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ORIGINAL ARTICLE

Sex differences in the thumbprint ridge density in a central Indian population

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KEYWORDS

Thumbprints;
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Abstract *Background:* Identification of sex plays a vital role in forensic and medico legal investigations. Fingerprints are considered to be the most precise and reliable indicators for personal and gender identification.
Objectives: The objective of this study was to determine any significant difference in the thumbprint ridge density of males and females in a central Indian (Marathi) population to enable the determination of gender.
Methods and materials: The study was conducted on 200 subjects (100 males and 100 females) in the age group of 18–30 years. Ridge densities on the right- and left-hand thumbprints were determined using a newly designed layout and analysed statistically.
Results: The results showed that females tend to have a higher thumbprint ridge density in both the areas examined, individually and combined. Applying the *t*-test, the differences in the ridge densities of males and females at LoC (Left of Centre), RoC (Right of Centre) and Combined (LoC + RoC) were found to be statistically significant at $p < 0.01$ levels, proving the association between gender and fingerprint ridge density. Probability densities for men and women derived from the frequency distribution (at LoC, RoC and Combined) were used to calculate the likelihood ratio and posterior probabilities of gender designation for the given ridge count for subjects using Baye's theorem.
Conclusion: It was concluded that differences in the thumb ridge density can be used as an important tool for the determination of gender in cases where partial thumbprints are encountered as evidence either at the crime scene or on any document(s) of forensic significance.

1. Introduction

Identification of sex plays a vital role in forensic and medico legal investigations. Identification means determination of the individuality of a person. It may be complete (absolute) or incomplete (partial). Complete identification means the absolute fixation of the identity of a person. Partial identification implies ascertainment of only some facts about the identity (like

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sex, age, stature, etc.) while others still remain unknown. The most successful approach for individualization utilises a combination of more than one method.[1] Amongst the number of parameters available for establishing the identity of an individual, fingerprints are considered to be the most precise and reliable indicators of personal and gender identification.[2–8] No two fingers are found to have identical prints, and it is an overwhelming mathematical probability that no two will ever be found to match.[9] It has been estimated that chances of two persons having identical finger impressions are about one in sixty-four thousand million of the world population.[10] Identical twins, originating from one fertilised egg, are arguably the most alike of any beings on earth. They share the same DNA profile because they began their existence as one entity, yet their fingerprints are as distinctive as any unrelated persons.[11]

While comparing the fingerprints of the suspects with the latent fingerprints found at the crime scene, the fingerprint examiners usually study the ridge counts and ridge characteristics. Consequently, these two characteristics of the fingerprints have been widely studied by the researchers and analysts.[2–6,12–18] The ever increasing frequency of crime has made fingerprinting an indispensable tool in the hands of investigating officers. If the sex of the individual could be established with certainty, the burden of the investigating officer would be reduced by half.[14,15]

Thumb impressions are of distinct importance. They are even used in lieu of signature in India in many important documents including (but not limited to) wills, sale deed, notarized documents, bank cheques, bank documents, property documents, competitive examinations, attendance forms, etc. Thumb impressions are often considered in civil and criminal cases as prominent evidence. Whenever a person touches, holds, and/or lifts any object such as a pen, paper, glass, firearm, a knife, a currency note, etc. there is a more than certain chance that the thumbprint would get transferred onto the object(s). To the best of our knowledge the use of thumbprint ridge density for sex determination amongst Indians has not been achieved till now, hence this study.

Fingerprint ridge density is defined as the fingerprint ridge count corresponding to a defined fingerprint area. Fingerprint ridge density has been shown to be sexually dimorphic in Spanish Caucasians,[2] Spanish populations[3–5] the Sardinian population,[6] Egyptian,[16] Chinese, Malaysian[15] and some Indian populations[14] including the south Indian population,[17] Indo-Mauritian population,[18] etc. Other fingertip features;[16] palm print ridge density[19] and footprint ridge density[20] were also studied in the past for sex differences. In the present study an attempt has been made to identify the sex of a person in a Central Indian (Marathi) population using thumbprint ridge density.

2. Materials and methods

2.1. Collection of samples

In this study, 200 Marathi subjects (100 males and 100 females) were chosen randomly from the Central Indian (Marathi) population, aged between 18 and 30 years, residing in Nagpur city, India. The purpose of the study was explained and verbal informed consent was taken from all the subjects' individually.[14] Subjects with any evidence of disease and injury of the fingertips that was likely to alter the fingerprint pattern (leprosy, scars of the fingertips, lacerations) were excluded.[17]

Table 1 Sex wise distribution.

Sex	Male	Female
Prints	100 * 2	100 * 2
Total number	200	200

The selected subjects were asked to wash and dry their hands. A clean fingerprint plate was smeared with Kores® thumb impression ink (black), with the help of a roller.[14] The subjects were then asked to ink their right and left thumbs, rolling nail to nail [17] on the inked surface, and imprint them on the finger-print slip in the designated area. Hence a total of 400 prints were analysed in the current study (Table 1). The prints were taken in triplicate to avoid any confusion at any later stage.

2.2. Analysis

A new and improvised method for thumbprint ridge density calculation was devised. On a transparency sheet a format was drawn as shown in Fig. 1. Two straight lines bisecting each other were drawn. This bisecting point was placed at the core or centre of the print. 5 mm above this, another transverse line was drawn. Two squares of 25 mm^2 each were drawn on both sides (left and right). These were our chosen areas for analysis. Ridge counting was performed in these designated areas and the values were tabulated. At the time of counting the number of ridges, this transparency was superimposed on the print (Fig. 2), so that the lower intersection lies on the core/centre of the print, in cases of Whorls and Loops. In Arches the intersection was kept on the lowest ridge which flows continuously from one side to the other side of the print. The epidermal ridges from one corner of the square to the diagonally opposite corner were counted. Dots were not counted. Forks were counted as two ridges excluding the handle and a lake was counted as two ridges.[14] The tabulated values for both sides represented the ridge density in a 25-mm^2 area.

Various statistical calculations were performed on the obtained data. Posterior probability inferences of gender, based on ridge density values were made by calculating the likelihood ratio (LR) based on the Baye's theorem. The favoured odds were also calculated as:

$$LR = \frac{\text{Probability of a given finger print originating from a male contributor(C)}}{\text{Probability of a given finger print originating from a female contributor (C')}}$$

3. Results and discussion

Descriptive statistics of ridge densities in males and females is shown in Table 2. In males, the ridge density ranged from 9 to 15 ridges per 25 mm^2 at both the Left of Centre (LoC) and the Right of Centre (RoC) with the mean ridge density of 11.58 and 11.82, respectively. In females, the ridge density ranged from 12 to 19 ridges per 25 mm^2 at the LoC with the mean ridge density of 14.6 and 12–18 ridges per 25 mm^2 at the RoC with the mean ridge density of 14.56. The range of LoC and RoC combined is observed to be 19–27 ridges with 23.40 as the mean and 24–36 ridges with the mean value of

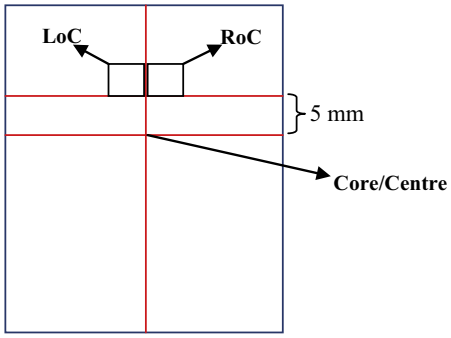

Figure 1 The format drawn on the transparency sheet used in the present study. (Not to scale.)

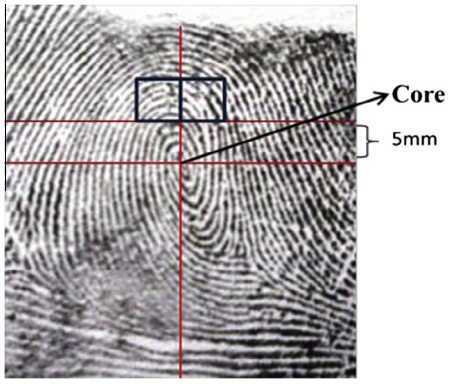

Figure 2 A fingerprint showing the areas (2 of 25 mm^2) used for counting thumbprint ridge densities at the left of centre (LoC) and right of centre (RoC).

29.16 in males and females respectively. Females were found to have a significantly higher ridge density than males at LoC, RoC and Combined.

Applying the *t*-test, the differences in the ridge densities of males and females at LoC, RoC and Combined were found to be statistically significant at $p < 0.01$ levels (Table 3).

Table 4 depicts the frequency distribution of ridge densities at the left and right of centre per 25 mm^2 in males and females. It is observed that none of the males have a mean ridge density of more than 15 and there are no females who have mean ridge densities below 12, which shows a little variation from the results of Nayak et al.[14]

Table 5 (Fig. 3) shows the frequency distribution of mean ridge densities of LoC and RoC combined. It is observed that none of the males have a mean ridge density of more than 27 and there are no females who have mean ridge densities below 23. Females have a significantly greater combined ridge density than males. A combined ridge density count was not achieved by others in the past. But our results suggest that combining the ridge densities at the LoC and RoC regions will improvise the result in terms of gender differentiation using thumbprints.

Probability densities for men (C) and women (C′) derived from the frequency distribution (at LoC and RoC respectively) were used to calculate the likelihood ratio [(C/C′) and (C′/C)] and posterior probabilities of gender designation for the given ridge count for subjects using Baye's theorem[21] (Tables 6–8).

At LoC, the statistical analysis of the likelihood ratio and the odds ratio shows that a ridge density of $\leqslant$12 ridges per 25 mm^2 is more likely to be of male origin ($p = 0.90$), whereas a ridge density of $\geqslant$13 ridges per 25 mm^2 is more likely to be of female origin ($p = 0.69$) (Table 6). Posterior probability using Baye's theorem shows that a fingerprint with a ridge density of $\leqslant$10 ridges per 25 mm^2 will have a higher probability of belonging to a male ($p = 0.99$). Similarly, a ridge density of $\geqslant$16 ridges per 25 mm^2 will be more indicative of females ($p = 0.99$).

At RoC, the statistical analysis of the likelihood ratio and the odds ratio shows that a ridge density of $\leqslant$12 ridges per 25 mm^2 is more likely to be of male origin ($p = 0.95$), whereas a ridge density of $\geqslant$13 ridges per 25 mm^2 is more likely to be of female origin ($p = 0.64$) (Table 7). Posterior probability

Table 2 Descriptive statistics of the thumb ridge density in both males and females.

	Males			Females		
	Left of Centre (LoC)	Right of Centre (RoC)	Combined LoC + RoC	Left of Centre (LoC)	Right of Centre (RoC)	Combined LoC + RoC
Mean ridge density	11.58	11.82	23.40	14.6	14.56	29.16
Minimum ridges	9	9	19	12	12	24
Maximum ridges	15	15	27	19	18	36
Standard deviation	1.4609	1.37	1.995	1.689	1.542	2.578
Standard error	0.10	0.0969	0.1411	0.1195	0.109	0.1823
Range	9–15	9–15	19–27	12–19	12–18	24–36

Table 3 Intercomparison of the *t*-value and the *p*-value amongst LoC, RoC and Combined thumb ridge density in males and females.

Females	LoC		RoC		Combined	
Males	*t*-value	Significance	*t*-value	Significance	*t*-value	Significance
LoC	19.1221	$p < 0.01$	19.839	$p < 0.01$	83.8956	$p < 0.01$
RoC	18.0747	$p < 0.01$	18.7846	$p < 0.01$	83.9898	$p < 0.01$
Combined	47.6052	$p < 0.01$	49.5793	$p < 0.01$	24.9874	$p < 0.01$

Table 4 Frequency distribution of mean ridge density in 25 mm^2 at LoC and RoC region in male and female thumbprints.

Ridge density (in a square of 25 mm^2)	Males				Females			
	Left of Centre (LoC)		Right of Centre (RoC)		Left of Centre (LoC)		Right of Centre (RoC)	
	No. of samples	%	No. of samples	%	No. of samples	%	No. of samples	%
9	12	6	8	4	–	–	–	–
10	36	18	32	16	–	–	–	–
11	48	24	32	16	–	–	–	–
12	64	32	72	36	20	10	16	8
13	20	10	32	16	36	18	40	20
14	8	4	20	10	48	24	52	26
15	12	6	4	2	40	20	28	14
16	–	–	–	–	28	14	40	20
17	–	–	–	–	16	8	20	10
18	–	–	–	–	8	4	4	2
19	–	–	–	–	4	2	–	–
Total	200	100	200	100	200	100	200	100

Table 5 Frequency distribution of the combined mean ridge density (LoC + RoC region) in male and female thumbprints.

Combined ridge density LoC + RoC	Males		Females	
	No. of samples	%	No. of samples	%
19	04	2	–	–
20	08	4	–	–
21	24	12	–	–
22	40	20	–	–
23	28	14	–	–
24	28	14	04	2
25	40	20	08	4
26	12	6	20	10
27	16	8	28	14
28	–	–	16	8
29	–	–	40	20
30	–	–	32	16
31	–	–	16	8
32	–	–	12	6
33	–	–	12	6
34	–	–	08	4
35	–	–	–	–
36	–	–	04	2
Total	200	100	200	100

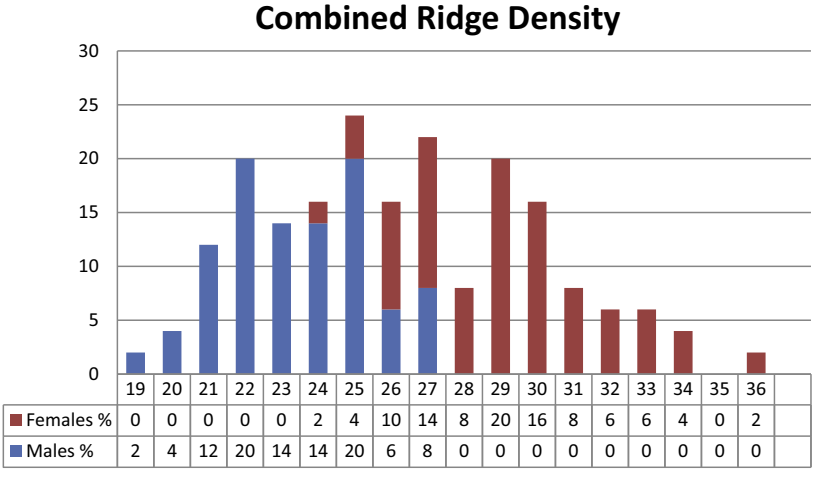

Figure 3 Percentage distribution of samples based on the combined ridge density.

Table 6 Probability densities and likelihood ratios derived from the observed ridge count at LoC.

Ridge density at LoC	Probability density		Likelihood ratio		Favoured odd
	Male (C)	Female (C′)	C/C′	C′/C	Male Female
9	0.06	0.001	60	0.017	0.99 > 0.01
10	0.18	0.001	180	0.006	0.99 > 0.01
11	0.24	0.001	240	0.004	0.99 > 0.01
12	0.32	0.1	3.2	0.313	0.90 > 0.10
13	0.1	0.18	0.556	1.8	0.31 < 0.69
14	0.04	0.24	0.167	6	0.03 < 0.97
15	0.06	0.2	0.3	3.333	0.09 < 0.91
16	0.001	0.14	0.007	140	0.01 < 0.99
17	0.001	0.08	0.0125	80	0.01 < 0.99
18	0.001	0.04	0.025	40	0.01 < 0.99
19	0.001	0.02	0.05	20	0.01 < 0.99

Table 7 Probability densities and likelihood ratios derived from the observed ridge count at RoC.

Ridge density at RoC	Probability density		Likelihood ratio		Favoured odd
	Male (C)	Female (C′)	C/C′	C′/C	Male Female
9	0.04	0.001	40	0.025	0.99 > 0.01
10	0.16	0.001	160	0.006	0.99 > 0.01
11	0.16	0.001	160	0.006	0.99 > 0.01
12	0.36	0.08	4.5	0.222	0.95 > 0.05
13	0.16	0.2	0.8	1.25	0.36 < 0.64
14	0.1	0.26	0.385	2.6	0.15 < 0.85
15	0.02	0.14	0.143	7	0.02 < 0.98
16	0.001	0.2	0.005	200	0.01 < 0.99
17	0.001	0.1	0.01	100	0.01 < 0.99
18	0.001	0.02	0.05	20	0.01 < 0.99

Table 8 Probability densities and likelihood ratios derived from the observed combined ridge count.

Combined ridge density [Left + Right]	Probability density		Likelihood ratio		Favoured odds
	Males (C)	Female (C′)	C/C′	C′/C	Male Female
19	0.02	0.001	20	0.050	0.99 > 0.01
20	0.04	0.001	40	0.025	0.99 > 0.01
21	0.12	0.001	120	0.008	0.99 > 0.01
22	0.2	0.001	200	0.005	0.99 > 0.01
23	0.14	0.001	140	0.007	0.99 > 0.01
24	0.14	0.02	7	0.143	0.98 > 0.02
25	0.2	0.04	5	0.200	0.96 > 0.04
26	0.06	0.1	0.6	1.667	0.36 < 0.64
27	0.08	0.14	0.5714	1.750	0.33 < 0.67
28	0.001	0.08	0.0125	80	0.01 < 0.99
29	0.001	0.2	0.005	200	0.01 < 0.99
30	0.001	0.16	0.0063	160	0.01 < 0.99
31	0.001	0.08	0.0125	80	0.01 < 0.99
32	0.001	0.06	0.0167	60	0.01 < 0.99
33	0.001	0.06	0.0167	60	0.01 < 0.99
34	0.001	0.04	0.025	40	0.01 < 0.99
36	0.001	0.02	0.05	20	0.01 < 0.99

using Baye's theorem shows that a fingerprint with a ridge density of $\leqslant$11 ridges per 25 mm^2 will have a higher probability of belonging to a male ($p = 0.99$). Similarly, a ridge density of $\geqslant$15 ridges per 25 mm^2 will be more indicative of females ($p = 0.98$).

For the Combined ridge density (LoC + RoC), the statistical analysis of the likelihood ratio and the odds ratio shows that a ridge density of $\leqslant$25 ridges per mm^2 is more likely to be of male origin ($p = 0.96$), whereas a ridge density of $\geqslant$26 ridges per mm^2 is more likely to be of female origin

($p = 0.64$) (Table 8). Posterior probability using Baye's theorem shows that a fingerprint with a ridge density of $\leqslant 23$ ridges per mm^2 will have a higher probability of belonging to a male ($p = 0.99$). Similarly, a ridge density of $\geqslant 28$ ridges per mm^2 will be more indicative of females ($p = 0.99$).

Statistically significant sex differences are observed in the thumbprint ridge density in the LoC and RoC areas analysed in this study. The females have a higher thumbprint ridge density than males in both these areas. Our findings are in agreement with the recent studies conducted on fingerprint ridge density. Thus, even when the areas analysed for thumbprint ridge density in our study differ from that of the earlier studies,[2–6,12–18,22–28] the basic quantitative differences remain the same, i.e., females have a higher finger (thumb) print ridge density than males which is in accordance with earlier studies on different ethnic groups.[2,5–8,13–18,22–28] Ridge thickness and furrows are the two important factors which determine the density of ridges. Cummins et al.,[24] Ohler et al.,[25] Kralik et al.[26] and Moore[28] worked on the ridge thickness in fingerprints and showed that males have coarser finger ridges than females which suggests that males will have less ridges in a given area than females and thus a lower ridge density. The higher fingerprint ridge density in females is attributed to the fact that females tend to have finer epidermal ridges than males.[28] Males generally have coarser ridges than females and the difference is approximately 10%.[26] In addition to frequently cited reason(s), we support the reasons proposed by Krishna et al.,[29] that the difference between the finger ridge density in males and females in a given area may be attributed to the fact that on an average body proportions of males are larger than females and thus the same numbers of ridges are accommodated amongst the males in a larger surface area and thus, a lower density is observed amongst males.

Findings of the present study did not show any marked differences between the ridge density for the left and right thumbs which is in contrast to the studies conducted by Ohler and Cummins[25] and Cummins et al.,[24] in which the ridges of the right hand were found to be coarser than the left hand. Thus, for the same area, the right hand would have a fewer ridges than the left hand.

4. Conclusion

This study shows that women of the Marathi population of Central India have a significantly higher thumb ridge density than men. The differences between male and female thumbprint ridge density (in the studied areas) are statistically significant. The results of this study are encouraging and would promptly act as a supportive tool for forensic experts and in law enforcement,[14,23] as they can be used as presumptive indicators of the gender of an unknown print left at a crime scene.[21] This can be achieved simply by qualitatively examining if prints appear to be coarse or fine and then rapidly quantifying ridge density in a manner analogous to methods described in this study. The findings can also be useful in identification of mutilated remains when a dismembered hand is brought for medico-legal examination. This study overcomes the serious limitation[14] where all ten fingerprints were required for the determination of the sex. Out of all the fingers, the thumb is considered as the most motile digit of the palm and is more likely to leave its impression than its other counterparts. Additional studies on individual fingers and thumbs in different population groups are anticipated in the near future.

Funding

None.

Conflict of interest

None.

Informed consent

Informed consent was obtained from the participants of the study.

Ethical approval

Necessary ethical approval was obtained from the institute ethics committee.

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