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Distribution of different minutiae in thumbprint and its application to determine sex distinctions

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Abstract

Background: The present study is an attempt to explore the distribution of different minutiae in two topological areas of thumbprint and its application to determine sex distinctions.

Methods: For this purpose, a sample of 100 subjects (50 males and 50 females) ranging in age from 18 years to 25 years were taken from the Shimla (North India). A modified standardized method was adopted to count and classify 20 different types of minutiae.

Results: Findings of the study indicated that the frequency of thumbprint minutiae was higher among males than their female counterparts. Ridge endings were the most frequently occurring minutiae followed by bifurcation and convergence in both the sexes. No M-B was noticed among female participant, while negligible percentage (0.04%) of males exhibited M-B. The mean values of most of the minutiae were found to be higher in the outer circle than inner circle of the thumbprint in both the sexes. Lower frequency of ridge ending (< 20 for right hand and 31–40 for both right and left hand), convergence (< 10 for both right and left hand), and bifurcation (< 10 and 31–40 for right hand and < 20 for left hand) have higher probability of female origin. While higher frequency of ridge ending (> 60 for right hand and > 50 for left hand), convergence (> 20 for both right and left hand) and bifurcation (> 40 for right hand and > 30 for left hand) was more likely of male origin.

Conclusions: Findings of present study identified sex distinction in the distribution of minutiae with respect to the topological areas on the thumbprint.

Keywords: Minutiae, Peripheral area, Sex distinction, Thumbprint

Background

Personal identification and establishing sex based on dermatoglyphic characteristics is a common tradition since decades throughout the world and is also recognized by the legal system (Gutiérrez-Redomero et al. 2007). A study performed by Vij (2001) observed that there can be the absolute or partial assessment of the individuality of a person, where partial identification illustrates limited facts concerning sex, age, stature etc. of the individual. Although several parameters are available for the identification of an individual, but the fingerprints are the most accurate, economical, and authentic method for individual and sex determination (Martín and Portabales 1986; Arrieta et al. 1990; Gutiérrez-Redomero et al. 2008).

The term minutiae are designated to the small distinguishing features present on the ridges of the dermatoglyphic pattern, which generally intervene the continuous flow of ridges thereby causing a great range of variability to the dermal ridges of the same as well as different individuals. A plethora of previous researches have generated sufficiently data base concerning evaluation of sex differences with respect to fingerprint pattern distribution (Stambouli et al. 2015; Králík

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et al. 2019) and ridge density (Rivaldería et al. 2016; Kaur and Kaur, 2019; Carvalho D da S et al. 2022), while limited work has done on this domain with respect to minutiae. Several authors across the globe (Gutiérrez-Redomero et al. 2011; Adamu et al. 2017; Akpan et al. 2019) documented great variations in terms of fingerprint minutiae in different areas of finger as well as in different population. A study conducted by Stoney and Thornton (1986) also highlighted direct significance of the variations of epidermal ridge minutiae in the forensic science and criminal investigations for analyzing and comparing different fingerprints especially in case of partial fingerprints. Another interesting finding of Wilder and Wentworth (1918) noted that the frequency of minutiae depends on the type of dermatoglyphic pattern of the individual, with high frequency of minutiae are recorded in the loops as well as in the delta region. Due to lack of comprehensive research on distribution and variability of minutiae on the dermal ridges with respect to sex and different ethnic groups, our present understanding about these papillae characteristics is still not very encouraging.

In recent years, both scientific and legal researchers have highlighted the need for more extensive information about frequency and variability of minutiae to widen their practical application in different spheres. For better comprehension of this domain, the present study was carried out to ascertain (i) frequency distribution of different types of minutiae in the thumbprint of adult male and female, (ii) frequency distribution of different type of minutiae in inner and outer circle of the thumbprint, and (iii) sex differences in thumbprint minutiae among adults of Shimla, Himachal Pradesh.

Methods

The thumbprints of the 100 subjects (50 males and 50 females) ranging in age from 18 to 25 years were collected from different educational institutes of Shimla, Himachal Pradesh (North India).

Data collection were carried out from 12th November to 21st November, 2018. The nature and objective of the study was explained to all the participants and they gave verbal consent for the study. Inclusion criteria encompassed only those participants who were devoid of any lesion, damage or disease on the thumb. The rolled thumbprints of the subjects were taken by simple ink method following the procedure explained by Cummins and Midlo (1943). The hands of the subjects were thoroughly cleaned with soap and water, and then dried before taking the thumbprint. For clean, complete, and decipherable print, thumb was evenly inked with pressure pad. The thumb was kept with ulnar edge downwards and rolled towards the body.

A magnifying glass was used to recognize various types of minutiae based on a modified version (Gutiérrez-Redomero et al. 2007; Gutiérrez-Redomero et al. 2011) of the classification system used by the Spanish Scientific Police (Barberá and De Luis y Turegano 1993; Champod 1996). The following twenty minutiae, i.e., bifurcation (B), convergence (C), break (BR), big fragment (F-BG), small fragment (F-SM), big enclosure (EN-BG), small enclosure (EN-SM), point or dot into ridge (P-IN), point or dot between ridges (P-BW), trifurcation bifurcate (TF-B), trifurcation convergent (TF-C), a meeting point of two convergences and one bifurcation (M-C), a meeting point of two bifurcations and one convergence (M-B), return (R), ridge ending (E), crossbar (CR), overlap (O), bridge (BD), dock (D), and opposited bifurcation (OB) were counted in the present study (Fig. 1).

Standardized procedure used for categorizing minutiae in two topological areas involved drawing two perpendiculars on the fingerprint thereby intersecting it at the center of the thumbprint. Then, a circle was drawn on these quadrants so that its radius perpendicularly cuts fifteen ridges, in one of the distal quadrants. Therefore, the distal phalange of the thumbprint was divided into four quadrants with two sectors, i.e., one was inside and other was outside of the circle as is displayed in Fig. 2.

Statistical analyses

Descriptive statistics including means, standard deviations, and percentage frequency was determined for each minutia by employing Statistical Package for Social Sciences (SPSS) version 20. Before commencing the analysis for the whole sample in the present study, minutiae of ten females and an equal number of males in both the inner and outer circles were identified by the third author at about 24-h intervals to gauge intra-observer error. The minutiae in the inner as well as outer circle of the thumbprint were also analyzed by the second author to document inter-observer error. Results of paired t test indicated non-significant values for both intra, as well as inter-observer error. Shapiro-Wilk's test was applied to check normality of distribution of the sample, and it was found that data did not exhibit symmetrical distribution, so, non-parametric statistic was used. Mann-Whitney U test was carried out to demonstrate statistically significant sex differences in the minutiae. The minutiae in the inner and outer circle were compared by employing Wilcoxon signed rank test. The level of significance for all analyses was set at $p < 0.05$ and a confidence interval of 95% were considered for all statistical analyses. Probability inference based on the most frequently occurring minutiae only, i.e., ridge ending, convergence and bifurcation for both males and females was ascertained from the likelihood ratio (LR). This is depicted as probability of given minutiae originating from male contributor (C)/

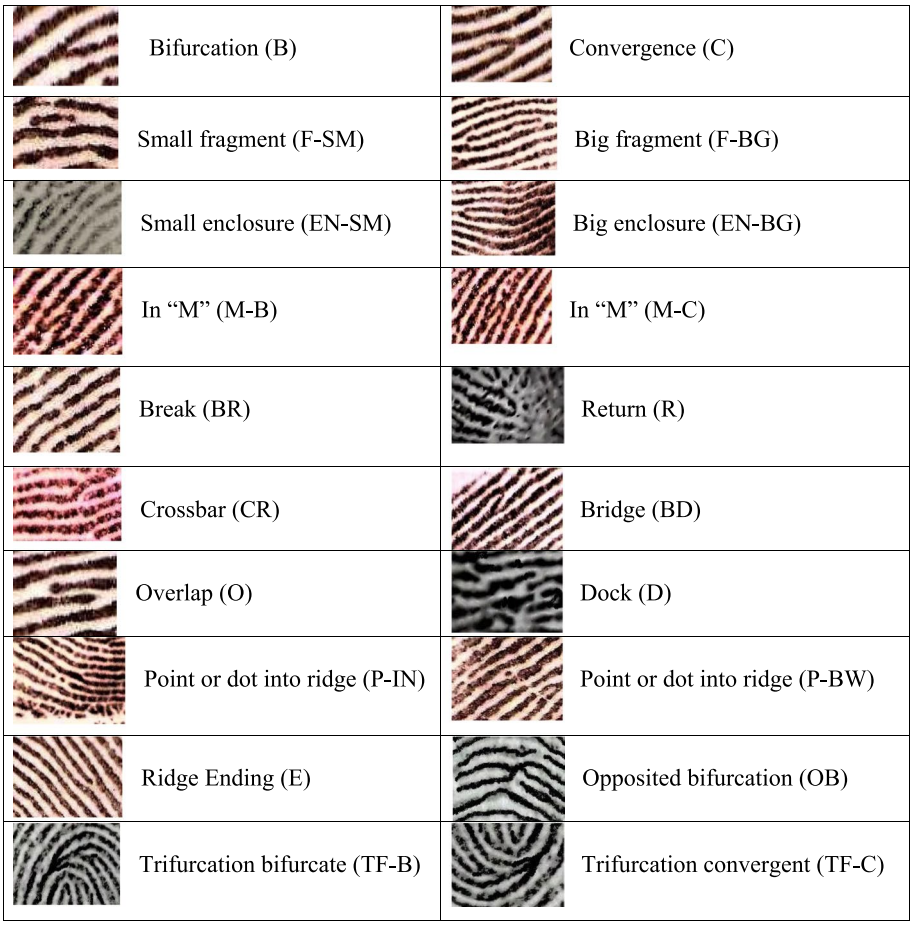

Fig. 1 Twenty different types of minutiae as per modified standardized method of Gutiérrez-Redomero et al. (2011)

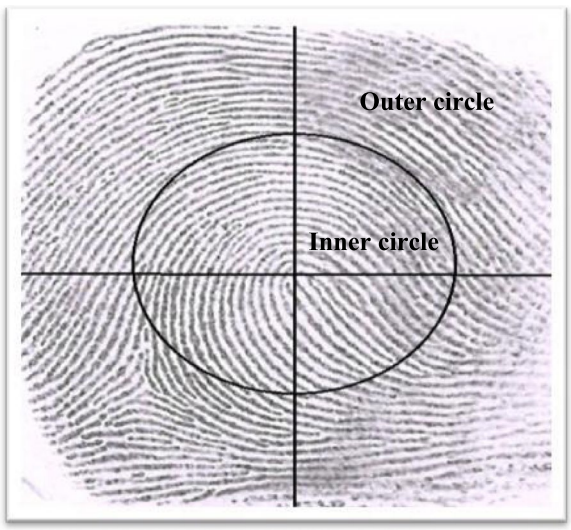

Fig. 2 Thumbprint showing two topological areas of thumb print, i.e., inner circle and outer circle

probability given minutiae originating from female contributor (C').

Results

The sex wise frequency distribution of twenty different types of minutiae on thumbprint is depicted in Table 1. A total of 20 different types of minutiae were located and identified in two topological areas and total 24,146 minutiae (male = 13101, female = 11045) were recorded in the current cross-sectional study. It is observed that out of the total twenty minutiae, ridge endings showed highest frequency (males 29.03%; females 33.51%) followed by bifurcation (males 17.84%, females 16.47%) and convergences (males 16.08%, females 13.25%) in both the sexes. Minutiae like crossbar, trifurcation bifurcate, trifurcation convergent, M-B, M-C, opposite bifurcation, and dock demonstrated frequencies less than 1% and rest of the minutiae ranged between 1% and 8% in both the groups under study.

Descriptive statistics for minutiae count in inside and outside the circle of the right hand thumbprint

Table 1 Frequency distribution of different types of minutiae in the thumbprint of males and females

Minutia type	Total *N* (%)	Male *N* (%)	Female *N* (%)
Bifurcation	4156 (17.21%)	2337 (17.84%)	1819 (16.47%)
Convergence	3571 (14.79%)	2107 (16.08%)	1464 (13.25%)
Ridge ending	7504 (31.08%)	3803 (29.03%)	3701 (33.51%)
Enclosure-small	1595 (6.61%)	963 (7.35%)	632 (5.72%)
Enclosure-big	784 (3.25%)	488 (3.72%)	296 (2.68%)
Fragment-small	1921 (7.96%)	994 (7.59%)	927 (8.39%)
Fragment-big	579 (2.40%)	259 (1.98%)	320 (2.90%)
Crossbar	179 (0.74%)	89 (0.68%)	90 (0.81%)
Overlap	346 (1.43%)	186 (1.42%)	160 (1.45%)
Break	550 (2.28%)	232 (1.77%)	318 (2.88%)
Bridge	603 (2.50%)	332 (2.53%)	271 (2.45%)
Trifurcation bifurcate	23 (0.09%)	15 (0.11%)	8 (0.07%)
Trifurcation convergent	16 (0.07%)	15(0.11%)	1 (0.01%)
M-B	5 (0.02%)	5 (0.04%)	0 (0.00%)
M-C	18 (0.07%)	11 (0.08%)	7 (0.06%)
Point or dot into ridge	774 (3.20%)	384 (2.93%)	390 (3.53%)
Point or dot between ridges	1197 (4.96%)	713(5.44%)	484 (4.38%)
Opposited bifurcation	80 (0.33%)	44 (0.34%)	36 (0.33%)
Return	232 (0.96%)	117(0.89%)	115 (1.04%)
Dock	13 (0.05%)	7 (0.05%)	6 (0.05%)
Total	24,146(100)	13,101(99.98%)	11,045(99.98%)

(Table 2) and left hand thumbprint (Table 3) was ascertained using Wilcoxon signed rank test. It was noticed that mean values of minutiae were higher in the outer/peripheral circle as compared to inner circle for most of the minutiae for both the male and female groups.

Tables 4 and 5 summarized the sex differences in the mean value of minutiae count inside and outside the circle of the right and left thumbprint respectively using Mann-Whitney *U* test. In the right hand for both outer and inner circles, males had higher mean values for most of the minutiae than their female counterparts except for ridge ending, fragment-big, cross bar, break, and return in peripheral circle and fragment—big, crossbar, break, trifurcation bifurcate, M-C, and point or dot into ridge in central circle, where females revealed only a slightly higher mean value (Table 4). In the peripheral area, statistically significant sex differences were obtained for bifurcation (2.63*), convergence (2.72**), enclosure-small (4.45**), enclosure-big (2.70*), bridge (2.71**), trifurcation convergent (2.28**), and point or dot between ridges (3.28**), whereas in central area significant *Z*-values were noted for bifurcation (1.72*), convergence (3.38**), enclosure-small (3.52**), and trifurcation bifurcate (− 2.03*).

In the left hand, mean value for minutiae count was higher in both the circles of males as compared to their female counterparts except for fragment big, crossbar, point or dot into ridge, return and dock in outer circle and for ridge ending, fragment small, fragment big, break, bridge, opposite bifurcation, and dock in inner circle (Table 5). Statistically significant sex differences were recorded in bifurcation (2.65**), convergence (4.50**), enclosure-small (3.97**) and enclosure-big (3.11**), point or dot between ridges (3.41**), and return (2.21*) as is evident from their *Z*-values in peripheral area, while in inside circle significant sex differences were observed only in bifurcation (3.20**), convergence (2.43**), enclosure-big (3.77**), break (2.12*), and trifurcation (2.03*).

Probability of proportions, likelihood ratio and favored odds of ridge ending, bifurcation and convergence were calculated for both the sexes in right (Table 6) and left hand (Table 7). In the right hand ridge ending less than 20 and between 31 and 40 were more likely to have female origin, while more than 60 ridge ending have more chances of male origin, while for left hand ridge ending between 31 and 40 were more likely to have female origin and more than 50

Table 2 Descriptive statistics for minutiae count in inside and outside the circle of the right thumbprint

Minutiae type	Male					Female				
	Inside circle		Outside circle		*z*-value	Inside circle		Outside circle		*z*-value
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Bifurcation	7.42	4.16	12.62	6.17	− 4.44**	5.90	3.24	9.68	6.04	− 3.96**
Convergence	8.50	3.89	15.42	6.77	− 5.12**	6.06	3.69	11.52	4.88	− 5.31**
Ridge ending	13.56	6.37	24.40	11.03	− 5.36**	12.80	5.33	26.18	8.80	− 5.69**
Enclosure-small	4.84	2.73	5.20	2.82	− 0.71	2.94	2.12	2.84	2.02	0.20
Enclosure-big	1.76	1.90	3.12	2.42	− 3.18**	1.58	2.12	2.06	2.52	− 1.09
Fragment-small	3.56	3.13	6.98	4.74	− 4.29**	3.14	2.68	5.98	4.25	− 3.84**
Fragment-big	0.68	0.95	1.84	1.75	− 4.10**	1.12	1.53	1.98	1.50	− 3.29**
Crossbar	0.46	0.67	0.46	0.70	0.00	0.50	1.07	0.48	1.05	− 0.16
Overlap	0.70	0.95	1.50	1.26	− 3.77**	0.56	0.81	1.26	1.50	− 2.99**
Break	1.50	1.26	1.18	1.08	− 1.30	1.64	1.91	2.08	2.16	− 1.07
Bridge	1.14	1.12	1.92	1.41	− 2.94**	0.86	1.16	1.20	1.30	− 1.36
Trifurcation bifurcate	0.00	0.00	0.12	0.59	− 1.63	0.08	0.27	0.00	0.00	− 2.00*
Trifurcation convergent	0.04	0.19	0.14	0.49	− 1.27	0.02	0.14	0.00	0.00	− 1.00
M-B	0.00	0.00	0.02	0.14	− 1.00	0.00	0.00	0.00	0.00	0.00
M-C	0.00	0.00	0.14	0.35	− 2.65**	0.02	0.14	0.10	0.58	− 1.00
Point or dot into ridge	1.36	2.09	2.68	3.83	− 3.23**	1.86	2.19	2.46	2.15	− 1.63
Point or dot between ridges	3.44	3.52	4.30	3.02	− 1.80	2.64	3.10	2.58	2.28	− 0.46
Opposited bifurcation	0.30	0.61	0.18	0.38	− 1.27	0.24	0.55	0.08	0.27	− 1.69
Return	1.04	1.00	0.28	0.64	− 3.95**	0.78	0.93	0.40	0.78	− 2.29*
Dock	0.08	0.27	0.06	0.24	− 0.38	0.02	0.14	0.04	0.28	− 0.45

Level of significance $p < 0.01$**, $p < 0.05$

have greater possibility of male origin. In the right hand bifurcation, < 10 and between 31 and 40 were more likely to have female origin, while < 40 bifurcation in right hand had higher probability of male origin. For left hand bifurcation less than 20 were more likely to have female origin and < 30 have more likelihood of male origin. Convergence less than 10 were more likely to have female origin, while more than 20 had more chances to have male origin in both the right and left hand.

Discussion

Minutiae is one of the important diagnostic tools for sex distinction and establishing identity of the individual has been comparatively less investigated although, it has enormous applications in the fields of genetics, criminology, and biological anthropology. Previous researchers (Ashbaugh 1999; Vanderkolk 2001) also highlighted the importance to perform such studies to analyze the scientific bases for sex distinction as well as personal identification based on the variability of minutiae in dermal ridges. It is difficult to compare the results of the present study with previously published reports because different methodologies were selected by different workers to count as well as classification of minutiae and different digits were preferred to analyze minutiae by researchers. Therefore, only the general trend of frequency of different types of minutiae is compared.

The current research recorded that ridge endings was the most commonly occurring minutiae followed by bifurcation and convergence in both the sexes. All others minutiae like enclosure-small, enclosure-big, fragment-small, fragment-big, crossbar, overlap, break, bridge, trifurcation bifurcate, trifurcation convergent, M-B, M-C, point or dot into ridge, point or dot between ridges, opposited bifurcation, return, and dock were appearing with frequency less than 8%. Similar findings were observed by Gutiérrez-Redomero et al. (2007) on the right hand index finger of the adult Spanish population that the ridge endings showed highest frequencies followed by bifurcations and convergences, but they also noticed that all the other types of minutiae showed frequencies lower than 5%. A

Table 3 Descriptive statistics for minutiae count in inside and outside the circle of the left thumbprint

Minutiae type	Male					Female				
	Inside circle		Outside circle		*z*-value	Inside circle		Outside circle		*z*-value
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Bifurcation	9.98	4.38	16.72	6.54	− 4.76**	7.48	3.31	13.32	6.11	− 4.71**
Convergence	7.30	3.72	10.92	5.68	− 3.66**	5.44	3.20	6.26	4.62	− 0.91
Ridge ending	13.88	7.05	24.22	11.47	− 4.91**	14.14	4.70	20.90	8.37	− 3.95**
Enclosure-small	4.28	2.36	4.94	2.42	− 1.12	3.74	3.18	3.12	2.67	− 1.15
Enclosure-big	1.84	1.81	3.04	2.53	− 2.78**	0.68	0.84	1.60	1.49	− 3.30**
Fragment-small	3.20	2.87	6.38	3.66	− 4.68**	3.94	2.91	5.48	4.28	− 2.06*
Fragment-big	0.64	1.04	2.02	1.79	− 4.37**	0.92	1.25	2.38	1.89	− 4.21**
Crossbar	0.26	0.52	0.60	0.78	− 2.74**	0.16	0.37	0.66	0.84	− 3.46**
Overlap	0.54	0.81	0.98	1.18	− 2.30*	0.42	0.57	0.96	1.36	− 2.36*
Break	0.80	1.10	1.54	1.70	− 2.74**	1.42	1.55	1.22	1.35	− 0.70
Bridge	1.50	1.23	2.08	1.53	− 2.09*	1.52	1.38	1.84	2.00	− 0.66
Trifurcation bifurcate	0.08	0.27	0.10	0.58	− 0.33	0.02	0.14	0.06	0.24	− 1.00
Trifurcation convergent	0.10	0.36	0.02	0.14	− 1.41	0.00	0.00	0.00	0.00	0.00
M-B	0.02	0.14	0.06	0.24	− 1.00	0.00	0.00	0.00	0.00	0.00
M-C	0.04	0.19	0.04	0.19	0.00	0.00	0.00	0.02	0.14	− 1.00
Point or dot into ridge	1.76	3.09	1.88	2.00	− 1.01	1.48	1.72	2.00	2.47	− 1.14
Point or dot between ridges	2.28	2.33	4.24	3.24	− 4.04**	2.16	2.64	2.30	2.55	− 0.59
Opposited bifurcation	0.20	0.49	0.20	0.49	0.00	0.28	0.70	0.12	0.38	− 1.43
Return	0.94	0.79	0.08	0.27	− 5.05**	0.82	0.87	0.30	0.61	− 2.96**
Dock	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.04	0.19	− 0.57

Level of significance $p < 0.01$**, $p < 0.05$

comparative study on two Argentinian populations and one Spanish population was carried out by Gutiérrez-Redomero et al. (2012) and their findings revealed that the frequency of endings (E) was markedly higher than the rest of the minutiae (Ramal: 50.14%; Puna–Quebrada: 51.69%), followed by the frequency of bifurcations (B) (Ramal: 21.17%, Puna–Quebrada: 19.91%) and convergences (C) (Ramal: 19.19%, Puna–Quebrada: 18.28%) in both the populations. Findings of Adamu et al. (2017) who analyzed thumbprint minutiae of Hausa lineage also mentioned that the highest frequencies were of bifurcation followed by ridge endings and convergence.

In the present study, least frequently occurring minutiae were dock and M-B in both the adult males and females of North India. A perusal of previous studies noted that least commonly occurring minutiae across some populations were return in Spanish population (Santamaria 1955), break in German population (Steffens 1965), short break in Japanese population (Okajima 1970), trifurcation bifurcation in American population (Sclove 1979), dock in Spanish population (Gutiérrez-Redomero et al. 2007), return in Puna-Quebrada population, M-C in Ramal population (Gutiérrez-Redomero et al. 2012), trifurcation bifurcation, and M-C in Hausa lineage of Nigeria (Adamu et al. 2017). Previous literature on diverse populations highlighted that instead of most frequently occurring minutiae, it is the less commonly reported minutiae that serves as a potential marker for evaluating population variability as well as illustrating characteristics of different population (Adamu et al. 2017).

Concerning the sexual dimorphism with respect to frequency of minutiae, it is observed in the present study that total number of minutiae was higher in males (13101) as compared to their age matched female counterparts (11045). Probability inference also supported that lower frequency of most frequently occurring minutiae, i.e., ridge ending (< 20 for right hand and 31–40 for both right and left hand), convergence (< 10 for both right and left hand) and bifurcation (< 10 and 31–40 for right hand and < 20 for left hand) have more chances of female origin. Whereas more frequency of ridge ending (> 60 for right hand and > 50 for left hand), convergence (> 20 for both right and left hand), and bifurcation (> 40 for right hand and >30 for left

Table 4 Sex differences of minutiae count inside and outside the circle of the right thumbprint

Minutiae type	Inside circle					Outer circle				
	Male		Female		*z*-value	Male		Female		*z*-value
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Bifurcation	7.42	4.16	5.90	3.24	− 1.72**	12.62	6.17	9.68	6.04	− 2.63**
Convergence	8.50	3.89	6.06	3.69	− 3.38**	15.42	6.77	11.52	4.88	− 2.72**
Ridge ending	13.56	6.37	12.80	5.33	− 0.31	24.40	11.03	26.18	8.80	− 1.07
Enclosure-small	4.84	2.73	2.94	2.12	− 3.52**	5.20	2.82	2.84	2.02	− 4.45**
Enclosure-big	1.76	1.90	1.58	2.12	− 0.59	3.12	2.42	2.06	2.52	− 2.70**
Fragment-small	3.56	3.13	3.14	2.68	− 0.48	6.98	4.74	5.98	4.25	− 1.19
Fragment-big	0.68	0.95	1.12	1.53	− 1.23	1.84	1.75	1.98	1.50	− 0.58
Crossbar	0.46	0.67	0.50	1.07	− 0.92	0.46	0.70	0.48	1.05	− 0.86
Overlap	0.70	0.95	0.56	0.81	− 0.68	1.50	1.26	1.26	1.50	− 1.39
Break	1.50	1.26	1.64	1.91	− 0.56	1.18	1.08	2.08	2.16	− 1.68
Bridge	1.14	1.12	0.86	1.16	− 1.58	1.92	1.41	1.20	1.30	− 2.71**
Trifurcation bifurcate	0.00	0.00	0.08	0.27	− 2.03**	0.12	0.59	0.00	0.00	− 1.75
Trifurcation convergent	0.04	0.19	0.02	0.14	− 0.58	0.14	0.49	0.00	0.00	− 2.28**
M− B	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.00	0.00	− 1.00
M-C	0.00	0.00	0.02	0.14	− 1.00	0.14	0.35	0.10	0.58	− 1.69
Point or dot into ridge	1.36	2.09	1.86	2.19	− 1.32	2.68	0.83	2.46	2.15	− 0.68
Point or dot between ridges	3.44	3.52	2.64	3.10	− 1.46	4.30	3.02	2.58	2.28	− 3.28**
Opposited bifurcation	0.30	0.61	0.24	0.55	− 0.37	0.18	0.38	0.08	0.27	− 1.48
Return	1.04	1.00	0.78	0.93	− 1.42	0.28	0.64	0.40	0.78	− 0.92
Dock	0.08	0.27	0.02	0.14	− 1.37	0.06	0.24	0.04	0.28	− 0.99

Level of significance $p < 0.01$**, $p < 0.05$*

hand) was more likely of male origin. Similarly, higher frequency of minutiae in males than their age matched female counterparts have been observed in index finger of Spanish population (Gutiérrez-Redomero et al. 2007), in thumbprint of Hausa population of Nigeria (Adamu et al. 2017) and in all fingers of two Argentinian populations of Buenos Aires and Chubut province (Rivaldería et al. 2017). This may be attributed to the thickness of ridge breadth, finer ridges may be more continuous and less fine ridges are prone to more interruptions, therefore frequency of minutiae may be higher in males. A study performed by Kralik and Novotny (2003) noted that ridge breadth is approximately 10% thicker in males than their female counterparts.

In our study, mean values of minutiae were higher in the peripheral area as compared to central area for both the right and left hand thumbprint. Even the studies (Sclove 1979; Lin 1981) carried out decades ago have emphasized that density of minutiae vary according to the dermatoglyphic area on the fingerprint. In contrast to the findings of present study, few studies (Champod and Margot 1996; Rivaldería and Gutiérrez-Redomero 2021) have noticed that density of minutiae was greater in nucleus and in the delta region as compared to the outer region of the fingerprint. A report from Gutiérrez-Redomero et al. (2012) also recorded abundant minutiae in the central region of the impression. Higher frequency of minutiae in the outer circle of the present study may be due to more broader ridges in the outer circle of the thumbprint as compared to the central circle of the thumbprint.

Limitation of the study

In the present study, only minutiae in thumbprint were taken into consideration. It would have been more informative if all the digits of the hand were taken into consideration. Hence, more studies in this domain are needed to further widen our understanding.

Conclusions

Hence, this report concludes that minutiae exhibit sufficient sexual dimorphism in their frequency, with males exhibiting higher minutiae in both the inner and outer circle than the females. These findings are further supported by the probability inference based on

Table 5 Sex differences of minutiae count inside and outside the circle of the left thumbprint

Minutiae type	Inside circle					Outer circle				
	Male		Female		*z*-value	Male		Female		*z*-value
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Bifurcation	9.98	4.38	7.48	3.31	− 3.20**	16.72	6.54	13.32	6.11	− 2.65**
Convergence	7.30	3.72	5.44	6.11	− 2.43**	10.92	5.68	6.26	4.62	− 4.50**
Ridge ending	13.88	7.05	14.14	4.70	− 0.29	24.22	11.47	20.90	8.37	− 1.30
Enclosure-small	4.28	2.36	3.74	3.18	− 1.73	4.94	2.42	3.12	2.67	− 3.97**
Enclosure-big	1.84	1.81	0.68	0.84	− 3.77**	3.04	2.53	1.60	1.49	− 3.11**
Fragment-small	3.20	2.87	3.94	2.91	− 1.38	6.38	3.66	5.48	4.28	− 1.41
Fragment-big	0.64	1.04	0.92	1.25	− 0.94	2.02	1.79	2.38	1.89	− 1.03
Crossbar	0.26	0.52	0.16	0.37	− 0.84	0.60	0.78	0.66	0.84	− 0.27
Overlap	0.54	0.81	0.42	0.57	− 0.32	0.98	1.18	0.96	1.37	− 0.56
Break	0.80	1.10	1.42	1.55	− 2.12**	1.54	1.70	1.22	1.36	− 0.82
Bridge	1.50	1.23	1.52	1.38	− 0.15	2.08	1.53	1.84	2.00	− 1.39
Trifurcation bifurcate	0.08	0.27	0.02	0.14	− 1.37	0.10	0.58	0.06	0.24	− 0.43
Trifurcation convergent	0.10	0.36	0.00	0.00	− 2.03**	0.02	0.14	0.00	0.00	− 1.00
M-B	0.02	0.14	0.00	0.00	− 1.00	0.06	0.24	0.00	0.00	− 1.75
M-C	0.04	0.19	0.00	0.00	− 1.42	0.04	0.19	0.02	0.14	− 0.58
Point or dot into ridge	1.76	3.09	1.48	1.72	− 0.84	1.88	2.00	2.00	2.47	− 0.19
Point or dot between ridges	2.28	2.33	2.16	2.64	− 0.68	4.24	3.24	2.30	2.55	− 3.41**
Opposited bifurcation	0.20	0.49	0.28	0.70	− 0.32	0.20	0.49	0.12	0.38	− 0.89
Return	0.94	0.79	0.82	0.87	− 0.98	0.08	0.27	0.30	0.61	− 2.21*
Dock	0.00	0.00	0.02	0.14	− 1.00	0.00	0.00	0.04	0.19	− 1.42

Level of significance $p < 0.01$**, $p < 0.05$*

Table 6 Probability of proportions, likelihood ratio, and favored odds of male and female in right hand

Minutiae	Number of minutiae	Frequency		Probability of densities		Likelihood ratio		Favored ratio	
		Male	Female	Male (C)	Female (C′)	C/C′	C′/C	C	C′
Ridge ending	11–20	4 (8%)	10 (20%)	0.08	0.20	0.4	2.5	0.29	0.71
	21–30	13 (26%)	0 (0%)	0.26	0	–	0	1	0
	31–40	11 (22%)	19 (38%)	0.22	0.38	0.58	1.73	0.37	0.63
	41–50	11 (22%)	16 (32%)	0.22	0.32	0.69	1.45	0.41	0.59
	51–60	7 (14%)	5 (10%)	0.14	0.10	1.40	0.71	0.58	0.42
	61–70	2 (4%)	0 (0%)	0.04	0	–	0	1	0
	71–80	2 (4%)	0 (0%)	0.04	0	–	0	1	0
Bifurcation	1–10	3 (6%)	8 (16%)	0.06	0.16	0.38	2.67	0.27	0.73
	11–20	27 (54%)	31(62%)	0.54	0.62	0.87	1.15	0.47	0.53
	21–30	16 (32%)	8 (16%)	0.32	0.16	2	0.5	0.67	0.33
	31–40	1 (2%)	3 (6%)	0.02	0.06	0.33	3	0.25	0.75
	41–50	3 (6%)	0 (0%)	0.06	0	–	0	1	0
Convergence	1–10	1 (2%)	8 (16%)	0.02	0.16	0.13	8	0.11	0.89
	11–20	19 (38%)	27 (54%)	0.38	0.54	0.70	1.42	0.41	0.59
	21–30	20 (40%)	13 (26%)	0.40	0.26	1.54	0.65	0.61	0.39
	31–40	8 (16%)	2 (4%)	0.16	0.04	4	0.25	0.80	0.20
	41–50	2 (4%)	0 (0%)	0.04	0	–	0	1	0

Table 7 Probability of proportions, likelihood ratio, and favored odds of male and female in left hand

Minutiae	Number of minutiae	Frequency		Probability of densities		Likelihood ratio		Favored ratio	
		Male	Female	Male (C)	Female (C′)	C/C′	C′/C	C	C′
Ridge ending	11–20	6 (12%)	4 (8%)	0.12	0.08	1.5	0.67	0.60	0.40
	21–30	12 (24%)	9 (18%)	0.24	0.18	1.33	0.75	0.57	0.43
	31–40	8 (16%)	19 (38%)	0.16	0.38	0.42	2.38	0.30	0.70
	41–50	15 (30%)	17 (34%)	0.30	0.34	0.88	1.13	0.47	0.53
	51–60	6 (12%)	1(2%)	0.12	0.02	6	0.17	0.86	0.14
	61–70	2 (4%)	0 (0%)	0.04	0	–	0	1	0
	71–80	1(2%)	0 (0%)	0.02	0	–	0	1	0
Bifurcation	1–10	1(2%)	4 (8%)	0.02	0.08	0.25	4	0.20	0.80
	11–20	13 (26%)	22 (44%)	0.26	0.44	0.59	1.69	0.37	0.63
	21–30	17 (34%)	19 (38%)	0.34	0.38	0.89	1.12	0.47	0.53
	31–40	18 (36%)	5 (10%)	0.36	0.10	3.60	0.28	0.78	0.22
	41–50	1(2%)	0 (0%)	0.02	0	–	0	1	0
Convergence	1–10	7 (14%)	23 (46%)	0.14	0.46	0.30	3.29	0.23	0.77
	11–20	30 (60%)	23 (46%)	0.60	0.46	1.30	0.77	0.57	0.43
	21–30	10 (20%)	4 (8%)	0.20	0.08	2.5	0.40	0.71	0.29
	31–40	2 (4%)	0 (0%)	0.04	0	–	0	1	0
	41–50	1 (2%)	0 (0%)	0.02	0	–	0	1	0

the most commonly occurring minutiae. With respect to topological area, the frequency of minutiae was higher in the outer circle as compared to the inner circle in both the groups of the present study. Hence, the findings of the present study will address the gap concerning identification of sex as well as variability of minutiae in different ethnic groups.

Abbreviations

B: Bifurcation; C: Convergence; BR: Break; F-BG: Big fragment; F-SM: Small fragment; EN-BG: Big enclosure; EN-SM: Small enclosure; P-IN: Point or dot into ridge; P-BW: Point or dot between ridges; TF-B: Trifurcation bifurcate; TF-C: Trifurcation convergent; M-C: A meeting point of two convergences and one bifurcation; M-B: A meeting point of two bifurcations and one convergence; R: Return; E: Ridge ending; CR: Crossbar; O: Overlap; BD: Bridge; D: Dock; OB: Opposited bifurcation; SPSS: Statistical Package for Social Sciences; LR: Likelihood ratio.

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Authors' contributions

The present study was designed and conceived by Dr. Maninder Kaur and Jatinder Kaur. Data collection was carried out by AK. Analysis and interpretation of the data were done by MK, JK, and AK. The manuscript was written by MK, JK, AK, and PK. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due (required permission from competent authority) but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was not required for the present study while the nature and the purpose of the study was explained to the participants before the commencement of the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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