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ABSTRACT

The objectives of the present study were to identify gender from thumbprints ridge thickness using likelihood ratio and posterior probability density as well as to determine which of the three areas of thumb has more potential in sex determination. Ridge thickness for 97 male and 97 female subjects within the age range of 18-25 years were examined within the 25 mm^2 areas of the ulnar, radial and proximal parts of the thumb making up 1164 areas of the thumbprints. Female subjects exhibited finer ridge count compared to males in ulnar area of both sides of the thumbs. In the radial area, females were found to have finer ridge counts as in ulnar side, but with some coarse ridge. For the right proximal ridge thickness, a similar trend to that in the radial area was noticed, however, in the left thumbprint, males tend to have finer ridge counts compared to females. It was noticed that chance of sex inference from likelihood ratio decreased in the following order: proximal ridge thickness < radial ridge thickness < ulnar ridge thickness as ridge thickness decreases in favor of females but left proximal ridge thickness showed increased in likelihood ratio as ridge thickness decreased in favor of males. Ridge thickness in ulnar area showed more discrimination power compared to the other two areas studied. Considering equal probability for each sex, likelihood ratio reveals the applicability of ridge thickness in sex inference among Hausa population.

Keywords: Forensic sciences, likelihood ratio, Hausa population, ridge thickness, sex inference.

INTRODUCTION

The true breadth of a ridge is defined as the distance between the centre of one epidermal furrow and the centre of the next furrow along a line at right angles to the direction of the furrows (Penrose, 1968). For printed ridge (line) the term ridge width was suggested to be the more appropriate (Kralik and Novotny, 2003). However, the term epidermal ridge thickness was also used in the same context (Adamu *et al*., 2016). The pattern and arrangement of epidermal ridges showed remarkable number of features that reflect the biology of human population. These features differ statistically between the sexes, ethnic and age groups across human population (Cummins, 1941; Kralik and Novotny, 2003).

Dermatoglyphs parameters are both affected by genetic and prenatal environment; however, after formation, the arrangement of ridges remains constant throughout life (Holt, 1952; Kralik and Novotny, 2003; Reed *et al*., 2006). Theoretically, it is possible to use human epidermal ridges of fingerprints for determination of interconnected biological profile of the individual who left the prints (Kralik and Novotny, 2003). This may support the usefulness of the epidermal ridge thickness in the process of personal identification. In addition to the use of fingerprints within the forensic community for many decades, their persistence and biological uniqueness allow them to be used for identification of victims of mass disasters when traditional identification becomes difficult or other anthropometric methods are not feasible (Krishan *et al*., 2013; Rivalderia *et al*., 2016).

Previous studies have dealt with features such as minutiae (Stoney and Thornton, 1986; Gutierrez-Redomero *et al*., 2007; Reinart, 2014; Adamu *et al*., 2017), ridge density (Gutierrez-Redomero *et al*., 2013; Kapoor and Badiye, 2015; Adamu *et al*., 2016; Rivalderia *et al*., 2016), epidermal ridge width (Cseplák, 1982; Kamp *et al*., 1999; Králík *et al*., 2002) in connection with biological profile such as gender and age of an individual. The studies conducted by Adamu *et al.*(2016) which predicted sex among same population using ridge density and thickness probably is the only study reported among Hausa ethnic group of Kano state, Nigeria. The objectives of the present study were to identify sex from thumbprints ridge thickness using likelihood ratio and posterior probability density as well as to determine which of the three areas of thumb has more potential in sex determination.

MATERIALS AND METHODS

Study population

The target study population was Hausa ethnic group of Kano State. The state is one of the most populous states in Nigeria. The urban area comprises six major local government areas (LGAs) and covers about 137 km^2 area. The principal inhabitants of the state belong to Hausa ethnic group (Barau, 2007). Using simple random technique, the study population comprises of 97 males and 97 females within the age range of 18-25years. A total of 1164 areas (6 areas × 194 participants) thumbprints areas were analyzed for the entire population. Any participants with hand deformity, unclear impression, thumbprint, non-Hausa ethnic group of Kano State, Nigeria were excluded from the study. Informed consent was obtained from all participants before their enrolment in the study. Ethical approval was obtained from the ethical committee of Kano state Hospitals Management Board and Ahmadu Bello University, Teaching Hospital, Zaria, Faculty of Medicine (ABUTHZ/HREC/506/2015).

Estimation of epidermal ridge thickness

Live scanner (digital persona, China) was used to capture thumbprint of each participant. Software (Printanalyse) was designed using the Microsoft visual basic (version 6.0) programming language for capturing and determination of ridge density. Each captured plain thumbprints was saved with the name of digit (thumb), sex of the participants, side of the finger (left or right) and unique code of the participants. The thumbprints were classified into three basic patterns; loops, whorl and arches. Two versions, original and enlarge (at a ratio of 7.74), were captured. The original size was used for scaling purpose and enlarged version was used to determine the ridge density in ulnar, radial and proximal area of the thumbs. For the purpose of ensuring real size measurements, Cummins and Midlo (1943) ink method was adopted to capture the plain thumbprints of 30 randomly selected participants from the 194 study population.

Ridge density was examined within the 25 mm^2 of the three areas of the thumb as previously described (Acree, 1999; Gutie´rrez-Redomero *et al*., 2008; Adamu *et al*., 2016). The ridge thickness (in mm) was estimated indirectly from the obtained ridge density using methods reported in the previous literature (Cummins, 1941; Adamu *et al*., 2016).

Repeatability and strength of the measurements

To assess the random error and precision of measurements, two sets of measurements were taken and compared using technical error of measurement (TEM) (Aldridge *et al*., 2005).

$$\text{Absolute TEM} = \frac{\sqrt{\Sigma \mathrm{di}^2}}{2\mathrm{n}}$$

Where

Σd^2 = summation of deviations (the difference between the first and second measurements) raised to the second power,

n = number of volunteers measured,

i = the number of deviations

The absolute TEM was expressed as a percentage as follows:

$$\text{Relative TEM} = \frac{\text{Absolute TEM}}{\text{VAV}} \times 100$$

Where VAV = variable average value, which is the arithmetic mean of the two measurements obtained (first and second measurements) from each volunteer for the same variable. This procedure was performed for each of the *n* participants and the *n* averages obtained were summed up and divided by *n* (total of number of participants) (Perini *et al*., 2005). The percentage scores exceeding 10% were deemed poor (Weinberg *et al*., 2004). To determine the strength of measurements (r), intra class correlation (ICC) was determined between the variables. The values for the reliability coefficient ranged from 0 to 1 (Shrout and Fleiss, 1979). Thirty randomly selected participants were selected for the evaluation of measurement error. The interval between the first and second measurements was at least one week. All the measurements were within acceptable level of TEM and reliability coefficient.

Calculation of likelihood ratio and favor odd

The calculated LR gives the strength of support for one of the hypotheses: C or C'. Posterior probabilities P(C/RT) and P (C'/RT) were calculated using Bayes' theorem (Grieve and Dunlop, 1992). Favoured odds for support of the most likely hypothesis for a given ridge thickness P (RT/C) and P (RT/C') were obtained from information both LR computations and posterior probabilities. The likelihood ratio (LR) was calculated using relative frequency of ridge thickness (RT). The likelihood ratio (LR) was calculated as:

$$\text{LR} = \frac{\text{probability of observing a given ridge thickness if the donor was male (C)}}{\text{probability of observing a given ridge thickness if the donor was female (C')}} = \frac{\text{P (RT/C)}}{\text{P }(\frac{\text{RT}}{\text{C}'})}$$

Where $\text{RT} = \frac{\text{Frequency of a given ridge thickness}}{\text{Total frequency of all ridge thickness}}$,

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 ridge density with likelihood ratio of > 1 is more likely to be of male origin, for < 1is likely to female origin. The favor odd (FO) was calculated as:

$$\text{FO} = \frac{\text{P (RT/C)}}{\text{P (RT/C) + P (RT/C')}}$$

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

Statistical Analyses

The data were expressed using frequency distribution charts. Median was used to report central values of the ridge thickness after the data failed normality test (Shapiro-Wilk test, P <0.001). Mann Whitney test was used to test for sex differences in the ridge thickness. The analyses were carried out using SPSS version 20 (IBM Corporation, NY, USA). P < 0.05 was considered as level of significance.

RESULTS

Figure 1 shows the frequency distribution of the fingerprint pattern in males and females for both left and right thumbs. In both males and females the loops were the most frequent followed by the whorls and the least was the arches. Males tend to have more whorls in the right thumb, whereas females exhibited more whorls in the left thumb. For arches both sexes have frequency in left thumb, however, females had slightly higher frequency of arches than the males counterpart.

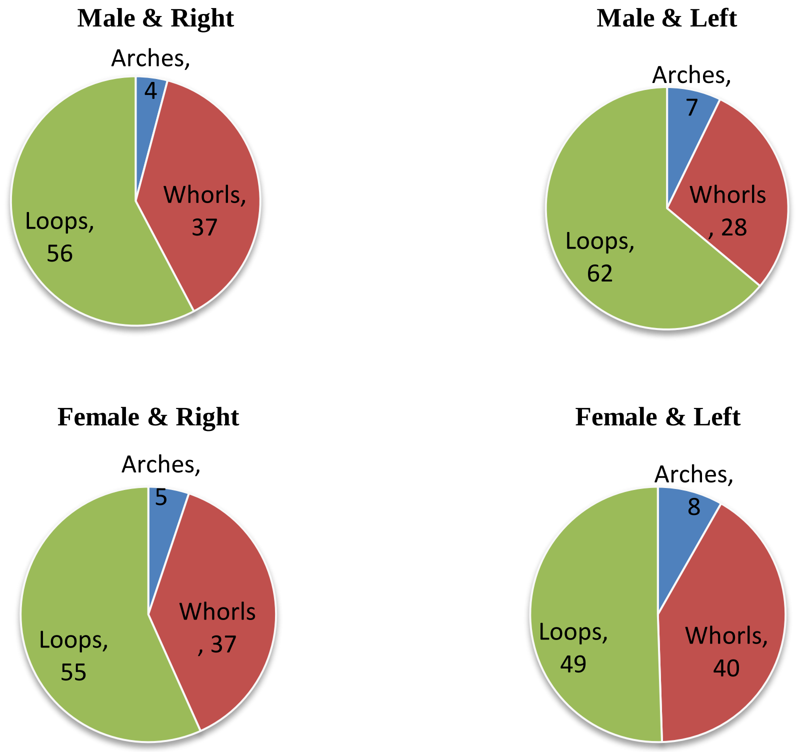

Figure 1: Frequency (%) of fingerprint patterns according to sex and side of the thumbs of selected subjects among Hausas in Kano State.

Figure 2 shows the differences in ridge thickness in selected subjects. The significant difference was observed only in the right ulnar ridge thickness, where males had thicker ridges. The females were observed to have thicker ridges in the left proximal ridge thickness.

Figure 3 shows the absolute frequency distribution of ridge thickness in males. The ridge thickness was observed to depend on the areas (ulna, radial and proximal) of the fingerprints. The minimum ridge thickness in males was 0.45 mm and the maximum was 1.06 mm. Wider range of ridge thickness was observed in ulna and radial areas. In the right side the proximal area had higher frequency of thicker ridges (0.91 mm) whereas in the left the ulna area recorded higher ridge thickness (1.06 mm). In females (Figure 4) the absolute frequency distribution of ridge density is shown to vary with count areas, with ridge thickness range between 0.45 mm to 1.27 mm. In all the areas and sides 0.71 mm ridge thickness is more frequent, although have similar frequency as 0.64mm in the left ulna area and 0.80 mm in the right proximal area of the thumbprints respectively, except for female right ulnar, 0.64mm had the highest frequency

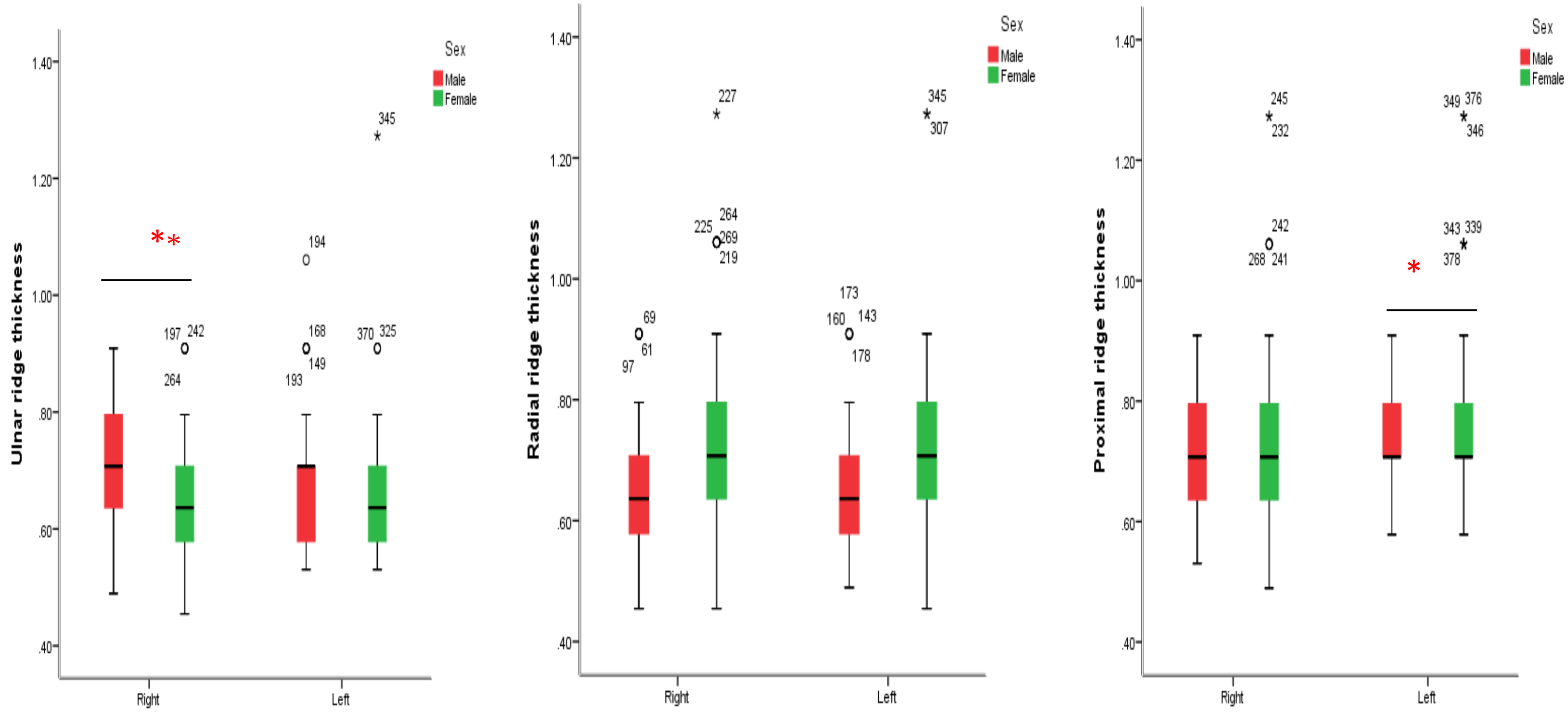

Figure 2: Box and Whiskers showing sex differences in ridge thickness of selected male and female subjects among Hausas in Kano State.
The data was represented using box and whiskers plot. Mid-point (black) of the box represents the median; the bottom of the box indicates 25th percentile (2nd quartile) and top of the box 75th percentile (3rd quartile). The lower and upper limit of the whiskers (T-bars at the bottom and top of the box) represents the minimum to maximum. The dot/asterisk (black) indicates outliers [values that do not fall in the whiskers (1.5 times the height of the box)] and the numbers indicate the serial number of the outliers in the data series ** P < 0.01, *P < 0.05

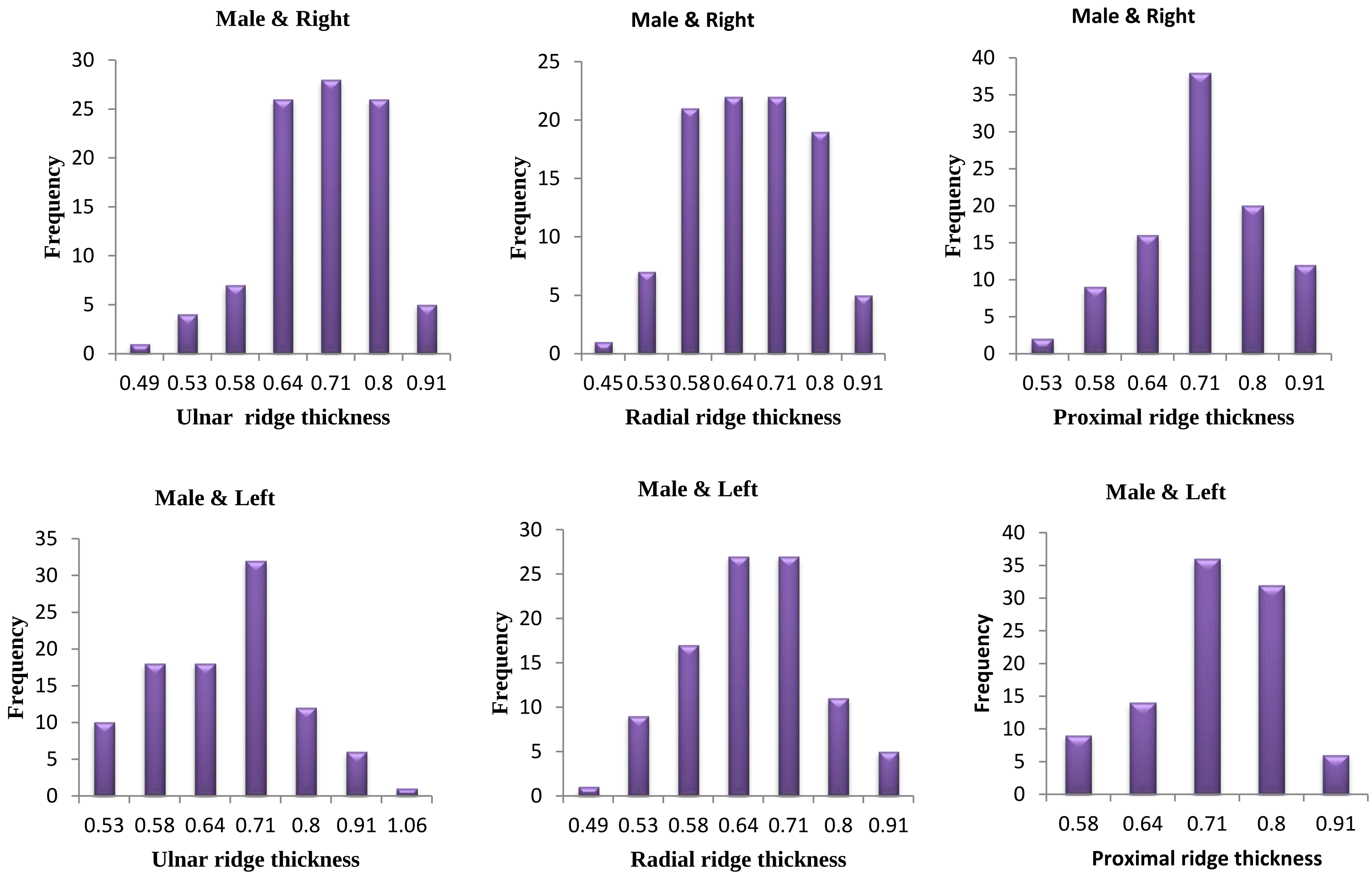

Figure 3: Absolute frequency distribution of thumbprint ridge thickness in selected Hausa males in Kano State

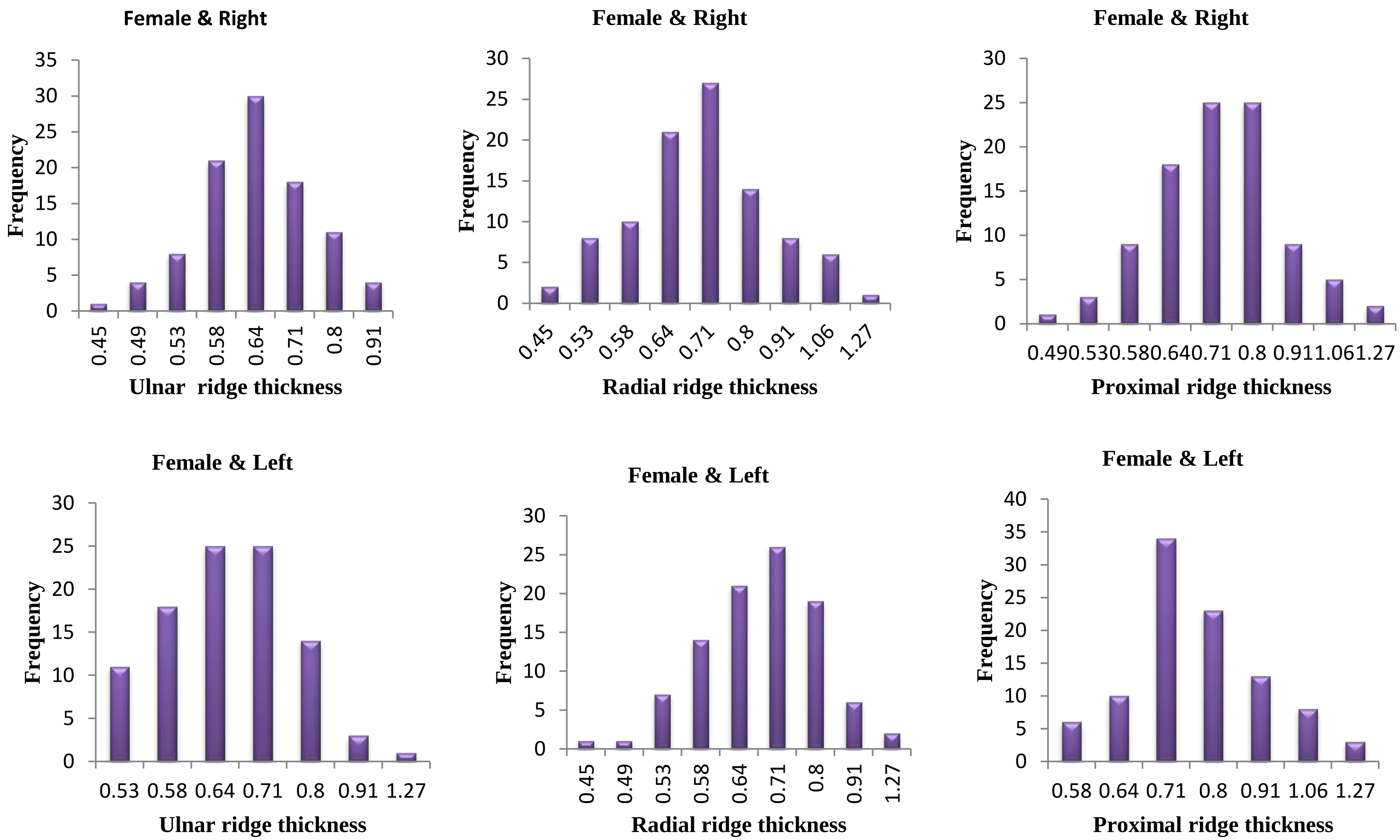

Figure 4: Absolute frequency distribution of thumbprint ridge thickness in selected Hausa females in Kano State

Table 1 shows observed ridge thickness, probability densities, likelihood ratios and favor odds in ulnar area of both left and right thumbs. It was observed that ridge thickness ≥ 0.71mm in ulnar area of the right thumb is likely to be of male origin (likelihood ratio > 1). In the ulnar area of the left thumbprint only ridge thickness of 0.71 mm and 0.91 mm are likely to be of male origin. In the radial area, the ridge thickness of 0.49-0.71 mm is most likely to be of male origin and a ridge thickness of ≥0.8 mm is most likely to be of female origin in the left thumbprints (Table 2). From the proximal area of left thumb ridge density of ≥ 0.91 is most likely to be of female origin and a ridge count of 0.8 mm or less is most likely to be of female origin (Table 3).

DISCUSSION

Several parameters are employed for identification purposes, however, fingerprints standout to be the most precise and reliable indicators of sex and personal identity (Arrieta *et al*., 1990; Esteban and Moral, 1993; Dittmar, 1998; Gutie´rrez-Redomero *et al*., 2008). Even identical twins who develop from one fertilized egg and share the same DNA profile were reported to have unmatched fingerprints (Cunliffe and Piazza, 1980; Mozayani and Noziglia, 2006).

The frequency of the patterns of the fingerprints among Hausa population of Kano state is in agreement with previous reports in other populations which documented lower and higher frequencies for arch and loop patterns respectively (Galton, 1892; Cummins and Midlo, 1943). The utility of the pattern type of fingerprint may be more to the anthropological perspective than the forensic. Although, comparison of the pattern type where applicable may seem to be an important step for inclusion or exclusion of a suspect in the process of establishment of identity.

The differences in likelihood ratio which was used to infer sex in the present study is in line with sex variation in the epidermal ridge breadth documented earlier (Cummins, 1941; Ohler and Cummins, 1942; Mundorff *et al*., 2014). The females were observed to have finer ridges except for the proximal ridge thickness which was suggested to exhibit contrasting results of sexual dimorphism with respect to ridge density (Gutie´rrez-Redomero *et al*., 2008; Gutierrez-Redomeroa *et al*., 2011; Adamu *et al*., 2016; Ahmed and Osman, 2016; Rivalderia *et al*., 2016). This may further indicate variation of different parts of thumb with proportions of different of the body. Hence, support the fact that different parts of the thumb seem to respond to different developmental instructions, which would be enough justification considering them as an isolated entity (Jantz and Owsley, 1977). Compared to other population (Cummins, 1941), the ridges observed in the current study were thicker. This is in keeping with the previous studies on the ridge density, where Africans, Hausa ethnic group (Adamu *et al*., 2016) and Sudanese (Ahmed and Osman, 2016) were observed to have lower ridge density compared to Argentinians, Spaniards and central Indians (Gutie´rrez-Redomero *et al*., 2008; Kapoor and Badiye, 2015; Rivalderia *et al*., 2016). This led to the suggestion that lower ridge density was more an indicator of African descent (Adamu *et al*., 2016). The lower ridge density in a given area explains the coarser ridges in this population. However, some of these inter-population variations documented were due to differences in methodological approach of ridge thickness estimation, rather than the expected biological and anthropometric distinction of each population, or developmental differences existing among individuals and populations. Therefore, to draw final conclusion seems to be challenging (Gutierrez-Redomeroa *et al*., 2011; Gutierrez-Redomero *et al*., 2013).

Table 1: Observed ridge thickness, probability densities, likelihood ratios and favor odds in ulnar area of both left and right thumbs of selected male and female subjects among Hausas in Kano State.

.		**Probability distributions**		**Likelihood ratio**	**Favor Odds**	
		Male	**Female**			
Side	**Ulnar**	**P(RD/C)**	**P(RD/C')**	**P(RD/C)/P(RD/C')**	**Male**	**Female**
Right	0.45	0.00	0.02	0.00	0.00	1.00
	0.49	0.02	0.08	0.25	0.20	0.80
	0.53	0.08	0.16	0.50	0.33	0.67
	0.58	0.14	0.43	0.33	0.25	0.75
	0.64	0.54	0.62	0.87	0.46	0.54
	0.71	0.58	0.37	**1.56**	0.61	0.39
	0.80	0.54	0.23	**2.36**	0.70	0.30
	0.91	0.10	0.08	**1.25**	0.56	0.44
Left	0.53	0.21	0.23	0.91	0.48	0.52
	0.58	0.37	0.37	**1.00**	0.50	0.50
	0.64	0.37	0.52	0.72	0.42	0.58
	0.71	0.66	0.52	**1.28**	0.56	0.44
	0.8	0.25	0.29	0.86	0.46	0.54
	0.91	0.12	0.06	**2.00**	0.67	0.33
	1.06	0.02	0.00	**-**	1.00	0.00
	1.27	0.00	0.02	0.00	0.00	1.00

Table 2: Observed ridge thickness, probability densities, likelihood ratios and favor odds in radial area of both left and right thumbs of selected male and female subjects among Hausas in Kano State.

		Probability distributions		**Likelihood ratio**	**Favor Odds**	
		Male	**Female**			
Side	**Radial**	**P(RD/C)**	**P(RD/C')**	**P(RD/C)/P(RD/C')**	**Male**	**Female**
Right	0.45	0.02	0.04	0.50	0.33	0.67
	0.53	0.14	0.16	0.88	0.47	0.53
	0.58	0.43	0.21	**2.10**	0.68	0.32
	0.64	0.45	0.43	**1.05**	0.51	0.49
	0.71	0.45	0.56	0.81	0.45	0.55
	0.8	0.39	0.29	**1.36**	0.58	0.42
	0.91	0.10	0.16	0.63	0.38	0.62
	1.06	0.00	0.12	0.00	0.00	1.00
	1.27	0.00	0.02	0.00	0.00	1.00
Left	0.45	0.00	0.02	0.00	0.00	1.00
	0.49	0.02	0.02	**1.00**	0.50	0.50
	0.53	0.19	0.14	**1.29**	0.56	0.44
	0.58	0.35	0.29	**1.21**	0.55	0.45
	0.64	0.56	0.43	**1.29**	0.56	0.44
	0.71	0.56	0.54	**1.04**	0.51	0.49
	0.8	0.23	0.39	0.58	0.37	0.63
	0.91	0.10	0.12	0.83	0.45	0.55
	1.27	0.00	0.04	0.00	0.00	1.00

Table 3: Observed ridge thickness, probability densities, likelihood ratios and favor odds in proximal area of both left and right thumbs of selected male and female subjects among Hausas in Kano State.

		Probability distributions		Likelihood ratio	Favor Odds	
Side	Proximal	Male P(RD/C)	Female P(RD/C')	P(RD/C)/P(RD/C')	Male	Female
Right	0.49	0.00	0.02	0.00	0.00	1.00
	0.53	0.04	0.06	0.67	0.40	0.60
	0.58	0.19	0.19	**1.00**	0.50	0.50
	0.64	0.33	0.37	0.89	0.47	0.53
	0.71	0.78	0.52	**1.52**	0.60	0.40
	0.8	0.41	0.52	0.80	0.44	0.56
	0.91	0.25	0.19	**1.33**	0.57	0.43
	1.06	0.00	0.10	0.00	0.00	1.00
	1.27	0.00	0.04	0.00	0.00	1.00
Left	0.58	0.19	0.12	**1.50**	0.60	0.40
	0.64	0.29	0.21	**1.40**	0.58	0.42
	0.71	0.74	0.70	**1.06**	0.51	0.49
	0.8	0.66	0.47	**1.39**	0.58	0.42
	0.91	0.12	0.27	0.46	0.32	0.68
	1.06	0.00	0.16	0.00	0.00	1.00
	1.27	0.00	0.06	0.00	0.00	1.00

Sex inference using likelihood ratio may indicate more significant differences between genders that may be used to infer sex better than that which can be obtained using other inferential statistic (Reinart, 2014). It was also suggested that the inferential statistics such as the independent sample analyses may be influenced by the degree of freedom which has little or no influence on the likelihood ratio. In likelihood ratio analyses each ridge thickness is treated as a separate entity, therefore the outliers were used separately in the sex inference. Furthermore, it was demonstrated that racial discrimination that depends on descriptive statistics within the domain of dermatoglyphic and larger community of forensic sciences need to be avoided. More to this, in DNA analyses likelihood ratios are calculated using probabilities based on race (Budowle *et al*., 1999; Reinart, 2014). However, the use of likelihood ratio depends on the set prior probability, which means that different ratio will be obtained with adjustment of the prior probability. Although given equal chance to the independent groups seems to eliminate bias in making judgments. With regards to both sexes with two independent groups (male and female), it was suggested that if males are more likely to commit a crime, prior probabilities should be set at a higher value in favor of males (Gutierrez-Redomero, 2013). The use of equal prior probability may still hold more weight as the shift may occur in committing crime with respect to independent group in question.

Significant variations in the epidermal ridge breadth in different dermatoglyphic regions were reported in the previous studies (Cummins, 1941; Ohler and Cummins, 1942). It is therefore important to note that the application of the present study may be more accurate with regards to thumbprints. However, it was suggested that the thumb is as good as the other four digits in most of the handy active due to its complementary role to other digits in object manipulation (Adamu *et al*., 2016). It is therefore more often encountered in the criminal scene than any other digit (Gutierrez-Redomero *et al.,* 2008).

The application of the current study in the field of forensic sciences and by law enforcement agents can be justified especially when dealing with partial fingerprints where all other details such as pattern type and minutiae cannot be appreciated. To emphasize on the application, it is already documented that the ridge density or partial fingerprint of a latent print found at the scene of a crime investigation should be a useful evidence to infer the sex of the perpetrator. This will go in line to help the forensic expert to narrow down the processes of investigation towards suspects belonging to the most likely sex, thereby, reducing the time and effort spent on each case (Gutierrez-Redomeroa *et al*., 2011). In the context of extrapolation of scientific research into real world scenario it should be remembered that this study used indirect methods of fingerprint ridge thickness determination. Using the method employed in this study atleast three ridges are needed to obtain the thickness of the prints, which is defined as the distance between the center of one epidermal furrow and the center of the next furrow along a line at right angles to the direction of the furrows (Penrose, 1968). Therefore, the partial fingerprint with not more than two ridges may seem to poise some level of inaccuracy in indirect methods of ridge thickness estimation.

CONCLUSION

Considering equal probability for each sex, likelihood ratio reveals the applicability of ridge thickness in sex inference among Hausa population. Ridge thickness in ulnar area showed more discrimination power compared to the other two areas. The use of likelihood ratio in sex identification from thumbprint ridge thickness proves a useful approach in gender identification among Hausa population of Nigeria

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