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FINGERPRINT PATTERNS AND RIDGE DENSITY VARIATIONS IN PAKISTANI POPULATION: A COMPARATIVE STUDY

ABSTRACT: This comparative study was subjected to determine fingerprint pattern distribution and gender variation on the basis of fingerprint ridge density in Pakistani population. Seventeen hundred and sixty fingerprints were taken from 176 subjects (15–65 years old), including 61 males and 115 females. Although, loops (62.22%) were found most common above whorls (32.78%) and arches (5%), but the digitus quartus of both hands had greater percentage of whorls as compared to loops and arches. Comparative analysis of gender difference was conducted by computing ridge density and pattern frequency. However, significant deviations were found in fingerprint pattern (types and sub-types) at 0.05 significance level. Mean fingerprint ridge count was 12 and 14 per 25 mm² in males and females respectively. Results revealed that 10–14 fingerprint ridge count was more likely to be males and 12–16 ridges were in females. Moreover, significant differences were observed in ridge count (RC) and percentage of patterns when compared with other populations.

KEY WORDS: Forensic science - Fingerprint patterns - Fingerprint classification - Frequencies - Ridge density - Loops - Whorls - Arches

INTRODUCTION

Biometric identifiers are more reliable to be used for the personal identification as they are unique to individuals (Jain *et al.* 2000, Marciano 2019, Weaver 2006). To associate a certain identity or characteristic, i.e. either physical or behavioral, with a certain individual is known as personal identification (Jain *et al.* 2006). Biometrics is an extension of personal identification in which fingerprints are widely used (Nayak *et al.* 2010). Biometrics is considered more competent than password-based or token-based approach in identity management (Kho *et al.* 2019). There is least

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possibility to have same fingerprint patterns of any two individuals across the world. Although the genetics of the identical twins is closest to similar, but the probability of exact fingerprint patterns match is yet not proved to be equal to 1. There are certain measures which can identify even the minute differences in the fingerprint patterns of identical twins (Cunliffe, Piazza 1980, Jain *et al.* 2002). Usually, the study of dermatoglyphics is either quantitative or qualitative. Qualitative study majorly emphases on the fingerprints patterns and types of details while quantitative study includes finger ridge density or ridge count (Saladin, Porth 2010).

Moreover, there is a lot of features that make the fingerprint patterns, easily classifiable. This helps a lot in identification of not only criminals but also the corpses of unknown individuals and victims of amnesia. If gender of the person is not clear, sex based analysis of the fingerprint patterns and ridge density count becomes quite helpful (Jantz 1977). Many fingerprint examiners have proven this particular hypothesis (Mi *et al.* 1982) that women have finer epidermal ridge count than men (Moore 1994). Ridge density (RD) has been increasingly mentioned in various populations, to aid the forensic investigations. For personal identification, the important aspect is gender determination. To facilitate the investigation based on sex differences in a specific population, it is highly important to develop numerical cut-off values regarding fingerprint pattern frequency and ridge count among males and females (Agnihotri *et al.* 2012).

Human fingerprint patterns are classified into three types, which include (a) Arch (b) Loop (c) Whorl. The minutiae of fingerprint patterns include ridge count, ridge density and etc. (Gornale 2015). Analysis of any two minutiae sets increases the reliability of the global fingerprint matching (Jiang, Yau 2000). Ridge features of the fingerprints are described at three different levels in an order i.e. ridge flow, minutiae pores and ridge outlines (Parmar, Degadwala 2015). Fingerprint pattern indexing and analysis requires various schemes to provide the numerical values (Gupta *et al.* 2019). The present study presents an analysis of fingerprint patterns frequency along with ridge count for gender discrimination in Pakistani population. By the virtue of our analysis we added few parameters to the earlier studies mentioned for comparison. The results were found to be conclusive and highly significant in determination of the gender from the pattern frequency and comparison with other populations. However, significant differences have also been observed in ridge count and pattern types among males and females at significance level of 0.05.

MATERIALS AND METHODS

The study was conducted on the 1760 fingerprints of 176 individuals i.e. 61 males and 115 females, in the year 2018–2019. Individuals were randomly chosen between 15–65 years with consent for fingerprint collection from native Punjabi population of Pakistan. Automated fingerprint identification system used for imaging of the fingerprints was "Digital Persona U .are. U 4500 USB Fingerprint Reader" via Digital Persona software.

Parameters for fingerprint analysis

Fingerprint identification included the major details about types of the patterns i.e. clockwise and anti-clockwise rotating whorls, ulnar/radial loops, plain and tented arches. Macro details also included ridge count and ridge density.

Fingerprint pattern classification

Fingerprint patterns were classified into three main classes i.e. a) loops, b) whorls and c) arches (Chang, Hilbert 1996). Furthermore loops were subdivided into radial or ulnar depending on which side the lines enter. Arches were stated into tented and plain patterns.

Direction of pattern

Ridge flow was observed in fingerprint patterns to analyze the further types. Ridge flow in the direction of thumb was considered as radial and for ulnar loop ridge flow was towards *digitus quintus*. Double loop was categorized as a whorl. Arches with no upturns and zero ridge count were plain arches and those with recurves were tented. The clockwise and anti-clockwise rotations of whorls were analyzed with respect to the obtained fingerprint patterns.

Ridge count/ridge density (rc/rd)

Around each sub region there was a flow pattern i.e. central region is called core, the fork shapes region on both ends are deltas and lines in between are ridges (FATHEL 2014, Kawagoe, Tojo 1984). Ridge count was completed by joining the line from the core from both the deltas on right and left sides (Kapoor, Badiye 2015). The number of intervening lines, were computed to note down the ridge count (RC). The ridges were illustrated within the 5mm × 5mm square area and

were summed. The obtained value was referred to as the ridge density of that person and used for comparative analysis (Acree 1999, Gutiérrez-Redomero *et al.* 2011, Nigeria 2012).

Statistical analysis

Statistical analysis with the help of IBM SPSS Statistics V25.0 software system was carried out (IBM Corp 2011). Chi-square test was executed to determine significant differences among fingerprint patterns (loops, whorls and arches) with respect to gender specification and the results were evaluated with level of significance at $p < 0.05$.

RESULTS

In the present study, 1760 fingerprints (subjects) were analyzed. The breakdown of fingerprint patterns (*Figure 1*), number with their frequency and percentage has been shown in *Table 1*. Loops were found most common with frequency of 0.62 followed by whorls (0.33) and arches (0.05). The pattern frequencies were compared with different populations and the frequencies of Pakistani population were closest to those of The Netherlands population (de Jongh *et al.* 2019) as mentioned in *Figure 2*. Frequency distribution was used to calculate the pattern variation on all fingers. Of all the loops, mostly were ulnar and only 2.5% were radial (*Table 2*). In all fingerprint patterns, *digitus quartus* had greater percentage of whorls as compared to loops (*Table 2*). It was also observed, frequency of ulnar loops is greater than radial loops, both in males and females. The anti-clockwise rotation of whorls has greater frequency as compared to clockwise rotation of whorls. In males the frequency of clockwise whorls rotation was greater on left hand as compared to right hand and vice versa in females. The overall frequency of anti-clockwise rotation of whorls on both hands was comparatively higher as shown in *Table 2*. However, significant deviations were observed in all pattern (types and sub-types) frequencies by performing Chi-square test as given in *Table 3*. Descriptive statistical analysis of the of the ridge density in the present study showed that the obtained minimum ridge count value was 10 and 12 in males and females respectively, as given in *Table 5*.

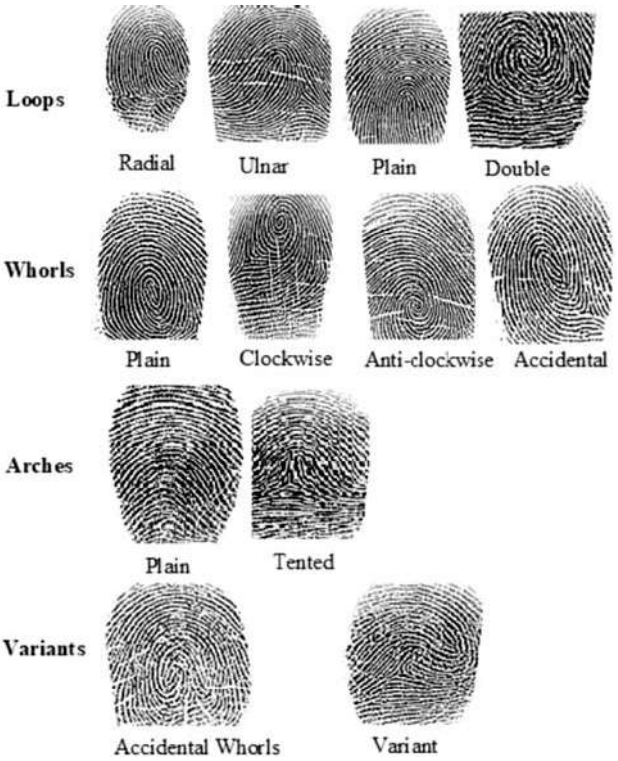

FIGURE 1: Extended set of fingerprint patterns found in Pakistani population.

TABLE 1: Distribution of Fingerprint Patterns on 1760 subjects in Pakistani population.

	Males		Females		Overall		
Fingerprint Patterns	Count	Frequency	Count	Frequency	Count	Frequency	Percentage (%)
Loops	379	0.62	714	0.62	1093	0.62	62.22
Whorls	206	0.34	371	0.33	577	0.33	32.78
Arches	25	0.04	65	0.05	90	0.05	5
Total fingerprint patterns	610	1.00	1150	1.00	1760	1.00	100.00

TABLE 2: Fingerprint patterns frequencies among all fingers. *LF: Left (hand) Finger, Left hand fingers sequence (LF1: Thumb, LF2: *digitus secundus*/pointer finger, LF3: *digitus medius*, LF4: *digitus quartus*, LF5: *digitus quintus*); RF: Right (hand) Finger, Right hand fingers sequence (RF1: Thumb, RF2: *digitus secundus*/pointer finger, RF3: *digitus medius*, RF4: *digitus quartus*, RF5: *digitus quintus*), C.W: Clockwise, A.C.W: Anti-clockwise.

	Fingerprint Patterns	LF1	LF2	LF3	LF4	LF5	RF1	RF2	RF3	RF4	RF5
Patterns Count in All Subjects	Loops (count)	111	99	122	73	125	115	104	138	76	132
	Frequency of Ulnar Loops	0.080	0.060	0.107	0.053	0.147	0.113	0.067	0.113	0.060	0.167
	Frequency of Radial Loops	0.000	0.013	0.000	0.000	0.007	0.007	0.027	0.000	0.000	0.000
	Whorls (count)	54	58	45	94	46	55	58	31	97	39
	Frequency of C.W of Whorls	0.05	0.05	0.04	0.07	0.01	0.01	0.00	0.01	0.03	0.01
	Frequency of A.C.W of Whorls	0.01	0.04	0.01	0.02	0.01	0.04	0.09	0.04	0.09	0.01
	Arches (count)	11	19	9	9	5	6	14	7	3	5
Patterns Count in Males	Loops (count)	41	34	43	21	45	39	39	45	25	47
	Frequency of Ulnar Loops	0.053	0.053	0.080	0.027	0.107	0.120	0.053	0.107	0.067	0.187
	Frequency of Radial Loops	0	0	0	0	0	0	0.04	0	0	0
	Whorls (count)	17	20	16	37	15	21	19	13	35	13
	Frequency of C.W of Whorls	0.053	0.053	0.040	0.053	0.000	0.000	0.013	0.013	0.040	0.000
	Frequency of A.C.W of Whorls	0.00	0.05	0.01	0.03	0.03	0.04	0.07	0.07	0.09	0.01
	Arches (count)	3	7	2	3	1	1	3	3	1	1
Patterns Count in Females	Loops (count)	70	65	79	52	79	76	65	93	51	84
	Frequency of Ulnar Loops	0.080	0.053	0.133	0.080	0.147	0.107	0.107	0.120	0.053	0.147
	Frequency of Radial Loops	0.000	0.027	0.000	0.000	0.013	0.013	0.013	0.000	0.000	0.000
	Whorls (count)	37	38	29	57	31	34	39	18	62	26
	Frequency of C.W of Whorls	0.067	0.053	0.040	0.080	0.027	0.013	0.000	0.027	0.040	0.013
	Frequency of A.C.W of Whorls	0.013	0.040	0.013	0.013	0.000	0.040	0.080	0.040	0.080	0.013
	Arches (count)	8	12	7	6	5	5	11	4	2	5

DISCUSSION AND CONCLUSION

A comparative study of pattern distribution was also conducted between Pakistani Population and other Indian populations like Maharashtra, district Patiala and South India (Kapoor, Badiye 2015, Nayak *et al.* 2010, Singh *et al.* 2005). The study of whorls showed that, in Pakistani population the clockwise rotation is greater on left hands and anti-clockwise rotation is greater on right hands. Significant differences in whorl pattern frequency were observed when compared to Indian populations (Kapoor, Badiye 2015, Nayak *et al.* 2010) as clockwise rotated whorl patterns were more frequent on right hand and less frequent on left hand and vice versa in anticlockwise rotated whorl patterns shown in *Table 4*. On the other hand, frequency of loops and arches patterns was greater than American African population (Wang, Alexander 2014) whereas whorls were less frequent in Pakistani population (*Table 4*). The pattern frequencies were compared with other

TABLE 3: Analysis of Fingerprint pattern types and sub-types via Chi-square test. Level of significance at $p<0.05$. Null hypotheses was rejected and the p-values showed that there is a significant difference in the values of each category, including (i) Patterns (L, W, A), (ii) Loops (Ulnar & Radial Loops) and (iii) Whorls (Rotation of the core of whorls clockwise & anti-clockwise).

	(i) Patterns (L , W , A)			**(ii)** Loops (Ulnar & Radial Loops)		**(iii)** Whorls (Rotation of the core of whorls clockwise & anti-clockwise)	
	Loops (L)	Whorls (W)	Arches (A)	Radial Loops	Ulnar Loops	clockwise whorls	anti-clockwise whorls
Males	379	206	25	03	64	20	30
Females	714	371	65	10	77	27	25
x^2 value	2.159			2.411		1.018	
p-value	<0.05			<0.05		<0.05	

TABLE 4: Comparison of fingerprint pattern percentages in present study with already published data.

	Present study	Present Study		Kapoor, Badiye 2015		Singh *et al.* 2005		Nagesh *et al.* 2015, Nayak *et al.* 2010		Wang, Alexander 2014
Patterns Count in All Subjects	Parameters	Left hand (880 fingers)	Right hand (880 fingers)	Left hand (250 fingers)	Right hand (250 fingers)	Left hand (578 fingers)	Right hand (734 fingers)	Left hand (215 fingers)	Right hand (235 fingers)	Both hands (300 fingers)
	Loops	60.2	64.2	-	-	-	-	-	-	59.67
	Ulnar Loops	44.6	26	-	-	-	-	-	-	95.53
	Radial Loops	2	3.3	-	-	-	-	-	-	4.47
	Whorls	33.75	31.8	-	-	-	-	-	-	36
	Whorl Rotation (C.W)	22.6	6.7	80	5.6	96.28	4.08	84.2	3.8	-
	Whorl Rotation (A.C.W)	9.3	26.7	7.6	84.4	1	91.04	2.3	81.7	-
	Arches	6.02	3.97	-	-	-	-	-	-	4.33
Patterns Count in Males	Loops	60.32	63.93	-	-	-	-	-	-	46.93
	Ulnar Loops	32	53.3	-	-	-	-	-	-	-
	Radial Loops	0	4	-	-	-	-	-	-	-
	Whorls	34.4	33.11	-	-	-	-	-	-	53.7
	Whorl Rotation (C.W)	20	6.7	-	-	-	-	-	-	-
	Whorl Rotation (A.C.W)	12	28	-	-	-	-	-	-	-
	Arches	5.25	2.95	-	-	-	-	-	-	46.15
Patterns Count in Females	Loops	60	64.2	-	-	-	-	-	-	53.07
	Ulnar Loops	49.3	53.33	-	-	-	-	-	-	-
	Radial Loops	4	2.7	-	-	-	-	-	-	-
	Whorls	33.4	31.13	-	-	-	-	-	-	46.3
	Whorl Rotation (C.W)	26.7	9.3	-	-	-	-	-	-	-
	Whorl Rotation (A.C.W)	8	25.33	-	-	-	-	-	-	-
	Arches	6.6	4.7	-	-	-	-	-	-	53.85

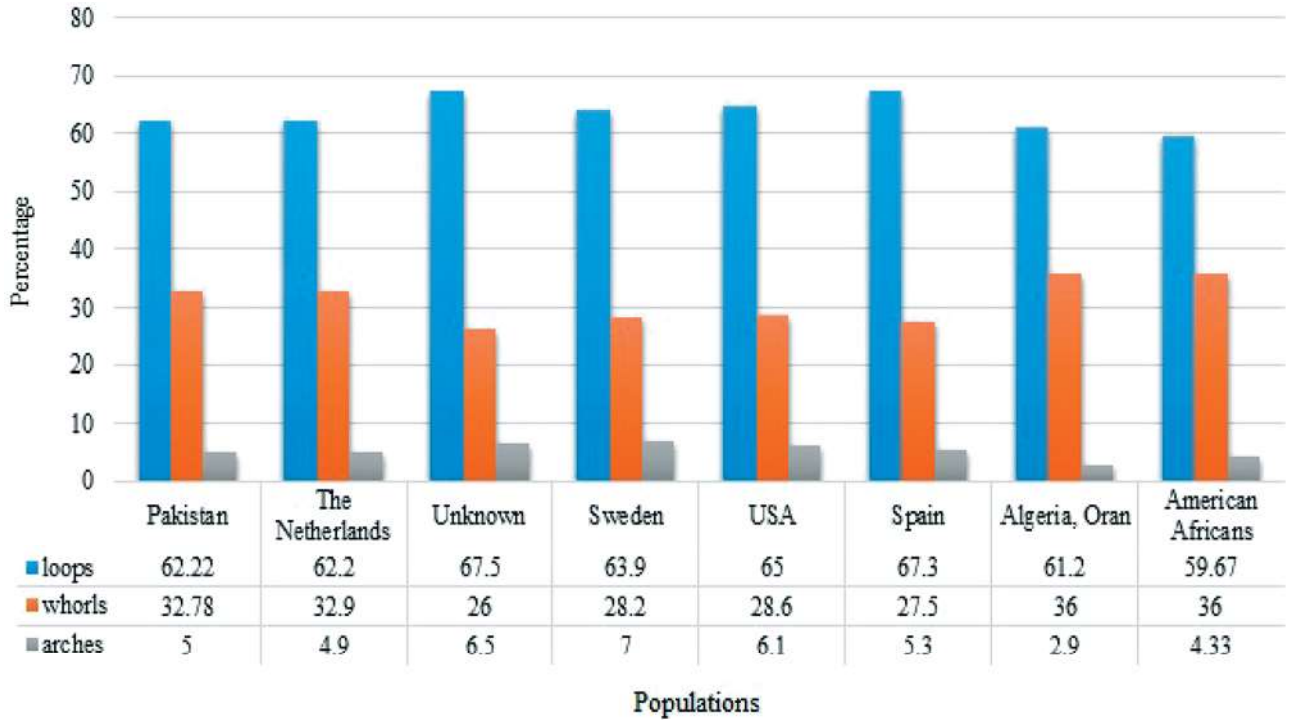

FIGURE 2: Occurrence of Fingerprint Patterns.

TABLE 5: Ridge count comparison of our study with previous studies.

	Statistical Parameters	Males	Females
Present Study	Mean Ridge Count	12	14
	SD	1.41	1.581
	Minimum Ridge Count	10	12
	Maximum Ridge Count	14	16
Chinese Population	Mean Ridge Count	11.73	17.15
	SD	1.066	1.038
	Minimum Ridge Count	9.3	14.9
	Maximum Ridge Count	14.9	16.4
Malaysian population	Mean Ridge Count	11.44	13.63
	SD	0.988	0.906
	Minimum Ridge Count	9.4	11.4
	Maximum Ridge Count	14.4	15.3

populations and the frequencies in our population were closest to that of The Netherlands population (de Jongh *et al.* 2019) as shown in *Figure 2*.

The study has been recapitulated in provisions of above analysis that in Pakistani population loops were found most repeated ones, afterwards the whorls and arches. In comparative analysis, signification variations were found reciprocally with Indian published data while whorls were found more common in American African population. The comparison with Chinese and

Malaysian populations (Gutiérrez-Redomero *et al.* 2011, Gutiérrez-Redomero *et al.* 2013) confirmed the reported analyses that females have finer ridge details as compared to males (*Table 5*). Therefore, this study revealed some racial differences in the fingerprint ridge densities and pattern distributions. However, genetic association of these patterns in Pakistan population needs to explore further studies that could be helpful for forensic experts and law enforcement authorities for resolving crime cases by using national finger print data base.

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