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SEX AND TOPOLOGICAL DIFFERENCES IN FINGERPRINT RIDGE DENSITY AMONG ADULT POPULATION OF NORTH INDIA

ABSTRACT: The analysis of dermal ridges and their configuration on fingertips has been of considerable interest due to their inimitable, permanent and unique characteristics. The present cross-sectional study is an attempt to assess sex as well as topological differences in fingerprint ridge density among adult population of Nahan, Himachal Pradesh, North India. The data comprised of 240 subjects (120 males and 120 females), aged between 18 to 24 years. The results obtained in the study revealed significantly ($p<0.001$) higher fingerprint ridge density in females than males at radial, ulnar and proximal topological areas. Both the sexes revealed a disto-proximal gradient of fingerprint ridge density i.e proximal < ulnar < radial in both the hands. In regard to radial area fingerprint ridge density of ≤11 ridges and ≥13 ridges had more possibility of male and female origin respectively. Fingerprint ridge density of ≤11 ridges and ≥12 ridges was more likely of male and female origin respectively in the ulnar regions. In proximal region, fingerprint ridge density of ≤8 ridges and fingerprint ridge density of ≥10 ridges had more probability of being male and female origin respectively. Results of discriminant function analysis further strengthen the conclusion of significant gender differences in the ridge density at all the counting areas, thereby confirming fingerprint ridge density as a potential tool for sex distinction.

KEY WORDS: Fingerprint – Ridge density – Sex differences – Topological zones

INTRODUCTION

The epidermal ridges patterns on the apical segment of digits, toes and in consistent sites on the palm and sole are formed between the 7th and 21st week of intrauterine life (Milicic *et al.* 2003). A study conducted by Kahn *et al.* (2008) illustrated that during foetal development ridges are influenced by blood vessel-nerve pairs at the border between the dermis and epidermis. Past literature (Sengupta, Karmakar, 2004, Medland *et al.* 2007)

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emphasized that the process of ridge formation was determined by genes as well as the content of the amniotic fluid, whereas genetic factors accounted a large proportion (90 to 95%) in determining ridge number. It was noticed by Kahn *et al.* (2001) that if an adverse fetal exposure were to occur before the middle of gestation this might affect the fingerprints of the offspring. Ridges are extremely narrow in the infants and gradually broadens as the child grows, but exhibiting no alterations in their original characteristics of branching, ending and other details (Cummins, Midlo, 1943). While studying dermal ridge width in the second (palmar) interdigital area with special reference to aneuploid states Penrose and Loesch (1967) found a positive correlation between ridge breadth and stature (men are taller than women), and this is emphasized by the narrower mean breadth reported in subjects with Down's and Turner's syndromes conditions in which stature is much reduced. Observations of Cummins and Midlo (1961) also noted that generally on average females had approximately 2.7±0.09 more ridges to the centimetre as compared to males. The high variability of these configurations makes them potential marker in personal identification, ethnic variations, genetic studies and other biological aspects of dermatoglyphics (Cummins, Midlo, 1961). A study carried out by Acree (1999) provided the first consideration of determination of gender from fingerprint ridge density within a defined area on radial side and observed that women have significantly higher ridge density, hence thinner epidermal ridges than men. The results obtained from various cross-sectional studies (Acree 1999, Nayak *et al.* 2010a, b, Gutierrez-Redomero *et al.* 2013, Dhall, Kapoor 2016, Soanboon *et al.* 2016) also exhibited sex differences with respect to fingerprint ridge density in various populations belonging to different geographic areas, but limited studies (Krishan *et al.* 2013, Dhall, Kapoor 2016) have been carried out at three topological areas in North Indian populations. Hence to gain a deeper understanding the present study intends to examine (i) sex as well as topological differences from fingerprint ridge density, (ii) bimanual differences in fingertip ridge density (iii) correlation of ridge density of all the fingers at three areas under consideration with height in adult population of North India.

MATERIAL AND METHODS

In the present cross-sectional study, 240 subjects (120 males and 120 females) aged between 18 and 24 years were chosen from the Nahan, district Sirmaur of North India. Field work was conducted from 26th September to 3rd October, 2016. The purpose of the study was explained to all the subjects and all the participants gave their verbal consent for the study. Height (cm) of all the participants was measured with anthropometer following the standard technique given by Weiner and Lourie (1981). Participants who were unrelated and healthy selected for the study. Only those subjects who were devoid of any scar, injury or disease on the digits were included in the study. The finger prints of all the participants were taken by simple ink method following Cummins and Midlo (1961). Prior to taking prints subjects were asked to wash and dry their hands, thereafter ink pad was used to spread printers ink evenly on their fingers and then rolled impressions of all the digits was obtained on the white sheet. Their finger prints were taken starting from thumb, index finger, middle finger, ring finger and little finger for both the hands. All the five digits of right and left hand were denoted as R1, R2, R3, R4, R5 and L1, L2, L3, L4, L5 respectively. The ridge density (RD) was assessed on the fingertip on surface area of 25 mm^2 (5 mm × 5 mm square) following the method given by Acree (1999) and ridge counting in the selected area was carried out on the diagonal of the square. Ridge counting was performed at two more counting area (ulnar area in distal part and proximal area) as per the method described by Gutiérrez-Redomero *et al.* (2013) (*Figure 1*).

STATISTICAL ANALYSIS

Statistical analysis using Statistical Package for Social Sciences (SPSS) version 20 was employed to interpret the data. The Mann Whitney U test was employed to find statistical significance of sexual differences. Ridge density of adjacent digits of right and left hand was subjected to Kruskal Wallis test at all the three topological areas to identify statistical significance of the differences. Bimanual distinctions in male and female groups were estimated by the Wilcoxon Signed Rank test. The Karl Pearson's correlation coefficient (r) test was carried out to find the association between height and ridge density of all the fingers at all the topological areas under consideration. Discriminant function analysis was carried out to summarize variation for ridge density in male and female groups. Probability inferences based on fingerprint ridge density values for both the male and female groups was estimated by computation of likelihood ratio (LR). This is expressed as probability of given fingerprint ridge

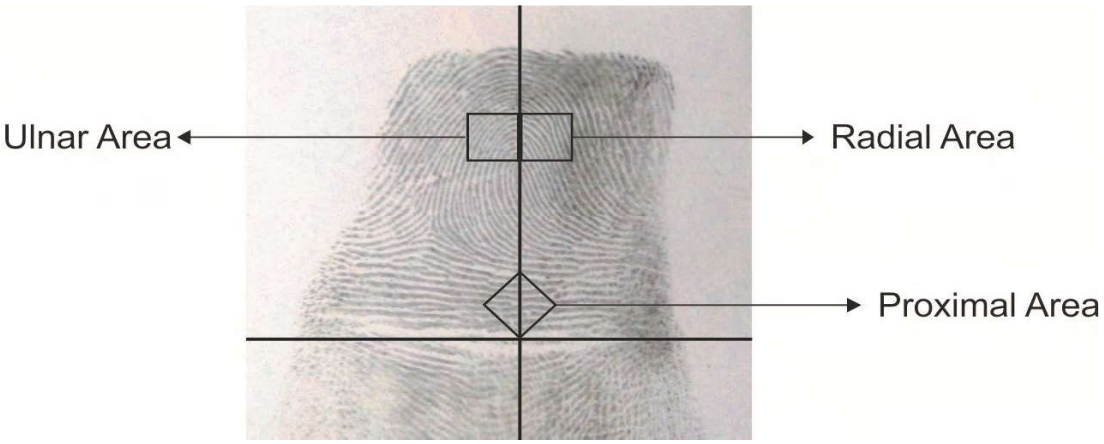


FIGURE 1: Location of different topological areas.

TABLE 1: Descriptive statistics for fingerprint ridge density of each digit in three topological areas in males and females. Level of significance :p < 0.05(*), p< 0.01(**)

SEX(N)	R1	R2	R3	R4	R5	Chi Square	L1	L2	L3	L4	L5	Chi Square
RADIAL REGION												
Males												
MEAN	11.94	11.57	12.07	12.02	11.88	12.69**	11.12	11.20	11.04	11.24	11.55	5.66*
S.D.	1.50	1.36	1.68	1.60	1.54		1.64	1.43	1.61	1.71	1.51	
Females												
MEAN	13.29	13.80	14.26	14.72	14.27	38.20**	13.04	13.72	13.83	13.84	13.75	16.83**
S.D.	1.84	1.87	2.14	1.96	1.59		1.75	1.78	1.79	1.88	1.86	
Z value	**-7.41****	**-9.03****	**-8.62****	**-9.91****	**-9.50****		**-8.18****	**-9.82****	**-9.30****	**-9.19****	**-8.71 ****	
ULNAR REGION												
Males												
MEAN	10.52	10.59	11.39	11.28	11.14	42.70**	10.88	11.05	11.80	12.26	11.74	60.85**
S.D.	1.29	1.28	1.48	1.22	1.30		1.62	1.43	1.43	1.47	1.45	
Females												
MEAN	12.60	12.55	13.42	13.82	13.15	42.11**	13.04	13.49	14.33	14.53	14.29	48.88**
S.D.	1.53	1.67	1.81	1.84	1.76		1.69	1.85	1.81	2.04	1.96	
Z value	-9.40**	-8.73**	-8.50**	-10.06**	-8.78**		-8.77**	-9.48**	-9.75**	-8.68**	-9.42**	
PROXIMAL REGION												
Males												
MEAN	9.55	9.19	9.27	9.58	9.05	10.47**	9.60	9.13	9.03	9.45	8.64	24.99**
S.D.	1.55	1.57	1.61	1.55	1.52		1.60	1.46	1.52	1.58	1.39	
Females												
MEAN	10.55	10.39	10.03	10.80	10.23	16.43**	10.42	10.09	10.19	10.64	9.81	18.77**
S.D.	1.72	1.53	1.58	1.71	1.44		1.58	1.58	1.83	1.47	1.68	
Z value	-5.19**	-5.90**	-3.90**	-5.39**	-5.65**		-3.89**	-4.78**	-5.03**	-5.97**	-5.32**	

density originating from male (C') / probability of given fingerprint ridge density originating from female (C^0).

RESULTS

Descriptive statistics for fingerprint ridge density in radial, ulnar and proximal areas of each digit in both hands of males and females are presented in *Table 1*. In males highest fingerprint ridge density for right hand was observed at digit III in both the radial and ulnar areas. For left hand maximum ridge density was noticed at digit V in radial area and at digit IV in ulnar areas. In proximal region, highest ridge density for right hand was seen in digit IV and for left hand in digit I. In females maximum value for ridge density was noted in digit IV of both right and left hands at all counting areas (radial, ulnar and proximal). Sexual comparisons clearly reflect that females were presenting significantly ($p<0.01$) higher fingerprint ridge density than their male counterparts in all the digits at all the areas analysed in this study. In both the sexes fingerprint ridge density was higher on the distal end of the digits as compared to the proximal end, ridge density gradient in ascending order was proximal < ulnar < radial. Analysis of Kruskal Wallis test concluded that ridge density of adjacent digits show statistically significant differences at all the topological areas analysed as is reflected from their chi-square values (*Table 1*).

Bimanual differences in males as well as females using Wilcoxon signed test are displayed in *Table 2*. Results of Z value showed that significant bimanual differences were observed in most of the digits in radial area and all digits of ulnar regions in both the male and female groups, but they exhibit non-significant bimanual differences in proximal region except at RP5 vs LP5 in both the sexes. Correlation coefficient (r) of height (cm) of males (162.12 cm) and females (156.50 cm) with fingerprint ridge density of right and left hand at three topological regions is summarized in *Table 3*. It is evident from the Table that in males height showed a positive and significant correlation with the ridge density only at L4 in radial area, L2 and L3 in ulnar area and in most of the digits (R2, R3, R4, L2, L3, L5) in proximal area. In females significant association was witnessed in R5, L2, L5 in radial area, L2, L3 in ulnar. In contrast to males, females display no association with height in the proximal area.

Probability of proportions, likelihood ratio and favored odds of males and females in three topological regions (radial, ulnar and proximal) are depicted from *Table 4-6*. In the present study fingerprint ridge density of ≤11 ridges was more likely of male origin, whereas fingerprint ridge density of ≥13 ridges was more likely of female origin in the radial regions. Fingerprint ridge density of ≤ 11 ridges was more likely of male origin, whereas fingerprint ridge density of ≥12 ridges was more likely of female origin in the ulnar area. In regard to the proximal region, fingerprint ridge density of ≤8 ridges and fingerprint ridge density of ≥10 ridges was of greater possibility of male and female origin respectively.

Discriminant function analysis was carried out for both right (*Figures 2-4*) and left hands (*Figure 5-7*) of adult males and females. Right and left hand depicted significant gender differences at radial area (Right hand = Wilks lambda 0.481, Chi-square 172.29 ($p<0.01$)); Left hand = Wilks lambda 0.484, Chi-square

TABLE 2: Bilateral differences between males and females using Wilcoxon signed rank test. Level of significance: $p < 0.05$(*), $p< 0.01$(**). RR1= Right radial digit I, LR1=Left radial digit I, RU1= Right radial digit I, LU1= Left ulnar digit I, RP1= Right proximal digit I, LP1= Left proximal digit I.

	MALES	FEMALES
RADIAL		
RR1 Vs LR 1	-2.325*	-1.233
RR2 Vs LR 2	-2.468*	-0.174
RR3 Vs LR 3	-3.989**	-2.673*
RR4 Vs LR 4	-3.937**	-4.330**
RR5 Vs LR 5	-1.668	-2.484*
ULNAR		
RU 1 Vs LU 1	-2.155*	-2.806*
RU 2 Vs LU 2	-2.795*	-5.045**
RU 3 Vs LU 3	-2.602*	-4.818**
RU 4 Vs LU 4	-5.596**	-3.094*
RU 5 Vs LU 5	-3.602**	-4.972**
PROXIMAL		
RP 1 Vs LP 1	-0.160	-0.980
RP 2 Vs LP 2	-0.515	-1.764
RP 3 Vs LP 3	-1.178	-0.404
RP 4 Vs LP 4	-1.121	-0.800
RP 5 Vs LP 5	-2.774*	-2.353*

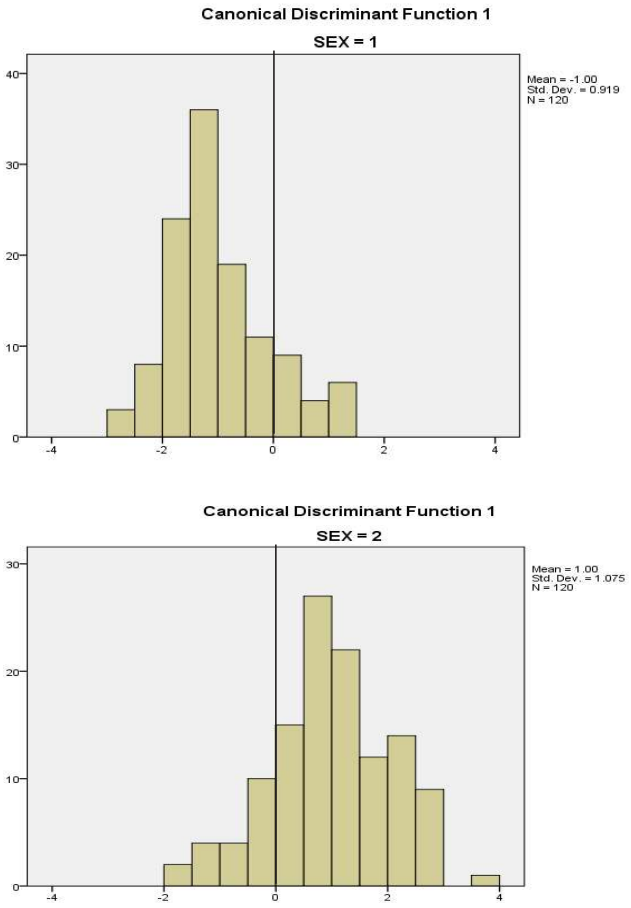


FIGURE 2: Canonical discriminant function analysis of ridge density of males (sex 1) and females (sex 2) for right hand in radial area.

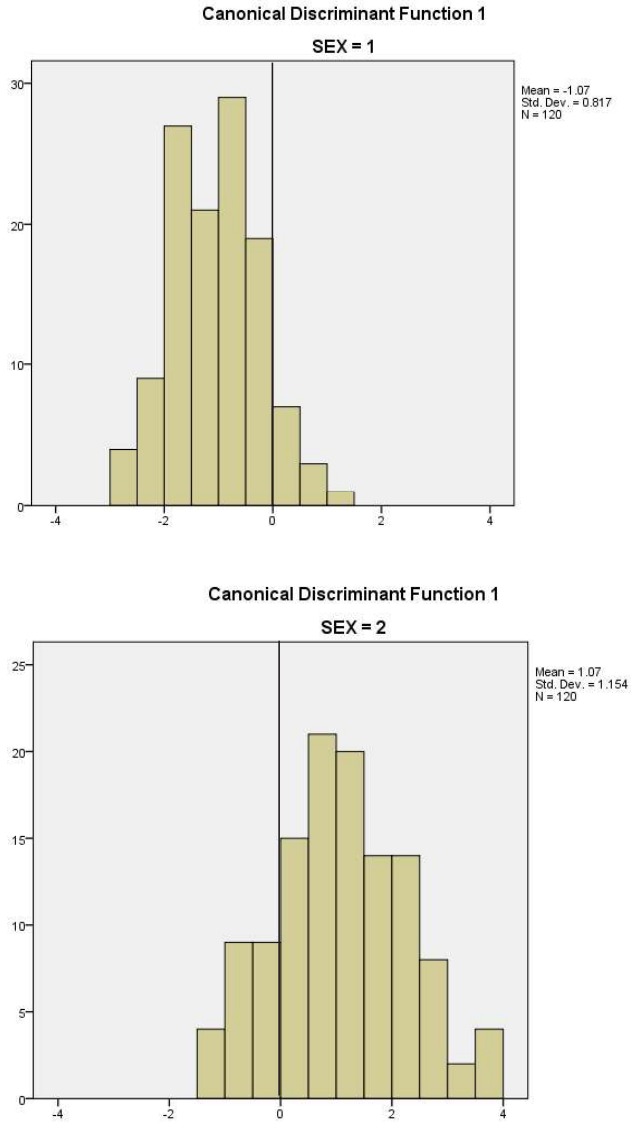


FIGURE 3: Canonical discriminant function analysis of ridge density of males (sex 1) and females (sex 2) for right hand in ulnar area. ▶

170.30 (p<0.01)), Ulnar area (Right hand= Wilks lambda 0.466, Chi-square 179.76 (p<0.01); Left hand= Wilks lambda 0.484,Chi-square 170.40 (p<0.01)), and proximal area (Right hand = Wilks lambda 0.769, Chi-square 61.76 (p<0.01); Left hand = Wilks lambda 0.795, Chi-square 53.92 (p<0.01)).

DISCUSSION

The observed sex differences for all the fingers demonstrated that females had higher ridge density in a defined space as compared to males and differences were statistically significant (p<0.01) at three topological areas. In the present study fingerprint ridge density of ≤11 ridges was more likely of male origin, whereas fingerprint ridge density of ≥13 ridges was more likely of female origin in the radial regions. Fingerprint ridge density of ≤11 ridges was more likely of male origin, whereas fingerprint ridge density of ≥12 ridges was more likely of female origin in the ulnar area. In proximal region, fingerprint ridge density of ≤8 ridges was more likely of male origin and fingerprint ridge density of ≥10 ridges was more likely of female

origin. This conclusion is further strengthened by the results of discriminant function analysis depicting significant ($p<0.01$) sex differences at all valuated areas. Our findings were in accordance with number of previous studies (Acree 1999, Gutierrez-Redomero *et al.* 2013, Nayak *et al.* 2010a, b, Nitin *et al.* 2011, Agnihotri *et al.* 2012, Krishan *et al.* 2013, Dhall, Kapoor, 2016, Ahmed, Osman 2016) highlighting sex differences with respect to digital ridge density on different populations. A study was carried out on Caucasian and African American population by Acree (1999) on a well-defined space in radial area of the digit and noted significantly higher ridge density in women than men. On the basis of Bayes' theorem he inferred that irrespective of population, a ridge density of 11 ridges or less and a ridge density of 12 ridges or greater was most likely to be of male and female origin respectively. Findings of Gutierrez-Redomero *et al.* (2013) emphasized that the females fingerprints showed significantly finer ridges (higher mean counts)

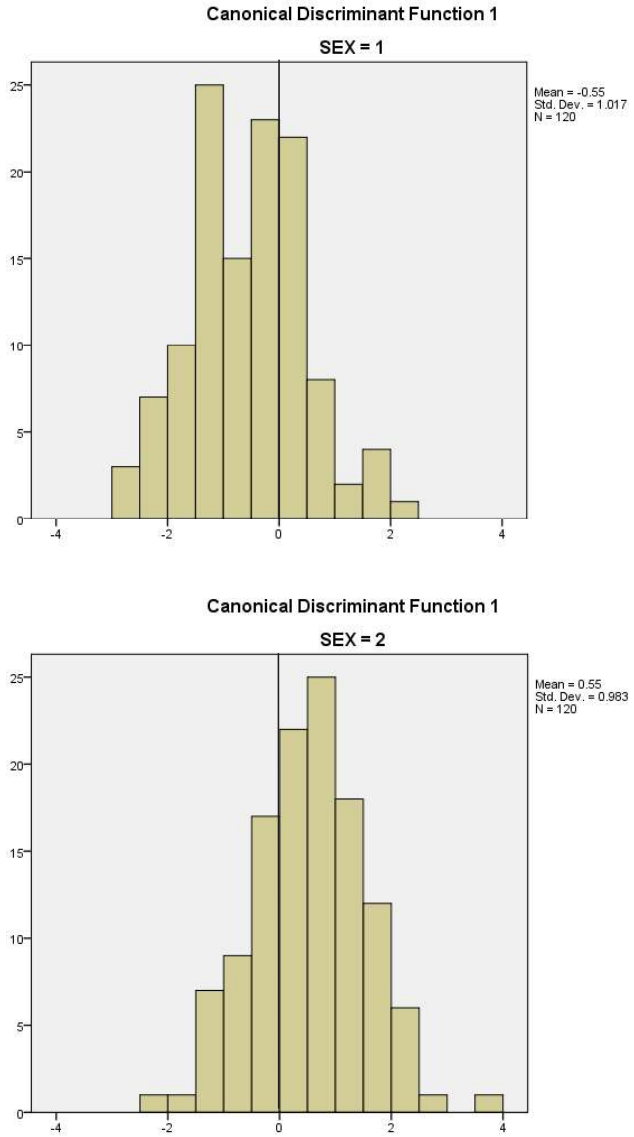


FIGURE 4: Canonical discriminant function analysis of ridge density of males (sex 1) and females (sex 2) for right hand in proximal area.

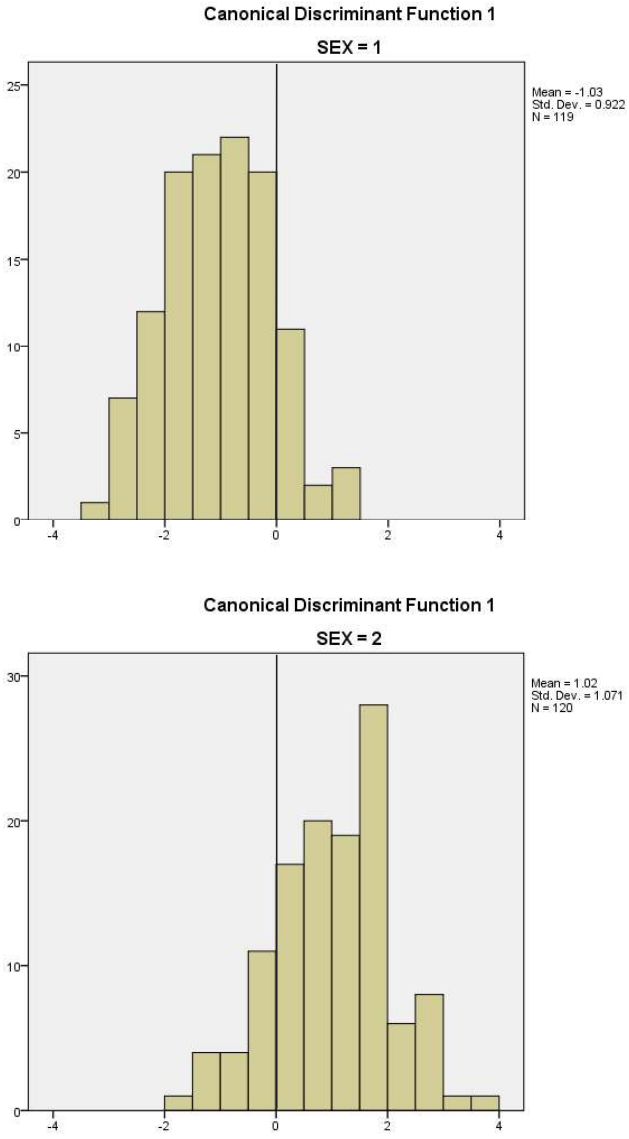


FIGURE 5: Canonical discriminant function analysis of ridge density of males (sex 1) and females (sex 2) for left hand in radial area.

TABLE 3: Correlation coefficient (r) of height (cm) with fingerprint ridge density of right and left hand of males and females at three topological regions. Level of significance :p < 0.05(*), p< 0.01(**).

Right Hand						**Left Hand**				
	R1	**R2**	**R3**	**R4**	**R5**	**L1**	**L2**	**L3**	**L4**	**L5**
Males										
Radial	0.065	0.102	0.024	0.103	0.127	0.050	0.105	0.095	0.259**	0.136
Ulnar	0.122	0.086	0.011	0.007	0.014	0.066	0.197*	0.193*	0.096	0.100
Proximal	0.126	0.229*	0.210*	0.226*	0.123	0.064	0.397**	0.189*	0.167	0.212*
Females										
Radial	0.014	0.054	0.131	0.155	0.188*	0.056	0.250**	0.163	0.122	0.222*
Ulnar	-0.062	0.115	0.175	0.138	0.009	0.083	0.197*	0.190*	0.108	0.147
Proximal	0.066	0.047	0.019	0.083	0.096	0.003	0.021	0.007	0.007	0.084

TABLE 4: Probability of proportions, likelihood ratio and favored odds of adult males and females in radial region.

Ridge count	Frequency Distribution		Probability of Densities		Likelihood ratio		Favoured Ratio	
	Male	Female	Male(C)	Female(C')	Male(C\C')	Female(C'\C)	Male(C)	Female(C')
9	14(11.67%)	-	0.11	0	-	0	1	0
10	48 (40%)	2(1.67%)	0.40	0.01	40	0.025	0.98	0.02
11	39(32.5%)	11(9.17%)	0.32	0.09	3.55	0.28	0.77	0.23
12	16(13.33%)	22(18.33%)	0.13	0.18	0.72	1.38	0.42	0.58
13	3(2.5%)	46(38.33%)	0.02	0.38	0.05	19	0.05	0.95
14	-	33(27.5%)	-	0.27	0	-	0	1
15	-	5(4.17%)	-	0.04	0	-	0	1
16	-	1(0.83%)	-	0.008	0	-	0	1

than males in three topological areas (radial, ulnar and proximal). A study of Dhall and Kapoor (2016) on the basis of discriminant function analysis and logistic regression identified 96.8% and 97.4% accuracy respectively in sex identification from fingerprint ridge density. Recently Soanboom *et al.* (2016) determined sex difference from fingerprint ridge density in north-eastern Thai teenagers and observed that females exhibit higher ridge density i.e. thinner ridges, than males at both radial and ulnar area. An increased ridge density among females may be attributed to ridge breadth, which is approximately 10% more in males as compared to females (Králík, Novotný 2003). Similarly, Cummins and Midlo (1961) also found the sex differences by highlighting that females had approximately 2.7±0.09 more ridges to the centimetre

as compared to their male counterparts. A positive association between thickness of the ridges and number of Y– chromosomes was recorded by Penrose and Loesch (1967).

In our cross-sectional study radial side of the digit had higher ridge density than on the ulnar area in both the sexes at all the counting areas. In contrast the reports of Oktem (2015) showed higher fingerprint ridge density in the ulnar region as compared to the radial region in men, whereas the opposite trend was witnessed in the women. Results showed that significant bimanual differences were observed in most of the digits in radial area and all digits of ulnar regions in both the male and female groups, but they exhibit non-significant bimanual differences in proximal region thereby indicating existence of significant bimanual differences at distal end of the digit, whereas on the proximal sides these differences were non-significant. Even the fingerprint ridge density was higher on the distal end than on the proximal end of the digits. The ascending order of ridge density in right and left hand was proximal<ulnar <radial in both the male and female groups. Our findings are in agreement with past studies (Sengupta, Karmakar 2004, Gutierrez-Redomero *et al.* 2013, Oktem *et al.* 2015) showing a distoproximal gradient trend of fingerprint ridge density and they attributed to broader ridges and wider valleys for reduced ridge density of proximal area.

Ridge density of both the male and female groups demonstrated a positive and significant association with height only at certain digits and this finding suggest that ridge density has little effect on the stature of an individual. Findings of Cummins and Midlo (1961) also documented that females are shorter in terms of height than male consequently their ridges are also narrower. They also inferred that men are taller than women, thereby having more ridge breadth (less ridge density) than their female counterparts. Our results could not confirm the findings of a recent study of Kaur and Sharma (2016) exhibiting insignificant correlation between ridge densities and stature, subsequently affirming that genetics of ridge density is independent of stature. Further studies are needed to confirm the relationship of ridge density with stature.

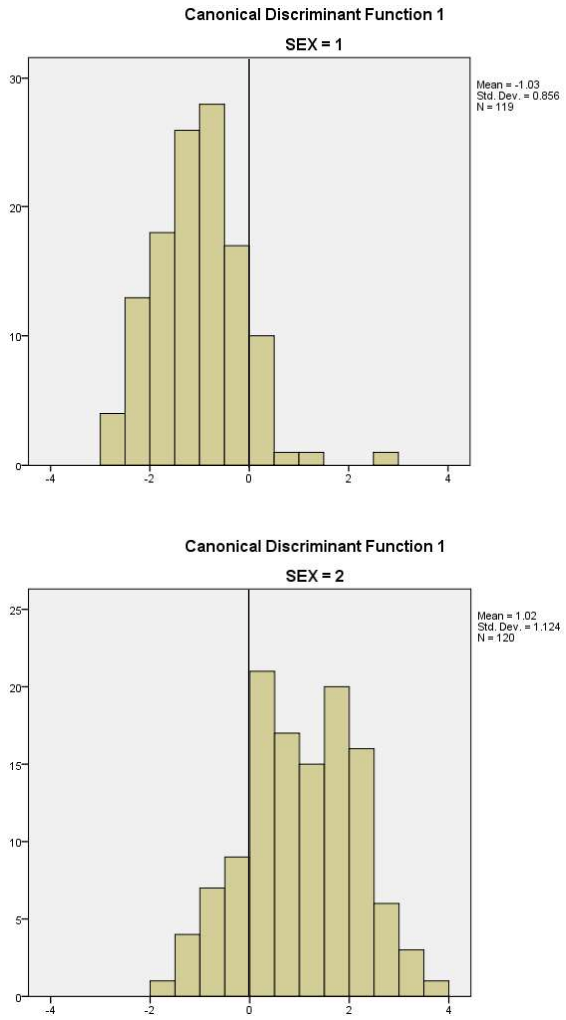
To assess inter as well as intra population variability present sample have been compared with various previous studies on different populations (*Table 7*). Most of the earlier work had been performed on the radial area only, so the comparative account was summarized with respect to this area only. In radial area, males and females of present study displayed lower ridge density than Spanish (Gutierrez-Redomero

TABLE 5: Probability of proportions, likelihood ratio and favoured odds of adult males and females in ulnar region.

Ridge count	Frequency Distribution		Probability of Densities		Likelihood ratio		Favoured Ratio	
	Male	Female	Male(C)	Female(C')	Male(C\C')	Female(C'/C)	Male(C)	Female(C')
8	1(0.83%)	-	0.01	0	-	0	1	0
9	17(14.17%)	-	0.14	0	-	0	1	0
10	51(42.5%)	3(2.5%)	0.42	0.02	21	0.05	0.94	0.06
11	45(37.5%)	19(15.83%)	0.37	0.16	2.31	0.43	0.70	0.3
12	5(4.17%)	35(29.17%)	0.04	0.29	0.14	6.90	0.13	0.87
13	1(0.83%)	36(30%)	0.01	0.3	0.03	30	0.03	0.97
14	-	22(18.33%)	-	0.18	0	-	0	1
15	-	4(3.3%)	-	0.03	0	-	0	1
16	-	1(0.83%)	-	0.01	0	-	0	1

TABLE 6: Probability of proportions, likelihood ratio and favoured odds of adult males and females in proximal region.

Ridge count	Frequency Distribution		Probability of Densities		Likelihood ratio		Favoured Ratio	
	Male	Female	Male(C)	Female(C')	Male(C\C')	Female(C'/C)	Male(C)	Female(C')
6	3(2.5%)	-	0.025	0	-	0	1	0
7	24(20%)	1(0.83%)	0.2	0.00	-	0	1	0
8	43(35.83%)	24(20%)	0.35	0.2	1.75	0.57	0.64	0.36
9	35(29.17%)	41(34.17%)	0.29	0.34	0.85	1.18	0.46	0.54
10	14(11.67%)	39(32.5%)	0.11	0.33	0.33	3	0.26	0.74
11	1(0.83%)	15(12.5%)	0.00	0.12	0	-	0	1



et al. 2008), Egyptian (Eshak *et al.* 2013), Filipinos (Tadurana *et al.* 2016), Chinese (Nayak *et al.* 2010a, b), Sudanese (Ahmed, Osman 2016), Uttrakhand (Kumar *et al.* 2013), Marathi (Kapoor, Badiye 2015), Karnataka (Gungadin 2007), Mysore (Nitin *et al.* 2011) and Palampur (Krishan *et al.* 2013) populations. Fingerprint ridge density of Nahan population was found to be higher than Caucasian and African American (Acree 1999) and Malaysian population (Nayak *et al.* 2010a, b).

Some population variability may be attributed to use of different methodologies particularly the selection of counting regions employed to assess fingerprint ridge density on the digit and some variations may be accounted to the genetic component also. From the perusal of all these populations it could be generalised that irrespective of ethnic or population group or methodological differences, females presented higher fingerprint ridge density as compared to males in each of the designated areas.

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FIGURE 6: Canonical discriminant function analysis of ridge density of males (sex 1) and females (sex 2) for left hand in ulnar area.

TABLE 7: Mean and standard deviation of fingerprint ridge density in different studies for radial, ulnar and proximal areas of males and females.

POPULATION	SEX	FINGERPRINT RIDGE DENSITY			REFRENCES
		RADIAL AREA	ULNAR AREA	PROXIMAL AREA	
INTERNATIONAL STUDIES					
Caucasian	M	11.14 (1.31)	-	-	Acree 1999
population	F	13.32 (1.24)	-	-	
African American	M	10.90 (1.15)	-	-	Acree1999
population	F	12.61 (1.43)	-	-	
Egyptian population	M R.H.	20.86 (2.34)	-	-	Eshak *et al.* 2013
	L.H.	20.15 (2.15)	-	-	
	F R.H.	21.30 (2.43)	-	-	
	L.H.	21.43 (3.37)	-	-	
Spanish population	M	16.23 (1.39)	-	-	Gutierrez-Redomero *et al.* 2008
	F	17.91 (1.47)	-	-	
Filipinos	M	14.57 (1.43)	13.10 (1.27)	11.39 (1.54)	Taduran *et al.* 2016
population	F	15.89 (1.69)	14.22 (1.51)	11.97 (1.70)	
Chinese	M	11.73 (1.07)	-	-	Nayak *et al.* 2010b
population	F	14.15 (1.04)	-	-	
Malaysian	M	11.44 (0.99)	-	-	Nayak *et al.* 2010b
population	F	13.36 (0.91)	-	-	
Sudanese	M	12.80 (0.92)	13.02 (0.90)	9.75 (0.80)	Ahmed, Osman 2016
population	F	14.50 (1.18)	14.73 (1.25)	10.80 (0.93)	
NATIONAL STUDIES					
Uttrakhand	M	11.9 (0.9)	-	-	Kumar *et al.* 2013
population	F	14.10 (1.0)	-	-	
Marathi	M	11.58 (1.46)	11.82 (1.37)	-	Kapoor, Badiye 2015
population	F	14.60 (1.6)	14.56 (1.5)	-	
Karnataka	M	12.80 (0.90)	-	-	Gungadin 2007
population	F	14.60 (0.09)	-	-	
Palampur	M	15.84 (1.23)	15.51 (1.08)	11.29 (1.11)	Krishan *et al.* 2013
population	F	17.94 (1.23)	17.11 (1.207)	12.05 (0.87)	
Mysore	M	12.57 (1.49)	-	-	Nitin *et al.* 2011
population	F	14.15 (1.68)	-	-	
	F	14.20 (0.63)	-	-	
Nahan population	M	11.55 (0.91)	11.26 (0.79)	9.33 (1.31)	Present study
	F	13.86 (1.08)	13.52 (1.14)	10.32 (0.92)	

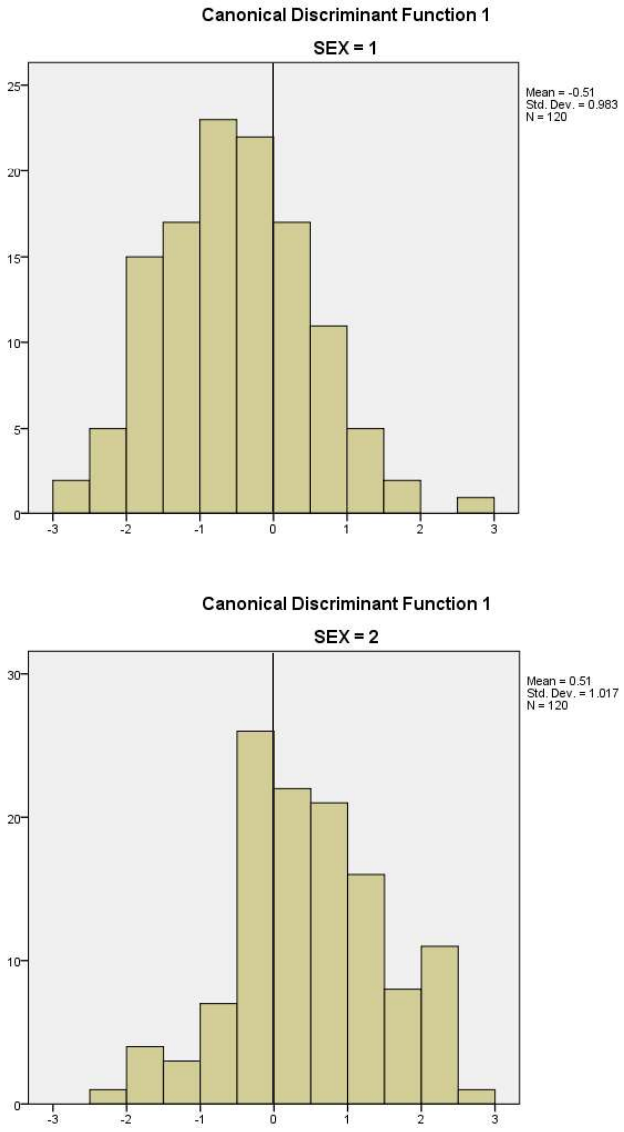

FIGURE 7: Canonical discriminant function analysis of ridge density of males (sex 1) and females (sex 2) for left hand in proximal area.

CONCLUSION

Hence the present cross-sectional study on sexual and topological distinction of adult males (N=120) and females (N =120) of Nahan (North India) concluded that females had significantly ($p<0.001$) higher fingerprint ridge density than males at radial, ulnar and proximal topological areas. Both the sexes revealed a disto-proximal gradient of fingerprint ridge density i.e proximal<ulnar <radial in both the hands. Findings of our study identified application of fingerprint ridge density in the field of forensic science in inferring sex of an unknown mutilated remains brought for medico-legal examination.

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REFERENCES

ACREE M. A., 1999: Is there a gender difference in fingerprint ridge density? *Forensic Sci Int*. 102: 35–44.

AGNIHOTRI A. K., JOWAHEER V., ALLOCK A., 2012: An analysis of fingerprint ridge density in the Indo-Mauritian population and its application to gender determination. *Med Sci Law*. 52, 3:143–147. doi: 10.1258/msl.2012.011093.

AHMED A. A., OSMAN S., 2016: Topological variability and sex differences in fingerprint ridge density in a sample of the Sudanese population. *J Forensic Leg Med*. 42: 25–32. doi: 10.1016/j.jflm.2016.05.005.

CUMINS H., MIDLO C., 1961: *Fingerprints, Palms and soles. An introduction to Dermatoglyphics*. New York: Dover publication.

DHALL J., KAPOOR A. K., 2016: Fingerprint Ridge Density as a Potential Forensic anthropological Tool for Sex Identification. *Journal of Forensic Sciences* 61, 2: 424–429. doi: 10.1111/1556-4029.12959

ESHAK G. A., ZAHER J. F., HASAN E. I., EL-AZEEM EWIS A. A., 2013: Sex identification from fingertip features in Egyptian population. *J Forensic Leg Med* 2, 20: 46–50. doi: 10.1016/j.jflm.2012.04.038.

GUNGADIN S., 2007: Sex determination from fingerprint ridge density. *Int. J. Med. Update* 2,2: 1–4.

GUTIERREZ-REDOMERO E., ALONSO C., ROMERO E., GALERA V., 2008: Variability of fingerprint ridge density in a sample of Spanish Caucasians and its application to sex determination. *Forensic Science International* 180: 17–22.

GUTIERREZ-REDOMERO E., SANCHEZ-ANDRES A., RIVALDERÍA N., ALONSO-RODRÍGUEZ M. C., DIPIERRI J. E., MARTÍN L. M. A., 2013: Comparative study of topological and sex differences in fingerprint ridge density in Argentinian and Spanish population samples. *J Forensic Leg Med*. 20, 5: 419–429. doi: 10.1016/j.jflm.2012.12.002.

KAHN H. S., RAVINDRANATH R., VALDEZ R., VENKAT NARAYAN K. M., 2001: Fingerprint Ridge-Count Difference between Adjacent Fingertips (dR45) Predicts Upper-Body Tissue Distribution: Evidence for Early

Gestational Programming. *American Journal of Epidemiology* 153, 4: 338–344.

KAHN H. S., GRAFF M., STEIN A. D., ZYBERT P. A., MCKEAGUE I. W., LUMEY L. H., 2008: A fingerprint characteristic associated with the early prenatal environment. *Am. J. Human Biol.* 20, 1:59 –65.

KAPOOR N., BADIYE A., 2015: Sex differences in thumb print ridge density in a central Indian population. *Egypt J Forensic Sci.* 5,1: 23–29. https://doi.org/10.1016/j.ejfs.2014.05.001

KAUR M., SHARMA K., 2016: Dermal digital ridge density of a penal population: Analysis of association and individualization. *Journal of Forensic and Legal Medicine* 44:143–149. doi: 10.1016/j.jflm.2016.10.011.

KRÁLÍK M., NOVOTNÝ V., 2003: Epidermal ridge breadth: an indicator of age and sex in a Paleo dermotoglyphics. *Var Evol.* 11: 5–30.

KRISHAN K., KANCHAN T., NGANGOM C., 2013: A study of sex differences in fingerprint ridge density in a North Indian young adult population. *J. Forensic Leg. Med.* 20, 4: 217–222. https://doi.org/10.1016/j.jflm.2012.09.008

KUMAR L., AGGARWAL S., GARG R., PRATAP A., MISHRA V. K., 2013: Gender determination using fingerprints in the region of uttrakhand. *J Indian Acad Forensic Med.* 35,4: 308–311.

MALTONI, D., MAIO, D., JAIN, A. K., PRABHAKAR, S., 2003: *Handbook of Fingerprint Recognition*. Springer Verlag. New York.

MEDLAND S. E., LOESCH D. Z., MDZEWSKI B., ZHU G., MONTGOMERY G. W., MARTIN N. G. 2007: Linkage analysis of a model quantitative trait in humans: finger ridge count shows significant multivariate linkage to 5q14.1. *PLos Genet* 3(9):e165. https://doi.org/10.1371/journal.pgen.0030165

MILICIC J., PETKOVIC Z. B., BOŽIKOV J., 2003: Dermatoglyphs of Digito-Palmar Complex in Autistic Disorder: Family Analysis. *Croatian Medical Journal* 44: 469–476.

NAYAK V. C., RASTOGI P., KANCHAN T., LOBO S. W., YOGANARASIMHA K., NAYAK S., RAO N. G., PRADEEP KUMAR G., SURESH KUMAR SHETTY B., MENEZES R. G., 2010a: Sex differences from fingerprint ridge density in the Indian population. Journal of Forensic and Legal Medicine 17, 2: 84–86. https://doi.org/10.1016/j.jflm.2009.09.002

NAYAK V. C., RASTOGI P., KANCHAN T., YOGANARASIMHA K., KUMAR G. P., MENEZES R. G. 2010b: Sex differences from fingerprint ridge density in Chinese and Malaysian population. *Forensic Sci Int.* 197, 1–3: 67–69. https://doi.org/10.1016/j.forsciint.2009.12.055

NITIN M. D., MANJUNATHA B., PREETHI D. S., BALARAJ B. M., 2011: Gender differentiation by finger ridge count among south Indian population. *Forensic Leg Med.* 18, 2: 79–81. https://doi.org/10.1016/j.jflm.2011.01.006

OKTEM H., KURKCUOGLU A., PELIN I. C., YAZICI A. C., AKTAŞ G., ALTUNAY V., 2015: Sex differences in fingerprint ridge density in a Turkish young adult population: A sample of Baskent University. *Journal of Forensic and Legal Medicine* 32: 34–38. doi: 10.1016/j.jflm.2015.02.011.

PENROSE L. S., LOESCH D. A., 1967: Study of dermal ridge width in the second (palmar) inter digital area with special reference to aneuploid states. *J. Mental Defic. Res.* 11: 36–42.

SENGUPTA M., KARMAKAR B., 2004: Mode of inheritance of finger dermatoglyphic traits among Vaidyas of West Bengal, India. *Ann Hum Biol.* 31: 526–540.

SHARMA P., GAUTAM A., TIWARI P., 2008: Dermatoglyphic variations in five ethno-geographical cohorts of Indian populations: A Pilot study. *The Internet Journal of Biological Anthropology* 2, 1: 1–7.

SOANBOOM P., NANAKORN S., KUTANAN W., 2016: Determination of sex difference from fingerprint ridge density in northern Thai Teenagers. *Egyptian Journal of Forensic Sciences* 6, 2: 185–193. https://doi.org/10.1016/j.ejfs.2015.08.001

TADURAN R. J., TADEO A. K., ESCALONA N. A., TOWNSEND G. C. 2016: Sex determination from fingerprint ridge density and white line counts in Filipinos. *HOMO* 67, 2: 163–171. DOI: 10.1016/j.jchb.2015.11.001

WEINER J. S., LOURIE J. A., 1981: *Practical Human Biology*. Academic Press, London.

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