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Identification of sex using discriminant function analysis of fingerprint ridge density at three topological areas among North Indian population

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Abstract: The present study attempted to identify sex of an individual using a fingerprint ridge density at three topological areas in the North Indian population. The study population consisted of 134 males and 136 females aged 17 to 25 years (mean age 19.34±2.12). Ridge density (RD) at radial, ulnar and proximal topological areas of the distal phalanges were determined on the surface area of 25mm^2. Fingerprint ridge density in a defined area was significantly higher among females as compared to their male counterparts at radial, ulnar and proximal topological areas for both hands. Sexual dimorphic ratio also supported this trend for all three counting areas in right and left hands. Univariate discriminant function analysis explained that the left 2 radial (L2R) (88.1%) had the highest percentage of accuracy for sex identification, followed by the left 3 ulnar (L3U) (82.1%) and the right 2 ulnar (R2U) (81.6%). Multivariate discriminant function analysis showed that the radial topological area of the left hand was the best predictor of sex with the overall accuracy of 84.4%with following discriminant function equation −8.263 − 0.236(L1R) + + 0.321(L2R) + 0.269(L3R) + 0.268(L4R) − 0.067(L5R).
It can be inferred that ridge density in the radial topological area of left hand is the most reliable tool for identifying the sex of an individual.

Key words: Distal phalanges, predictors, ridge density, sex differences

Introduction

Dermatoglyphics is a branch of science which studies epidermal ridges and their organisation on certain parts of the skin (i.e. palms, soles, toes and fingers) (Susan et al. 2005; Karmakar et al. 2008). Previous studies (Kajabova et al. 2010; Wertheim 2011) have established that the morphology of fingerprints remains permanent from the prenatal period to throughout human ontogeny, except the epidermal ridge breath which flattens with aging (Lavker et al. 1989) due to decline in the rate of proliferation of keratinocytes (Gilchrest 1984). According to Gutierrez-Redomero et al. (2011) there is a considerable range of variability in fingerprint patterns, ridge count, dermal ridge density and epidermal ridge

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breadth. Consequently, this diversity makes dermatoglyphics more applicable for evolutionary studies, genetic, and anthropological studies.

A study by Acree (1999) identified for the first time the sex of individuals in Caucasian and African American populations from fingerprint ridge density, which was ascertained by diagonally counting numbers of ridges within a defined area in radial region of distal phalanges of fingertip. Thereafter, numerous cross-sectional studies were performed to explain the variability in fingerprint ridge density with respect to sex (Agnihotri et al. 2012; Ahmed and Osman 2016; Thakar et al. 2018; Kaur and Kaur 2019) and topological area (Gutierrez-Redomero et al. 2008; Nanakorn and Kutanan 2012; Soanboon et al. 2016; Wahdan and Khalifa 2017; Kaur and Kaur 2019) which is crucial from anthropological, and forensic fields of study.

A plethora of studies in different populations such as Egyptian (Eshak et al. 2013), Marathi (Kapoor and Badiye 2015), Thai (Soanboon et al. 2016), Sudanese (Ahmed and Osman 2016) and Gujarati (Sharma et al. 2018) have employed fingerprint ridge density for understanding sex prediction. Most of these studies considered fingerprint ridge density either at radial or ulnar regions of the distal phalanges of fingertips only. Due to the difficulty in obtaining complete fingerprint samples at a crime scene, fingertip analysis is pertinent from different topological regions in order to identify the sex of the individual. Earlier studies in this field established that females had higher ridge density and narrower ridges in a defined area as compared to their male counterparts. These considerations have prompted our study for investigating fingerprint ridge density in an Indian population, as there are few studies (Kapoor and Badiye 2015; Sharma et al. 2018, Thakar et al. 2018; Kaur and Kaur 2019) conducted on this population. Hence, the aim of the present study was to identify sex using fingerprint ridge density at radial, ulnar and proximal areas of distal phalanges of adult population of district Uttarkashi (North India). A key challenge for forensic researchers conducting a criminal investigation is to identify the sex of an unknown individual and fingerprints can be accessed at a crime scene. Therefore, ridge density analysis at three topological areas plays an important part in forensic investigations, even where partial prints are accessible at a crime scene.

Materials and methods

The present cross-sectional study was conducted on 134 males (mean age 19.11±2.48) and 136 females (mean age 19.56±1.66) in Uttarkashi, ranging from 17 to 25 years of age. Uttarkashi is a district in Uttarakhand state of northern India. All of the participants were randomly selected from the Tiloth and Mustiksaud villages, as well as from the State Polytechnic Institute of Uttarkashi district. Most of the participants were engaged in farming with their mothers after their college hours. Fieldwork was conducted from 24th October to 3rd November, 2017. The purpose of the study was explained to all the participants and their verbal consent was taken before conducting the study.

1. Inclusion criteria: Only healthy individuals having no skin diseases, injury on the digits or deformities were included in the study.
2. Exclusion criteria: Individuals who were below 17 years or above 25 years

were not considered in the study in order to avoid the confounding effect of changes in bodily proportions.

For data collection, rolled fingerprint impressions of all the ten digits were taken using simple inking method (Cummins and Midlo 1943) on the fingerprint card. The rolled fingerprints were taken in the order starting from thumb (digit 1), index finger (digit 2), middle finger (digit 3), ring finger (digit 4) and little finger (digit 5) in both the right and left hands. All of the five digits of right hand were designated from R1 to R5,while for the left hand from L1 to L5 respectively. For the right hand radial topological area digits were written as R1R, R2R, R3R, R4R, R5R and for the left hand radial area L1R, L2R, L3R, L4R, L5R. The right hand ulnar regions were written as R1U, R2U, R3U, R4U, R5U and for left hand ulnar area they were L1U, L2U, L3U, L4U, L5U. A similar pattern was followed for the proximal area for both the right and left hands.

The fingerprint ridge density was calculated at three topological areas(i.e. radial, ulnar and proximal regions) (Gutierrez-Redomero et al. 2008) on the surface area of 25 mm^2 (5 mm × 5 mm square), of the fingertip following the method specified by Acree (1999) (Figure 1).

Statistical analysis: Statistical Package for Social Sciences (SPSS) version 20 was

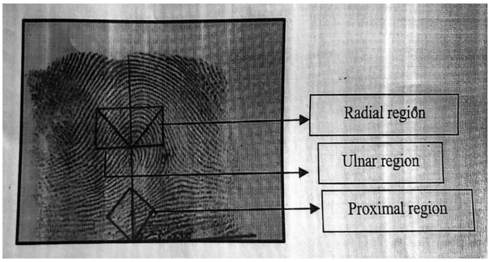

Fig. 1. Location of different counting areas of right thumb

used to determine the descriptive statistics such as mean and standard deviation values. Before initiating the analysis for the whole sample, ridge density of ten males and an equal number of females at three counting areas was assessed by the third author at 24 hr intervals to gauge intra –observer error. These fingerprints were also analysed by the first author to record inter-observer error. Results of paired t-test revealed non-significant values for both intra, as well as inter-observer error. Normality test (Shapiro-Wilk's test) revealed no normal distribution of all the variables under consideration. Hence, non-parametric statistic was performed. Mann Whitney U test was carried out to demonstrate statistically significant differences between the ridge density of male and female groups. Ridge density of distal (radial + ulnar) and proximal areas were compared by using Wilcoxon signed rank test. Significance of $p < 0.05$ and a confidence interval of 95% were taken for all tests. Sexual dimorphism ratio (SDR) was ascertained by dividing mean value of ridge density of male by mean value of ridge density of female multiplied with 100. Univariate and multivariate discriminant function analysis (DFA) was used to predict the sex estimation accuracy with reference to the individual, as well as combinations of fingerprint ridge density at different topological areas. Unstandardized discriminant coefficients were employed to construct the discriminant function equation.

Results

Descriptive statistics for fingerprint ridge density at three topological regions of each digit in males and females was summarized in Table 1. Fingerprint ridge

Table 1. Descriptive statistics for fingerprint ridge density in radial, ulnar and proximal area of each digit in males and females

Digits	Radial region				Ulnar region				Proximal region			
	Males Mean (SD)	Females Mean (SD)	z-value	SDR	Males Mean (SD)	Females Mean (SD)	z-value	SDR	Males Mean (SD)	Females Mean (SD)	z-value	SDR
R1	13.04 (1.44)	14.26 (1.41)	49.79**	91.44	13.42 (1.53)	15.01 (1.68)	18.99**	89.4	10.11 (1.66)	11.07 (1.95)	57.38**	91.32
R2	12.87 (1.23)	14.51 (1.61)	106.56**	88.69	12.96 (1.52)	14.95 (1.63)	18.25**	86.68	10.34 (1.80)	11.27 (1.76)	95.02**	91.74
R3	13.26 (1.55)	15.02 (1.68)	101.81**	88.28	13.66 (1.54)	15.55 (1.53)	20.95**	87.84	9.88 (1.61)	10.79 (1.63)	76.96**	91.56
R4	13.49 (1.53)	15.24 (1.74)	99.98**	88.51	13.68 (1.68)	15.70 (1.63)	25.45**	87.13	9.80 (1.72)	10.90 (1.87)	90.35**	89.9
R5	13.25 (1.36)	14.93 (1.78)	101.38**	88.74	13.28 (1.59)	15.24 (1.59)	12.25**	87.13	9.68 (1.44)	10.35 (1.70)	67.06**	93.52
L1	13.28 (1.57)	15.26 (1.69)	65.51**	87.02	12.95 (1.42)	14.38 (1.67)	98.53**	90	9.73 (1.79)	10.73 (1.65)	22.59**	90.68
L2	12.98 (1.43)	15.18 (1.66)	106.56**	85.5	12.93 (1.38)	14.71 (1.61)	136.01**	87.89	9.84 (1.70)	11.09 (1.97)	30.93**	88.72
L3	13.34 (1.52)	15.76 (1.69)	101.81**	84.64	13.32 (1.32)	15.04 (1.82)	154.85**	88.56	9.70 (1.71)	10.48 (1.73)	13.67**	92.55
L4	13.45 (1.50)	15.70 (1.69)	99.98**	85.6	13.44 (1.41)	15.42 (1.91)	134.60**	87.15	9.51 (1.59)	10.09 (1.74)	7.94**	94.25
L5	13.37 (1.69)	15.26 (1.83)	101.38**	87.61	13.23 (1.40)	14.79 (1.70)	77.25**	89.45	9.12 (1.53)	9.75 (1.53)	11.39**	93.53

Level of significance $p < 0.05$(*), $p < 0.01$(**); SDR= Sexual dimorphic ratio.

density of females in a defined area was significantly higher than their male counterparts in all the topological regions (i.e. radial, ulnar and proximal). Results of Mann Whitney U test revealed a statistically significant sex difference with respect to ridge density in all the fingers of right and left hands at radial, ulnar and proximal areas of the distal phalanges. In the radial region of both sexes, ridge density was higher in all the digits of the left hand except for digit 4 which was only found in males, where ridge density was slightly lower than digit 4 of the right hand. While in the ulnar and proximal areas ridge density was higher in the digits of the right hand than the left hand for both males and females (Figure 2). Sexual dimorphism ratio for all variables

Table 2. Differences between distal (radial+ulnar) and proximal ridge density in all the digits in males and females using Wilcoxon signed rank test

Digits	Males (z-value)	Females (z-value)
RD1 vs RP1	−9.912**	−9.597**
RD2 vs RP2	−9.760**	−8.516**
RD3 vs RP3	−10.121**	−9.637**
RD4 vs RP4	−9.941**	−9.628**
RD5 vs RP5	−10.026**	−9.633**
LD1 vs LP1	−10.088**	−9.797**
LD2 vs LP2	−9.840**	−9.754**
LD3 vs LP3	−10.108**	−9.685**
LD4 vs LP4	−10.052**	−9.920**
LD5 vs LP5	−10.125**	−10.003**

Level of significance $p < 0.05$(*), $p < 0.01$(**); RD= Right Distal (radial+ ulnar); LD= Left Distal (radial + ulnar); RP= Right Proximal; LP= Left Proximal.

was below 100, thereby, confirming that females had higher ridge density than males in all evaluating regions.

In the distal region (radial and ulnar) of the fingertip, maximum ridge density was witnessed in digit 4 of both right and left hands in both sexes except for left radial hand of females, where the highest ridge density was noted at digit 3. In the proximal area, the highest ridge density was recorded in digit 2 of both right and left hands in both sexes. Comparative analysis revealed that the distal region had a higher ridge density in a defined area than the proximal region. Wilcoxon signed rank test showed statistically

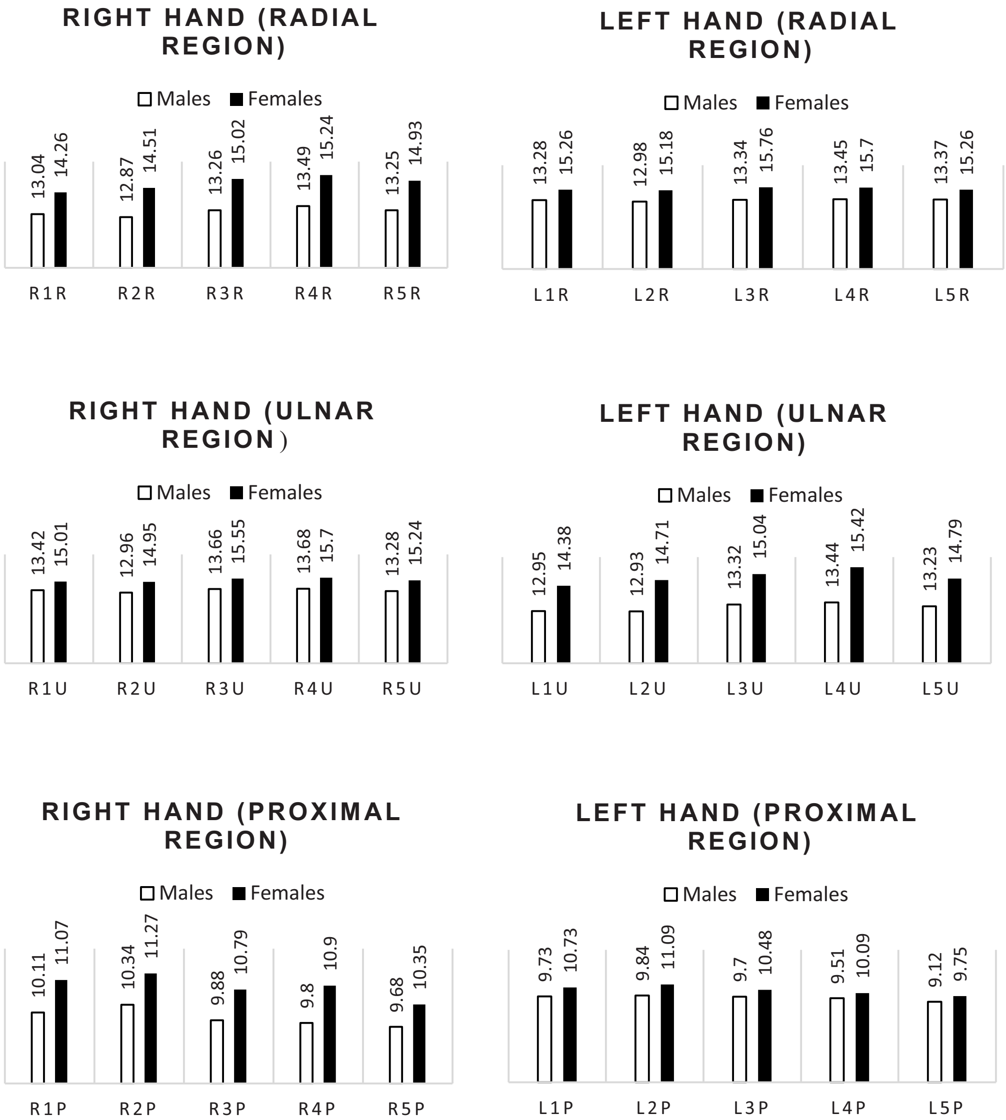

Fig. 2. Fingerprint ridge density in radial, ulnar and proximal area of each digit in both males and females

significant differences between distal and proximal ridge density in all the digits of males as well as females (Table 2).

Table 3 indicates univariate function analysis of fingerprint ridge density of ten digits at all three topological areas in males and females. By using all the variables it was evident from the Table 3 that the left 2 radial (L2R) (88.1%) exhibited the highest percentage of accuracy for sex identification followed by the left 3 ulnar (L3U) (82.1%) and the right 2 ulnar (R2U) (81.6%).

Multivariate discriminant function analysis of fingerprint ridge density at the three topological areas in the right and left hands of both sexes is presented in Table 4. It was apparent from the Table that radial side of the left hand was the best indicator of sex, which had correctly

Table 3. Univariate discriminant function analysis of fingerprint ridge density of ten digits at all the three topological areas in males and females

Topological area	Side	Wilk's lambda	F-value	CDFC	Group Centroid		Accuracy %	
					Female	Male	Female	Male
R1	R	0.843	49.79	0.700 Const −9.56	0.426	−0.433	69.1	62.7
	L	0.731	98.53	0.612 Const −8.74	0.600	−0.609	64.7	80.6
R2	R	0.752	88.54	0.695 Const −9.51	0.568	−0.577	72.8	75.4
	L	0.663	136.01	0.643 Const −9.07	0.705	−0.715	69.1	88.1
R3	R	0.771	79.58	0.617 Const −8.72	0.539	−0.547	64.7	76.1
	L	0.634	154.85	0.620 Const −9.02	0.752	−0.763	80.1	79.9
R4	R	0.776	77.34	0.609 Const −8.75	0.531	−0.539	71.3	73.1
	L	0.663	135.65	0.623 Const −9.08	0.707	−0.713	77	74.6
R5	R	0.783	74.36	0.627 Const −8.85	0.521	−0.529	61.8	79.1
	L	0.776	77.25	0.566 Const −8.10	0.531	−0.539	66.9	74.6
U1	R	0.804	65.51	0.620 Const −8.81	0.489	−0.496	61	74.6
	L	0.824	57.38	0.643 Const −8.79	0.458	−0.464	68.4	64.2
U2	R	0.716	106.56	0.633 Const −8.84	0.624	−0.633	81.6	65.7
	L	0.738	95.02	0.666 Const −9.21	0.589	−0.598	75.7	67.2
U3	R	0.725	101.81	0.648 Const −9.47	0.610	−0.619	77.2	70.9
	L	0.777	76.96	0.628 Const −8.92	0.530	−0.538	64.7	82.1
U4	R	0.728	99.98	0.603 Const −8.86	0.604	−0.613	77.2	70.1
	L	0.748	90.35	0.594 Const −8.58	0.574	−0.583	72.1	77.6
U5	R	0.726	101.38	0.628 Const −8.96	0.608	−0.617	71.3	79.1
	L	0.800	67.06	0.641 Const −8.98	0.495	−0.502	59.6	79.9
P1	R	0.934	18.99	0.552 Const −5.85	0.263	−0.267	55.1	59.7
	L	0.922	22.59	0.581 Const −5.94	0.287	−0.291	55.9	63.4
P2	R	0.936	18.25	0.560 Const −6.05	0.258	−0.262	64	59
	L	0.897	30.93	0.541 Const −5.66	0.336	−0.341	61.8	64.9
P3	R	0.927	20.95	0.615 Const −6.36	0.277	−0.281	58.1	62.7
	L	0.951	13.67	0.580 Const −5.85	0.223	−0.227	50	70.9
P4	R	0.913	25.45	0.555 Const −5.75	0.305	−0.309	56.6	73.9
	L	0.971	7.94	0.598 Const −5.87	0.170	−0.173	65.4	50
P5	R	0.956	12.25	0.632 Const −6.34	0.211	−0.215	45.6	76.1
	L	0.959	11.39	0.651 Const −6.15	0.204	−0.207	54.4	63.4

CDFC = Canonical discriminant function coefficient.

Table 4. Multivariate discriminant function analysis of fingerprint ridge density at all the three topological areas in males and females

Variable		Wilk's lambda	CDFC	SDFC	Group Centroid		FDFS		Accuracy %	
					Female	Male	Female	Male	Female	Male
Model 1 (right radial only)	R1R	0.904	−0.368	−0.570	0.804	−0.816	4.854	5.450	83.8%	79.1%
	R2R	0.768	0.318	0.469			3.559	3.045		
	R3R	0.785	0.162	0.267			0.360	0.099		
	R4R	0.787	0.119	0.199			2.253	2.060		
	R5R	0.791	0.152	0.245			2.496	2.250		
	Constant		−5.076				−99.641	−91.445		
Model 2 (left radial only)	L1R	0.995	−0.236	−0.359	0.931	−0.944	3.756	4.189	80.1%	88.8%
	L2R	0.666	0.321	0.495			2.938	2.336		
	L3R	0.640	0.269	0.432			2.262	1.759		
	L4R	0.668	0.268	0.429			2.318	1.815		
	L5R	0.760	−0.067	−0.118			0.557	0.682		
	Constant		−8.263				−87.655	−72.189		
Model 3 (right ulnar only)	R1U	0.965	0.456	0.759	0.220	−0.223	1.667	1.465	59.6%	58.2%
	R2U	0.995	−0.159	−0.257			2.482	2.552		
	R3U	0.975	0.291	0.492			1.018	0.889		
	R4U	0.994	−0.206	−0.363			1.414	1.506		
	R5U	0.979	0.190	0.312			2.569	2.484		
	Constant		−8.444				−70.331	−66.112		
Model 4 (left ulnar only)	L1U	0.974	0.593	0.892	0.209	−0.212	2.647	2.398	56.6%	58.2%
	L2U	1.000	−0.427	−0.625			1.488	1.668		
	L3U	0.984	0.392	0.572			2.647	2.482		
	L4U	0.994	0.112	0.178			1.704	1.656		
	L5U	0.999	−0.166	−0.253			2.106	2.176		
	Constant		−6.923				−72.010	−69.112		
Model 5 (right proximal only)	R1P	0.987	0.125	0.224	0.276	−0.280	1.960	1.891	63.2%	62.7%
	R2P	0.995	−0.113	−0.209			1.133	1.196		
	R3P	0.994	−0.232	−0.395			1.586	1.715		
	R4P	0.947	0.497	0.898			0.528	0.253		
	R5P	0.962	0.270	0.438			1.929	1.779		
	Constant		−5.535				−39.345	−36.288		
Model 6 (left proximal only)	L1P	0.983	0.139	0.244	0.232	−0.235	1.479	1.414	55.9%	62.7%
	L2P	0.973	0.266	0.481			0.732	0.608		
	L3P	0.998	−0.235	−0.388			1.352	1.462		
	L4P	0.991	−0.016	−0.027			1.062	1.069		
	L5P	0.961	0.475	0710			2.172	1.950		
	Constant		−6.107				−34.476	−31.639		

explained the sex of 84.4% of individuals, having sex bias of 8.7% in favour of males. The following discriminant function equation was obtained from canonical discriminant function constant;

$$-8.263 - 0.236(L1R) + 0.321(L2R) + \\ + 0.269(L3R) + 0.268(L4R) - \\ - 0.067(L5R)$$

The canonical centroids of −0.944 to 0.931 facilitates in determining sex of the individual (i.e. if the outcome was close to -0.944 then the sex of an individual will be male and if it is close to 0.931 then it will be a female).

Discussion

In this study, fingerprint ridge density of females in a given area was significantly higher than their male counterparts at all three counting regions of both hands as is evident from Mann Whitney U test. Our findings correlated with the results of various national and international studies on different populations (Gungadin 2007; Nayak et al. 2010; Nithin et al. 2011; Gutierrez-Redomero et al. 2013; Kumar et al. 2013; Rivalderia et al. 2015; Thakar et al. 2018; Kaur & Kaur 2019). A study of Ceyhan and Sagiroglu (2017) also determined sex using ridge density in the upper right corner of fingertips in the Turkish population. They noted an average value for ridge density as being 13.09 for men and 14.43 for women. Thakar et al. (2018) analyzed the ridge characteristics and ridge density of fingerprints in a Punjabi population in order to identify sex differences. Their results observed significantly lower mean ridge density (12.32 ridges/25 mm^2) in males as compared to females (13.94 ridges/25 mm^2). Similar results were obtained from a recent study by Kaur and Kaur (2019) on an adult North Indian population, where they witnessed significantly ($p<0.001$) higher fingerprint ridge density in females than males at radial, ulnar and proximal topological regions. Previous studies highlighted that higher ridge density of females may be due to their more narrow and finer ridges. Furthermore, Kralik and Novotny (2003) noticed that ridge breadth of males was 9% more broader than their female counterparts thus, supporting our hypothesis that males have fewer ridges as compared to females. In contrary to our findings, Adamu et al. (2018) revealed that males of the Hausa ethnic group of Nigeria had higher ridge density than their age matched female counterparts at the proximal area. Likewise, Kenyan and Tanzanian males also demonstrated a similar trend in their ridge density at the proximal area (Igbigbi and Msamati 2005). We speculate that the inverse trend reported in some populations may be due to different methodologies used to ascertain ridge density by various researchers, or the diverse biological backgrounds of participants.

Our study was compared with various other populations in order to observe the population specific variability in ridge density. It was noted that in all populations ridge density in defined areas was higher in females than in males. Ridge density at the radial region in both sexes in our study was also higher than in Caucasian (Acree1999), Egyptian (Wahdan and Khalifa 2017), Emirati (Singh et al. 2019), and Nahan populations (Kaur and Kaur 2019), but less than in the Thai (Promponmaung and Nanakorn 2012) and Sohag populations (Hilal and Mohamed2015) (Figure 3). Additionally, our study showed that fingerprint ridge density at the ulnar area was higher than in Egyptian (Wahdan and Khalifa 2017), Fillipino (Taduran et al. 2016), Sudanese (Ahmed and Osman 2016) and Nahan population (Kaur and Kaur 2019). Whereas our study indicated that at the proximal area ridge density was comparable with the Sudanese population (Ahmed and Osman 2016), it was less than Egyptian (Wahdan and Khalifa 2017), and Fillipino populations

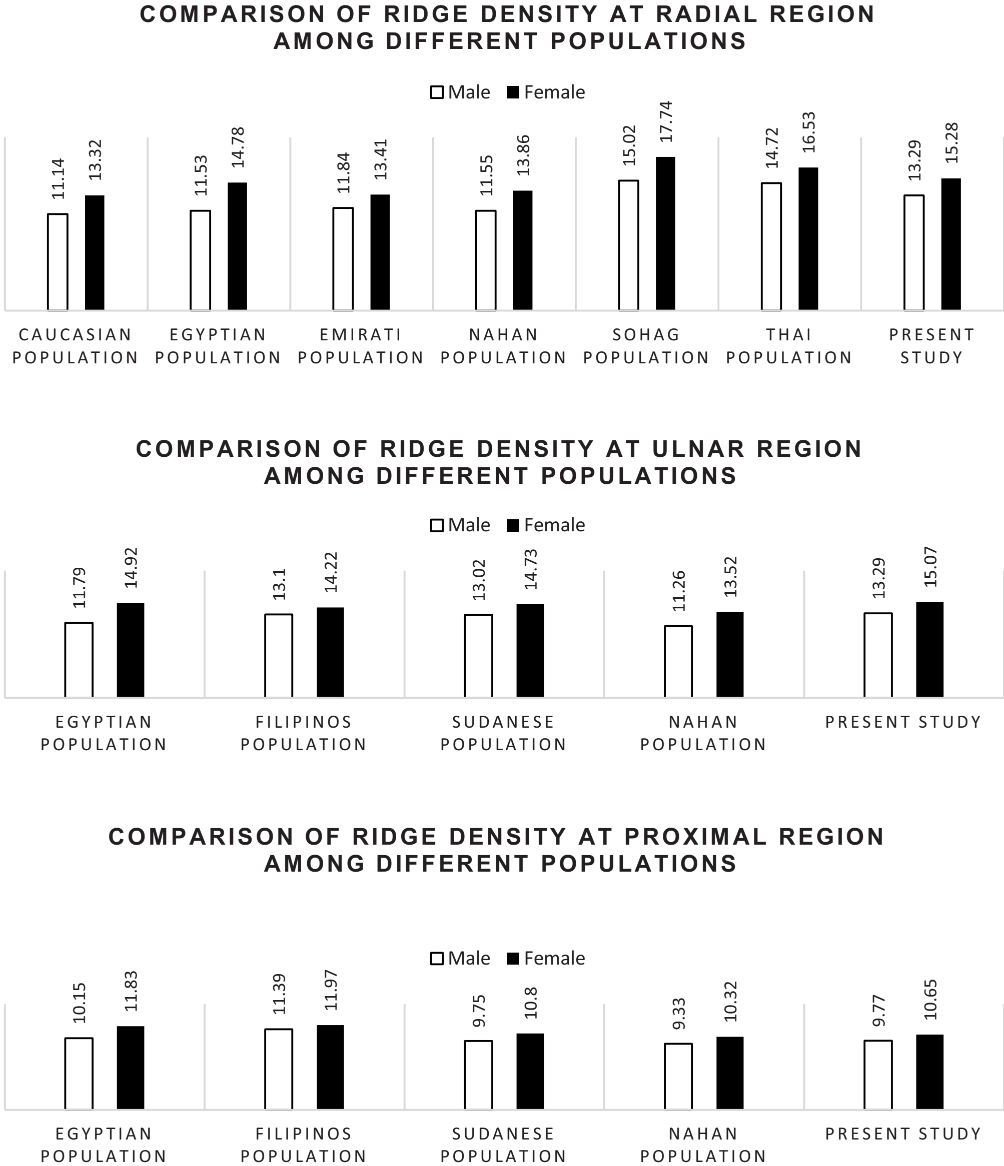

Fig. 3. Comparison of ridge density of present study at three topological areas with different populations

(Taduran et al. 2016) but higher than the Nahan population (Kaur and Kaur 2019).

Considering the bilateral differences it was also observed that in the right hand ridge density reached a peak in the ulnar area followed by radial and proximal areas, while for the left hand peak ridge density was noted in the radial area followed by the ulnar and proximal region of both male and female distal phalanges. Wilcoxon signed rank test revealed statistically significant differences between distal (radial + ulnar) and proximal ridge density in all the digits of males and females. Hence, it can be suggested that the distal area (radial and ulnar) demonstrated higher ridge density as compared to the proximal region. The findings of Kaur and Kaur (2019) noted following ascending trend of ridge density (i.e. proximal<ulnar <radial) in right and left hands of both sexes, thereby indicating greater ridge density in the distal part than the proximal region of the distal phalanges. Similar observations were noticed in Argentinian, Spanish (Gutierrez-Redomero et al. 2013), and Turkish populations (Oktem et al. 2015). This may be attributed to broader epidermal ridges and wider valleys in the proximal area as compared to the distal (radial and ulnar) topological area (Gutierrez-Redomero et al. 2013; Oktem et al. 2015). While performing factor analysis of finger ridge counts, Jantz and Owsley (1977) noted that both radial and ulnar sides of finger distal of the region may be influenced by different developmental instructions.

In our study, the left 2 radial (L2R) (88.1%) had the highest percentage of accuracy for sex identification followed by left 3 ulnar (L3U) (82.1%), and right 2 ulnar (R2U) (81.6%). Multivariate discriminant function analysis of fingerprint ridge density in all three topological areas of the right and left hands in both sexes revealed that the radial topological area of the left hand was the best indicator of sex. The canonical centroids of −0.944 to 0.931 facilitates in determining sex of the individual. For example, if the outcome approximates to −0.944, then the sex of an individual will be male, and if it approximates to 0.931 then it will be female. The discriminant function equation has been able to identify sex with the overall accuracy of 84.4%.

In accordance with the findings of present study Dhall and Kapoor (2016) also described fingerprint ridge density as a relevant forensic anthropological marker for sex determination applying discriminant function analysis with 96.8% accuracy. To the best of our knowledge no other study has identified topological areas with respect to the side of the human hand using discriminant function analysis. Consequently, further studies are needed to confirm these findings.

Conclusion

Females of the present study exhibited significantly higher fingerprint ridge density at all the three counting areas of all the digits of both hands than their male counterparts. Ridge density at distal (radial and ulnar) topological regions was more as compared to proximal areas. Ridge density at the left 2 radial (L2R) was determined as the best univariate variable for sex estimation with an accuracy of 88.1%. Multivariate discriminant function analysis documented that the left radial area identified the sex in approximately 84.4% of individuals (females 80.1%, males 88.8%), with sex bias of 8.7%. Therefore, we conclude that fingerprint ridge density is an important tool for sex identification in anthropological as well as forensic science studies.

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The Authors' contribution

The study was designed and conceived by MK1. Field work was carried out by JY. Analysis and interpretation were conducted by MK1 and MK2. The manuscript was written by MK1, MK2 and JY.

Conflict of interest

The authors declare that there is no conflict of interest.

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