Original Research Paper

Sex Determination Using Fingerprint Ridge Density In South Indian Population

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Abstract

Determination of sex is vital in establishing the identity of human remains and has always been a challenge for forensic pathologists, particularly when a fingerprint recovered from crime scene does not match with any of those available in the records. The present study was conducted on 100 males and 100 females of South Indian Population, aged between 18 and 81 years, to study the possibility of differentiation of gender using fingerprint ridge density. For calculating the finger print ridge density, the upper portion of the radial border of each print was chosen and the epidermal ridges in a defined area counted. Results show that women have a significantly higher fingerprint ridge density than men. Application of Baye's theorem suggests that a fingerprint having ridge density of <14/25mm^2 is more likely to be that of a male, and one having ridge density of >14/25mm^2 is more likely to be that of a female. Discriminant analysis on the study data could derive formulae to predict the sex using fingerprint ridge density. The results show that fingerprint ridge density can be used as a tool for sex determination.

Key Words: Fingerprint, Ridge density, Baye's theorem, Discriminant analysis, Sex determination

Introduction:

Identification using finger prints is absolute and infallible. [1, 2] It is perhaps more significant that never yet in the world's crime records, have identical prints come to light unless from the same finger.

Even a portion of the palm which bulged between a glove worn by a safe breaker has left sufficient detail for the proof of identity. [3] Fingerprints have universal application towards identification, especially in the field of criminology. Since the turn of the century, finger prints have been used as a very effective means of establishing identity of the individual. [7]

Establishing the identity of human remains is a challenge for a Forensic pathologist; determining the sex is of paramount importance in that respect. Study of finger prints as a method of identification is known as **Dactylography or Dactyloscopy or Dermatoglyphics** and at present, also as Henry-Galton system of Identification. [4]

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It is the study of the impressions of patterns formed by the papillary ridges on the bulbs of fingers and thumbs, when taken upon unglazed paper with the help of printer's ink. [2, 5, 6] Many studies have been carried out on the method of storing fingerprints, for rapid search and matching of fingerprints in computers etc., but very few studies are available on determining gender of an individual from fingerprints.

It has been assumed that the fingerprints of women tend to have fine epidermal ridge detail, while men have coarse ridge detail i.e. women tend to have higher fingerprint ridge density (number of ridges in a defined area) when compared to males.

Very few studies which have examined this hypothesis have clearly demonstrated whether the observed differences in fingerprint ridge density between males and females is statistically significant.

This becomes important in practical use when a chance print lifted from a scene of crime does not match with any of the fingerprints available in the records. If the sex of the individual is established, burden on the investigating officer would be reduced to half.

In this context, the difference in the density of finger ridges between males and females becomes relevant. In this study, an attempt has been made to determine the gender of an individual in South Indian population, using fingerprint ridge density.

Materials and Methods:

Two hundred subjects (100 males and 100 females) brought for medico legal autopsy at the Department of Forensic Medicine, State Medico-legal Institute, Medical College, Thiruvananthapuram, Kerala from May 2011 to April 2012 were selected for the study.

Only fresh, identified dead bodies of above 18 years of age brought for autopsy were included in this study. Subjects with any evidence of injury, scars or any alterations of fingertips, or Subjects other than those from South India were excluded from this study.

Materials used: (1) Pre-inked strips, (2) Cadaver spoon, (3) Foldable magnifying lens, (4) Transparent film strip, (5) Pointer

Method:

Hands were washed and dried to remove sweat, dirt and grease. The rolled impressions of each finger were obtained using pre-inked strip and cadaver spoon. Thus rolled finger prints were obtained.

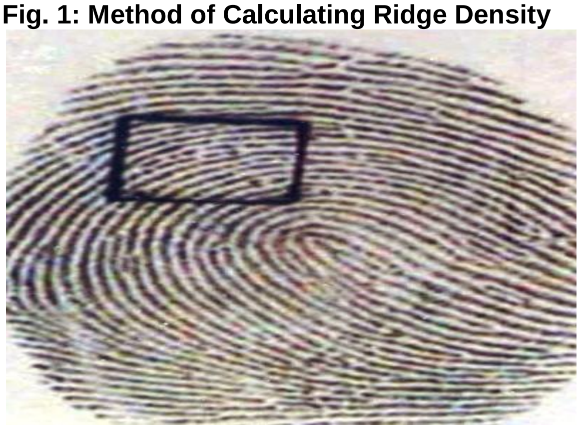
Similarly, prints of entire ten fingertips were prepared for each and every subject. For calculating the finger print ridge density, the upper portion of the radial border of each print (i.e. peripheral ridges) was chosen for data collection because all fingerprint pattern types show a similar ridge flow in this region. [11, 13]

Epidermal ridges in the central core region were not chosen for analysis due to variability of pattern shapes and the potential problem of recurving ridges being counted more than once within these regions. [8]

The epidermal ridges in the selected area were counted carefully within an area of 5mm × 5mm, drawn on a transparent film fixed to the magnifying lens, using a pointer.

Counting was done from one corner of the square to the diagonally opposite corner in a zigzag manner. Dots were not counted. Forks were counted as two ridges excluding the handle and a lake was counted as two ridges (Fig. 1). [11]

Fig. 1: Method of Calculating Ridge Density



Ridge counts were thus taken individually for ten fingers. Ridge thickness and furrows are two important factors which determine density of ridges. Since ridge counting is done within a well-defined area, both these parameters are taken into consideration.

Data analysis was done using SPSS version 17.0. The alpha level of significance was set at 0.05 for all statistical calculations. The likelihood ratio was calculated to obtain the probability inferences of gender, based on ridge density values. Likelihood ratio (LR) is based on the Baye's theorem,

$$LR = \frac{\text{Probability of a given fingerprint originating from a male (C)}}{\text{Probability of a given fingerprint originating from a female } (C^1)}$$

Discriminant analysis was used to derive a formula for predicting the gender using ridge density values. A discriminant function was developed for this purpose. The general structure is

$$Z_{jk} = a + w_1X_{1K} + w_2X_{2K} + \ldots\ldots\ldots + w_nX_{nK}$$

Where Z_{jk} = discriminant Z score of discriminant j for object k.

a = intercept

w_i = discriminant weight for independent variable i.

X_{iK} = independent variable i for object k.

Results:

Male subjects showed fingerprint ridge density values from 10 to 16. Female subjects showed fingerprint ridge density values from 11 to 19. (Table 1) The manner in which each of the ridge density value was distributed among males and females was analyzed. Fingerprint ridge density of 10 belonged to males only. Ridge density of 11 belonged to males in 98.7% cases and to females in 1.3% cases.

As the ridge density further increased, the proportion of males gradually decreased and simultaneously the proportion of females increased. Thus, ridge density of 16 belonged to females in 89.7% cases and to males in 10.3% cases. Ridge density of 17, 18 and 19 belonged to fingerprints of females only. (Table 2)

The mean fingerprint ridge density for males and females was derived. The mean fingerprint ridge density for males is 12.79 and that for females is 14.81. Independent sample T-test shows that fingerprint ridge density shows a statistically significant difference between males and females (p value<0.001). The mean ridge density of each of the ten fingers was also calculated for both males and females. It was found that the fingerprint ridge density differs significantly between males and females in each of the ten fingers of the study subjects.

In males, the highest mean ridge density was noted in the right ring finger (13.25) and the lowest one was noted in the left thumb (12.41). In females, the maximum ridge density was noted in the left ring finger (15.51) and the minimum value was noted in the right index finger (14.08). (Table 3)

Probability densities derived from the frequency distribution were used to calculate the likelihood ratio (LR) and posterior probabilities of both sex for given ridge density of the subjects, using Baye's theorem. Favored odds of more than 0.7 are considered to be 'most favourable'. For the ridge density values <14, odds ratio is in favour of males.

For values >14, odds ratio is in favour of females. Thus, a fingerprint ridge density of $<14/25mm^2$ is more likely of a male (P=0.81) and a ridge density of $>14/25mm^2$ is more likely of a female (P=0.9). Ridge density of $10/25mm^2$ is highly indicative of a male (P=1) and there were no females observed in that category. Ridge density of 17, 18 and $19/25\ mm^2$ is highly suggestive of a female (P=1) with no males observed in those categories. (Table 4)

Statistical analysis of probability densities and likelihood ratios was done separately for right and left hand. In the right hand, for the ridge density values <14, odds ratio is in favour of males. For values >14, odds ratio is in favour of females.

Thus, a fingerprint ridge density of $< 14/25mm^2$ is more likely of male origin (P=0.81) and a ridge density of $>14/25mm^2$ is more likely of female origin (P=0.89). In the left hand also, a fingerprint ridge density of $<14/25mm^2$ is more likely of male origin (P=0.81) and a ridge density of more than $14/25mm^2$ is more likely of female origin (P=0.91). (Table 5, 6)

Discriminant analysis was done using the fingerprint ridge density values of all the fingers of 100 male and 100 female subjects (i.e. 1000 male prints and 1000 female prints), and an equation was derived for prediction of sex. Box's Test of Equality of Covariance Matrices was done to test the null hypothesis of equal population covariance matrices. p value was 0.071, which indicates that the data do not differ significantly from multivariate normal. This means that discriminant analysis can proceed with the normal data. A formula can be derived of the form,

y = a + bx, where 'y' is the discriminant score, 'a' is the constant, 'b' is the discriminant function coefficient and 'x' is the ridge density. Thus,

Formula for predicting the sex from a single fingerprint was given as,

Score = (−9.866) + 0.715 × (ridge density)

If the score is < −0.722, fingerprint is that of a male. If the score is >0.722, it is that of a female. If the score is between −0.722 and 0.722, prediction is inconclusive. This formula could correctly predict the sex in 76.1% of the subjects (confirmed by cross validation method).

Discriminant analysis was also done using mean fingerprint ridge density i.e. mean value of the ridge densities of 10 ten fingers was calculated for the 100 male and 100 female subjects. Using that data, the following formula was derived for prediction of sex.

Score= (−13.815)+1.001×(mean ridge density)

If the score is < −1.012, fingerprint is that of a male. If the score is >1.012, it is that of a female. If the score is between −1.012 and 1.012, prediction is inconclusive.

This formula could correctly predict the sex in 84.5% of the subjects. Discriminant analysis was also done using the ridge density of each finger individually. Formulae were derived for the prediction of sex using the ridge density of a specific finger.

The results are summarized and there are ten formulae which can be used for prediction of sex using fingerprint ridge density of each of the ten fingers respectively. (Table 7)The ability to predict the sex correctly is highest for the left ring finger (82%) and lowest for the right thumb (74.5%).

Discussion:

This study confirms the hypothesis that women have higher fingerprint ridge density than men. [8] Thus, the mean fingerprint ridge density is higher in females than males, and the difference between males and females is statistically significant. This is in accordance with the previous studies conducted by other authors. [8-11, 13] But it is exactly opposite to the figures obtained by Reddy CC [14], who got higher mean fingerprint ridge density in males than females in his study. [Table 8]

The mean fingerprint ridge densities of males and females in this study are almost corresponding to those obtained by Gungadin and Nithin, [10, 13] who had conducted the study on South Indian population itself. Acree [8] got lesser values for mean fingerprint ridge density in Caucasian and Afro-American population, whereas Cummins got higher values in American population. This could probably be due to racial differences. In this study, analysis of probability densities and likelihood ratios in this study sample gives:

- Fingerprint ridge density of <14/25mm^2 is more likely to be that of a male.
- Fingerprint ridge density of >14/25mm^2 is more likely to be that of a female.

Hence the ridge density of 14 delineates males from females in the study population. The above conclusion is similar with that of Gungadin S [10] and Nithin MD [13], who had done the study in South Indian population.

According to Gungadin, [10] a ridge density of ≤13 ridges/25mm^2 is more likely to be of male origin and ≥14 ridges/25mm^2 is likely to be of female origin. As per the study conducted by Nithin, [13] a fingerprint possessing ridge density <13 ridges/25 mm^2 is most likely to be of male origin and one having ridge density >14 ridges/25 mm^2 is most likely to be of female origin. On the other hand, according to Nayak VC [12], who has done his study in Chinese and Malaysian population, 12 was the ridge density value that delineates males from females.

Acree [8] got an even lesser value, who concluded that a fingerprint possessing a ridge density of ≤ 11/25 mm^2 is most likely to be of male origin, and one having a ridge density of ≥12 ridges/25 mm^2 is most likely to be of female origin, regardless of race. The following conclusions could also be derived from the present study.

- Fingerprint ridge density of 10/25mm^2 has 100% sensitivity and positive predictive value for a male, as it was observed only in males.
- Fingerprint ridge densities of 17-19/25 mm^2 have 100% sensitivity and positive predictive value for a female, as they are observed only in females.
- Fingerprint ridge density of 14/25mm^2 is inconclusive in differentiating between males and females.
- Fingerprint ridge density does not vary significantly between the right and left hand.

Discriminant analysis of the study data could derive formulae for predicting the sex from, (1) a single fingerprint, (2) mean fingerprint ridge density of ten fingers and (3) each print of a known finger.

Conclusion:

This study concludes that fingerprint ridge density differs significantly between males and females and can be used as a tool to predict the sex. This can be of practical use for Forensic pathologists and scientists, in situations like retrieval of a severed arm/hand/finger, or of a chance print from a crime scene.

When such a print does not match with any one of those available in records, a clue regarding the sex of the individual might be of great use in establishing identity.

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Table 1: Ridge Density in Males and Females

Ridge density	Total No.	Males	Females
10	34	34	0
11	152	150	2
12	283	239	44
13	418	281	137
14	425	184	241
15	361	90	271
16	214	22	192
17	69	0	69
18	41	0	41
19	3	0	3
Total	2000	1000	1000

Table 2: Distribution of Ridge Density Values between Males and Females

Ridge density	Total No.	Males		Females	
		No.	% within group	No.	% within group
10	34	34	100	0	0
11	152	150	98.7	2	1.3
12	283	239	84.5	44	15.5
13	418	281	67.2	137	32.8
14	425	184	43.3	241	56.7
15	361	90	24.9	271	75.1
16	214	22	10.3	192	89.7
17	69	0	0	69	100
18	41	0	0	41	100
19	3	0	0	3	100

Table 8: Comparison of Ridge Density of Males and Females from Various Studies

Author	Mean fingerprint ridge density		Study population
	Males	Females	
Cummins	20.70	23.40	American
Reddy	13.41	12.04	South Indian
Acree	11.14	13.32	Caucasian
	10.90	12.61	African American
Gungadin	12.80	14.60	South Indian
Nayak	11.05	14.20	South Indian
Nithin	12.57	14.15	South Indian
Present study	***12.79***	***14.81***	***South Indian***

Table 3
Group Statistics

	Males		Females		T	p value
	Mean	Standard deviation	Mean	Standard deviation		
Right thumb	12.64	1.404	14.28	1.272	-8.658	<0.001
Right index finger	12.43	1.200	14.08	1.186	-9.779	<0.001
Right middle finger	13.01	1.251	14.96	1.392	-10.418	<0.001
Right ring finger	13.25	1.336	15.25	1.540	-9.810	<0.001
Right little finger	12.93	1.416	14.94	1.317	-10.395	<0.001
Left thumb	12.41	1.464	14.39	1.449	-9.613	<0.001
Left index finger	12.43	1.281	14.43	1.380	-10.621	<0.001
Left middle finger	12.90	1.291	14.99	1.314	-11.345	<0.001
Left ring finger	13.10	1.299	15.51	1.474	-12.269	<0.001
Left little finger	12.79	1.373	15.27	1.332	-12.964	<0.001
Mean ridge density	**12.79**	0.979	**14.81**	1.019	-14.306	**<0.001**

Table 4
Probability Densities & Likelihood Ratios derived from Observed Ridge Densities

Ridge density	Probability density		Likelihood ratio		Favored Odds	
	Males (C)	Females (C^1)	Males (C/C^1)	Females (C^1/C)	Males	Females
10	0.034	0	-	0	**1**	0
11	0.15	0.002	75.00	0.01	**0.99**	0.01
12	0.239	0.044	5.43	0.18	**0.97**	0.03
13	0.281	0.137	2.05	0.49	**0.81**	0.19
14	0.184	0.241	0.76	1.31	0.37	0.63
15	0.09	0.271	0.33	3.01	0.10	**0.90**
16	0.022	0.192	0.11	8.73	0.01	**0.99**
17	0	0.069	0	-	0	**1**
18	0	0.041	0	-	0	**1**
19	0	0.003	0	-	0	**1**

Table 5
Probability Densities & Likelihood Ratios for Right Hand

Ridge density	Probability density		Likelihood ratio		Favoured odds	
	Males (C)	Females (C^1)	LR (C/C^1)	LR (C^1/C)	Males	Females
10	0.028	0	-	0	**1**	0
11	0.138	0	-	0	**1**	0
12	0.238	0.052	4.58	0.22	**0.95**	0.05
13	0.294	0.144	2.04	0.49	**0.81**	0.19
14	0.18	0.26	0.69	1.44	0.32	0.68
15	0.096	0.28	0.34	2.92	0.11	**0.89**
16	0.026	0.164	0.16	6.31	0.02	**0.98**
17	0	0.06	0	-	0	**1**
18	0	0.038	0	-	0	**1**
19	0	0.002	0	-	0	**1**

Table 6
Probability Densities & Likelihood Ratios for Left Hand

Ridge density	Probability density		Likelihood ratio		Favoured odds	
	Males (C)	Females(C^1)	LR (C/C^1)	LR (C^1/C)	Males	Females
10	0.04	0	-	0	**1**	0
11	0.162	0.004	40.50	0.02	**0.99**	0.01
12	0.24	0.036	6.67	0.15	**0.98**	0.02
13	0.268	0.13	2.06	0.49	**0.81**	0.19
14	0.188	0.222	0.85	1.18	0.42	0.58
15	0.084	0.262	0.32	3.12	0.09	**0.91**
16	0.018	0.22	0.08	12.22	0.01	**0.99**
17	0	0.078	0	-	0	**1**
18	0	0.044	0	-	0	**1**
19	0	0.004	0	-	0	**1**

(Note: In table 5, 6 and 7, cells are left blank where the likelihood ratio is too large to be determined, as the denominator is zero.)

Table 7
Discriminant Statistics of Ridge Density of Each Finger

Finger	Formula for calculating the discriminant score	Discriminant score		% correctly predicted
		Male	Female	
Right Thumb	−10.049 + (0.747) × RD	< −0.612	> 0.612	**74.5**
Right Index	−11.109 + (0.838) × RD	< −0.691	> 0.691	75.0
Right Middle	−10.567 + (0.756) × RD	< −0.737	> 0.737	76.0
Right Ring	−9.885 + (0.694) × RD	< −0.694	> 0.694	76.0
Right Little	−10.192 + (0.731) × RD	< −0.734	> 0.734	75.5
Left Thumb	−9.201 + (0.687) × RD	< −0.680	> 0.680	76.0
Left Index	−10.087 + (0.751) × RD	< −0.751	> 0.751	75.5
Left Middle	−10.705 + (0.768) × RD	< −0.802	> 0.802	77.7
Left Ring	−10.299 + (0.720) × RD	< −0.868	> 0.868	**82.0**
Left Little	−10.372 + (0.739) × RD	< −0.917	> 0.917	80.5

(Note: RD - ridge density of the finger)