Acta Biomed 2021; Vol. 92, N. 5: e2021366 DOI: 10.23750/abm.v92i5.11471

Review

Sex estimation from fingerprint ridge density. A review of literature

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Abstract. Identification has always been very vital in forensic casework. Fingerprint patterns are population-specific and individualistic, that makes fingerprinting an important biological trait in human biology and forensics. Fingerprint is an impression of the friction ridges of the finger-ball, where friction ridges are raised portions of the epidermis. Skin on human fingertips contains ridges and valleys which together forms distinctive patterns. These patterns are fully developed in intra-uterine life and remain unaltered until the death of the individual. Injuries such as cuts, burns and bruises can temporarily damage quality of fingerprints but when fully healed, the patterns are restored. The number of ridges present in a unit area on a fingerprint is called the Fingerprint Ridge Density (FPRD). The epidermal ridge density can be determined by examining two parameters - ridge width and distance between the ridges. The thickness of the epidermal ridges varies between individuals and between the sexes. The present review of literature focuses on the sexual dimorphism on the basis of the FPRD and its possible use in forensic examinations. Most of the studies pertaining to the estimation of sex from the FPRD have been conducted in the last two decades when Mark A. Acree in 1999, devised a method of estimation of sex on Caucasian and African-American descent. The present analysis evaluates the studies found in the PubMed database conducted after Acree, 1999. The estimation of sex from the FPRD is based upon the fact that the females have a fine detailing of ridges and consequently more ridges are covered in a unit space in the fingerprints of females as compared to males. The paper also highlights recent advancements and future perspectives in the area of FPRD. (www.actabiomedica.it)

Key words: Fingerprinting, Ridge density, Identification, sexual dimorphism, Fingerprint Ridge Density (FPRD)

An Overview of Fingerprint Ridge Density (FPRD)

Identification is an important part of criminal investigation, and includes identification of perpetrators in addition to identification of the victims. Evidence collected from crime scenes vary depending on the nature and locality (1). However, fingerprints are ubiquitous due to the use of hands to do all types of work. Fingerprints may be found on a variety of items, including window glasses, utensils, door handles, knifes, car steering, guns, sticks and even human skin itself (2).

Fingerprint is an impression of the friction ridges of the finger-ball. Epidermal ridges possess a characteristic pattern that is unique and individual but at the same time, exhibit class or population differences. These patterns, especially when only partial prints are available, can greatly assist in the identification process. In addition, friction ridge patterns also show association with diseases (3,4).

FPRD can be defined as the number of ridges present in a unit area of a fingerprint (5,6). It can also be stated as the ridge count present in a defined area (7). The epidermal ridge density can be determined by examining the following two parameters:

i. Ridge width
ii. Distance between ridges.

The thickness of epidermal ridges varies among individuals and shows difference based on sex (5,6). FPRD has been shown to be less in males than in females. This is because males exhibit larger body proportions than females, with greater surface area, resulting in similar number of ridges being distributed over a larger surface. This phenomenon has been studied to establish sexual dimorphism of FPRD in humans (7). Moreover, the females are considered to have finer ridge details on their fingers, hence more ridge counting in females than the males in a defined space of a fingerprint area.

However, the studies have shown that the sexual dimorphism is population specific and therefore limits its use without further research on ethnically diverse populations. Ethnicity, environment, nutrition, socio-economic status, genetics and altitude are the other factors, which differentiate populations, even in the same geographical location, and have been shown to cause variations in FPRD (8,9).

Review of Literature on FPRD

Acree (10) conducted a study on 400 subjects from the files of the Homewood Police Department located in Homewood, Alabama, USA. He analysed fingerprints on randomly picked ten-print cards of 400 individuals (i.e. 200 Caucasian males and females, 200 Africa American males and females) all within the age range of 18–67 years. His results showed that women have significantly higher ridge density than men. He found that fingerprints possessing a ridge density of 11 ridges/25mm^2 or less is likely to be of male origin. Similarly, a fingerprint having ridge density of 12 ridges/25mm^2 or greater is likely to be of female origin (10). Subsequent studies on the analysis of FPRD and its forensic evaluation have been based on this study.

Gutiérrez-Redomero et al. (5) studied 200 subjects (100 males and 100 females) in a Spanish-Caucasian population and analysed the variability of FPRD and its application in sex determination. The FPRD was found to be 16 ridges/25 mm^2 or less which is most likely to be found in male and 17 ridges/ 25 mm^2 or more is to be found in females. They established that women represent higher ridge density than men and have finer ridges. Inter-digital ridge density was also found to be significant i.e. thumb and index finger exhibited lower ridge density than the other three fingers (5).

Nayak et al. (11) analysed the sex differences in Indian population from FPRD by evaluating 100 males and 100 females. The study found statistically significant differences in FPRD in male and female fingerprints. Ridge density for females ranged from 12 to 15.9 ridges/ 25mm^2 with a mean of 14.198 ridges/25 mm^2 and for males from 9.6 to 12.5 ridges/25 mm^2 with a mean of 11.049 ridges/25mm^2. Thus, females were found to have significantly higher ridge density than males. The degree of ridge densities can be used as a presumptive indicator of sex of an unknown print left at the crime scene. However, this study has a serious limitation in that fingerprints from all ten fingers are required (11).

In an another comparative study between Chinese and Malaysian population was also conducted by Nayak et al.(12), where data was collected on a sample of 200 Chinese (100 males and 100 females) and 100 Malaysian (50 males and 50 females) subjects aged between 18 and 25 years. All the subjects were studying in various institutions affiliated to Manipal University, India. The study was conducted with an objective to find the racial and sexual differences in FPRD. They observed that mean FPRD of 12 ridges/25 mm^2 or less is likely to belong to males and a mean ridge density of more the 13 ridges/25 mm^2 is likely of female origin in Chinese subjects. Similarly, FPRD of 11 ridges/25 mm^2 or less is likely to belong to males and a mean ridge density more than 13 ridges/25 mm^2 is likely of female origin in Malaysian subject (12).

Gutiérrez-Redomero et al. (6) conducted a study on 209 subjects (99 males and 110 females) and analysed the variation in FPRD based on sex, age and topology in Mataco-Mataguayo and Spanish populations and determined the extent of sexual dimorphism in ridge density and age at which it appears. The results indicated that sexual dimorphism in ridge breadth is established at the beginning of adolescence, after the age of 12 years, with females having higher ridge density. The FPRD mean in Spanish population in the entire three areas i.e.in Radial region the ridge density mean of males is 16.23 ridges / 25 mm^2 or less while in females it is 17.91 or more. In Ulnar region the ridge density mean in case of males is 15.31 ridges/ 25 mm^2 or less whereas 16.38 ridges/ 25 mm^2 or more in females. In Proximal region, the ridge density is 11.87 ridges / 25mm^2 in males and 11.96 ridges / 25 mm^2 in females In case of Mataco-Mataguayo population, the ridge density in all the three regions are Radial region (Males – 16.62 ridges/ 25 mm^2 or less and Females-17.82 and more) while in case of Ulnar and Proximal region, the ridge density distribution is as (Males have a ridge density as 16.54 ridges/ 25 mm^2 and a ridge density of 17.29 ridges/ 25 mm^2 in females) and (Males with a ridge density of 14.20 ridges /25 mm^2 and in females with a ridge density of 14.63 ridges/ 25 mm^2). They also found that ridge density decreased with age and was higher on the distal (radial and ulnar) areas, as compared to the proximal area. The study confirmed variations in ridge density based on sex, age and topology and further postulated developmental differences as the reason for such variations (6).

Nithin et al. (13) evaluated 550 subjects (275 men and 275 women) within the age range of 18 to 65 years, belonging to South Indian population, to study sex estimation by finger ridge count. This study showed that a fingerprint possessing ridge density less than 13 ridges/25 mm^2 is likely to be of male origin and a fingerprint having ridge count greater than 14 ridges/25 mm^2 is likely to be of female origin (13).

Krishan et al. (7) studied the sex differences in FPRD in North Indian young adults. The study was conducted on 194 individuals (97 males and 97 females) aged between 18 and 25 years. It was found that FPRD in the ulnar (Males = 15.51, Females = 17.11) and radial (Males= 15.84, Females =17.94) areas of the fingerprints were significantly higher than in the proximal area (Males 11.29 and Females= 12.05). In this study, various statistically significant differences were observed between males and females (7).

Gutierrez-Gutiérrez-Redomero et al. (14) conducted a comparative study on 393 individuals from three regions i.e., Puna, Quebrada and Ramal in with 193 subjects (100 males and 93 females) from Puna-Quebrada region and 200 subjects from Ramal (100 males and 100 females) examining FPRD of Argentinean and Spanish population living at different altitudes. The FPRD in the radial area for Ramal Population was found to be 17.04 in males and 19.08 in females. Similarly, the FPRD in ulnar region was found to be 16.10 in males and 17.75 in females. In contrast, the ridge density in the proximal region was found to be significantly lower, with 14.08 in males and 15.12 in females.

In the Puna-Quebrada Population, the FPRD in radial area was found to be 16.67 in males and 18.47 in females. Similarly, the FPRD in ulnar area was found to be 16.39 in males and 17.62 in females. In contrast, the FPRD in the proximal area was found to be 14.33 in males and 16.13 in females. Along with sex and ethnic variations, this study also confirmed intra-digital ridge variability in fingerprints of the same hand. Fingers on the radial side (Thumb and index finger) were found to have thicker ridges when compared to the ridges on the fingers of the ulnar side (ring and little fingers) (14).

Eshak et al. (15) studied a sample of 752 Egyptians (380 females and 372 males) for estimation of sex. They examined four parameters – ridge count, square area, finger breadth and ridge density. Multivariate logistic regressions were used for statistical analysis. In their study, the authors found that females exhibited narrower finger breadth, smaller square area, more ridge count and higher ridge density than males. The study found that males tend to have lower FPRD (20.500 ± 1.974) as compared to females (21.364 ± 2.652) The study also found that fingerprints of the left hand were more accurate in the estimation of sex (15). Gutiérrez-Redomero et al. (16) conducted a study to examine the differences between the ridge densities of fingerprints based on the area of counting and the procedures of obtaining the fingerprints, plain and rolled. Fingerprints were obtained from 102 Spanish adults (50 males and 52 females) using the plain method and rolled method. It was observed that the position of the counting area, the ridge density values on the core region were higher than those on the outer region, in both sexes. The mean FPRD in radial area was found to be 16.85 ridges/25 mm^2 in males and 19.11 ridges/25

mm^2 in females. The mean FPRD in the ulnar area was found to be 15.38 ridges/25 mm^2 in males and 16.84 ridges/25 mm^2 in females. Meanwhile, the mean FPRD in the proximal area was found to be 12.62 ridges/25 mm^2 in males and 13.76 ridges/25 mm^2 in females. The study also found that thumbs showed the greatest difference between the sexes. It was also observed that females have a higher ridge density than males in all the areas and all fingers (16).

Rivalderia et al. (17) evaluated a sample of two Argentinean population with a total of 335 individuals, to estimate the topological, digital, bilateral, sexual and population differences in FPRD. Out of 335 individuals, 172 individuals (83 males and 89 females) were natives of Buenos Aires and 163 individuals (83 males and 80 males) were natives of Chubut. Fingerprints were obtained by using an adhesive and graphite methods. In this study it was observed that females have a greater ridge density than that of the males in all the areas and on all the fingers.

In the Buenos Aires population, the FPRD in the ulnar area was found to be significantly lower in males (≤14.96) than females (≥17.00). Similarly, the FPRD in the radial are was found to be lower in males (≤15.56) than in females (≥17.82). The FPRD in the proximal area was also found to be significantly lower in males (13.27) than in females (14.27).

Similarly, in the Chubut population, FPRD in the radial region was found to be 16.08 in males and 18.36 in females. The FPRD in ulnar region was also found to be 14.65 in males and 16.58 in females. Similarly, the FPRD in the Proximal Region was found to be 14.07 in males and 14.78 in females.

The study found that the FPRD was highest at the radial area, followed by the ulnar area and the proximal area. The study also showed that females have a higher ridge density than males, and that examination of sexual dimorphism could be useful in establishing the identity of a suspect (17).

Soanboon et al. (18) studied native North-Eastern Thais aged between 12 to 24 years. Fingerprints, from 353 volunteers (191 males and 162 females) were classified into three groups on the basis of age. In group A, the FPRD in the radial and ulnar regions were found to be 12-18 ridges/25 mm^2 and 12-20 ridges/25 mm^2 among males and 14-20 ridges/25 mm^2 and 13-21 ridges/25 mm^2 in females respectively. In group B, the FPRD was found to be 13-18 ridges/25 mm^2 in radial area and 14-20 ridges/25 mm^2 in ulnar area, in males. In females of group B, it was found to be 15-20 ridges/25 mm^2 and 15-21 ridges/25 mm^2 in radial and ulnar areas respectively. In group C, the FPRD in males was found to be 12-17 ridges/25 mm^2 and 12-18 ridges/25 mm^2 in radial and ulnar areas respectively, whereas in females it was found to be 14-19 ridges/25 mm^2 in the radial area and 13-20 ridges/25 mm^2 in the ulnar area. They also found that females exhibit higher FPRD than males. Ridge density variations were found between different populations i.e., Thais, Indians and Sub-Saharans and were attributed to genetically diverse origins (18). Ahmed and Osman (19) analysed the Sudanese-Arab population to study topological variations in ridge density to help determine the sex. The prints were taken from the 200 individuals (100 male and 100 females) in an age group between 18 to 28 years. It was observed that females had a higher FPRD than males in all three regions (i.e. radial, ulnar and proximal). The FPRD in the radial region was found to be 12.80 in males and 14.50 in females. In the ulnar region, the FPRD was found to be 13.02 in males and 14.73 in females. The FPRD was found to be significantly lower in the proximal area, with males having mean FPRD of 9.75 and females having mean density of 10.80 (19). Taduran et al. (20) conducted a study on 400 Filipino subjects (200 males and 200 females) aged between 18 and 57 years. The FPRD in the radial area was found to be 14.57 ridge/25 mm^2 in males and 15.89 ridges/25 mm^2 in females, while, in the ulnar area, it was found to be 13.10 ridges/25 mm^2 in males and 14.22 ridges/ 25 mm^2 in females. The FPRD in the proximal area was found to be lower, with males having 11.36 ridges/25 mm^2 and females having 11.97 ridges/ 25 mm^2 . This study also showed that females have finer ridges and therefore have higher ridge density than males (20).

Kumar et al. (21) studied 200 South Indian individuals (100 male and 100 females) with an age range of 18 to 65 years. The ridge density in the radial region was found to be 13.56 ridges/25 mm^2 in males and 16.92 ridges/25 mm^2 in females. This particular study showed that males have coarser ridges and females have finer ridges, leading to less ridge density in males than in females (21). Thakar et al. (22) conducted a study in Punjab, examining the fingerprints of 400 subjects (200 males and 200 females), ranging from 16 to 18 years. In this age specific study, only the index and middle fingers were assessed for the fingerprint ridge density. In the index finger, the mean ridge density was found to be 12.32 ridges/25mm^2 in males and 13.94 ridges/25mm^2 in females. Meanwhile, in the middle finger, the mean ridge density was found to be 12.7 ridges/25mm^2 in males and 13.22 ridges/25mm^2 in females. The study found that females have higher ridge density in both index and middle fingers (22).

Andres et al. (23) evaluated the fingerprints of 213 Spanish adults (both males and females). The participants were divided into two groups based on their age – Junior group (18 – 30 years) and Senior group (55-60 years).The ridge density was recorded from the radial, ulnar and proximal areas on the distal ends of each finger. In the Junior Group, the FPRD in the radial area in males was found to be 16.19 ridges/25mm^2 in females. Similarly, in the ulnar region, it was found to be 14.63 ridges/25mm^2 in males and 16.44 ridges/25mm^2 in females. Meanwhile, in the proximal region, it was found to be 12.25 ridges/25mm^2 in males and 13.27 ridges/25mm^2 in females. It was found that the FRD was significantly lower in males as compared to females. In the Senior Group, the FPRD in the radial area was found to be 14.22 ridges/25mm^2 in males and 15.81 ridges/25mm^2 in females. Similarly, in the ulnar region, it was found to be 12.81 ridges/25mm^2 in males and 14.25/25mm^2 in females. Lastly, in the proximal region, it was found to be 12.07 ridges/25mm^2 in males while 13.05 ridges/25mm^2. The study showed that FPRD was higher in females than in males, with highest density in the radial area, followed by the ulnar and lastly the proximal areas (23).

Systematic Analysis of Studies on determination of sex from Fingerprint Ridge Density

Estimating the sex is an important aspect in confirming the individual's identity. This is a peculiar characteristic which can be used to confirm inclusion or exclusion of one-half of the population. Most studies follow the data collection method for obtaining the prints through ink-staining and rolling method described by Cummins and Midlo (24). The rolling method is used by all researchers because it includes all three regions, namely, radial, ulnar and proximal.

All studies in the last 20 years, analyse the FPRD using the counting method as described by Acree. After obtaining the print, the ridges are counted under a magnifying lens, in a diagonally square area measuring 5 x 5 mm^2 (10).

All reviewed studies examined the standards for sex estimation from ridge density. Studies have been reviewed from genetically and geographically different populations, including Spanish, Malaysian, American and Chinese, and Indians. The studies have been represented in tabular and graphical forms for ridge density in Radial area (Table 1 and Figure 1) as well as Ulnar area (Table 2 and Figure 2) and Proximal area (Table 3 and Figure 3). The studies reconfirm the well-established fact that anthropological standards developed from one population cannot be applied to other populations due to the geographical, genetic and environmental differences.

It is evident from the studies reviewed that the FPRD of individuals belonging to different ethnicities from different geographical locations showed remarkable differences. While males were found to have significantly lower ridge densities in all studies, the mean Radial ridge density varied from as low as 10.9/25 mm^2 in African-Americans to as high as 20.50/25 mm^2 in Egyptian population. Females on the other hand were found to have higher mean ridge density across all studies, with the Radial ridge density varying from 12.81/ 25 mm^2 in African-Americans to 21.36/25 mm^2 in the Egyptians. The ridge densities were also found to be highly variable, as evident from the standard deviations ranging from 0.92/ 25 mm^2 in Sudanese males to 2.71/25 mm^2 in Argentine males. Females also showed extreme variability, with the standard deviations ranging from 0.634/25 mm^2 in Indian females to 2.652/25 mm^2 among Egyptian females. (Table 1; Figure 1).

Similarly, females have a higher ulnar ridge density as compared to the males. However, in some studies, it was seen that the range of ulnar ridge density was higher, with individual males showing higher ulnar ridge density than females, and therefore, there

Table 1. Mean and standard deviation for FPRD in radial areas among males and females

No.	Author/ Year/ Population	Male		Female	
		Mean	SD	Mean	SD
1.	Acree - 1999 - African American-Alabama, USA (10)	10.9	1.15	12.61	1.43
2.	Acree - 1999 - Caucasian-Alabama, USA (10)	11.14	1.31	13.32	1.24
3.	Gutiérrez-Redomero et al. - 2008 - Madrid, Spain (5)	16.23	1.39	17.91	1.47
4.	Nayak et al. - 2009 - Udupi, India (12)	11.05	1.111	14.2	0.634
5.	Nayak et al. - 2010 - Chinese-Udupi, India (12)	11.73	1.066	14.15	1.038
6.	Nayak et al. - 2010 - Malaysian-Udupi, India (12)	11.44	0.988	13.63	0.906
7.	Gutiérrez-Redomero et al. - 2011 - Salta, Argentina (6)	16.62	2.71	17.82	2.87
8.	Nithin et al. - 2011 - Mysore, India (13)	12.57	1.493	14.14	1.684
9.	Krishan et al. - 2012 - Kangra, India (7)	15.84	1.231	17.94	1.232
10.	Gutiérrez-Redomero et al. - 2013 - Ramal, Argentina (14)	17.04	1.68	19.08	1.84
11.	Gutiérrez-Redomero et al. - 2013 - Puna-Quebrada, Argentina (14)	16.67	1.78	18.47	1.56
12.	Gutiérrez-Redomero et al. - 2014 - Madrid, Spain (14)	16.85	1.76	19.11	1.79
13.	Eshak et al. - 2013 - Minya, Egypt (15)	20.50	1.974	21.36	2.652
14.	Rivalderia et al. - 2015 - Buenos Aires, Argentina (17)	15.56	1.49	17.82	1.36
15.	Rivalderia et al. - 2015 - Chubut, Argentina (17)	16.08	1.47	18.36	1.83
16.	Soanboon et al. - 2016 - Khon Kaen, Thailand(18)	15.97	1.16	17.23	1.17
17.	Ahmed and Osman - 2016 - Khartoum, Sudan (19)	12.80	0.92	14.50	1.18
18.	Taduran et al. - 2016 - Quezon City, Philippines (20)	14.57	1.43	15.89	1.69
19.	Kumar et al. - 2017 - Belgaum, India (21)	13.56	1.38	16.92	1.48
20.	Sanchez-Andres et al. - 2018 - Madrid, Spain (Junior) (23)	16.19	1.22	18.24	1.66
21.	Sanchez-Andres et al. - 2018 - Madrid, Spain (Senior) (23)	14.22	1.07	15.81	1.21
22.	Thakar et al - 2018 - Patiala, India (Index finger) (22)	12.32	1.72	13.94	1.55
23	Thakar et al - 2018 - Patiala, India (Middle finger) (22)	12.70	1.6	13.22	1.05

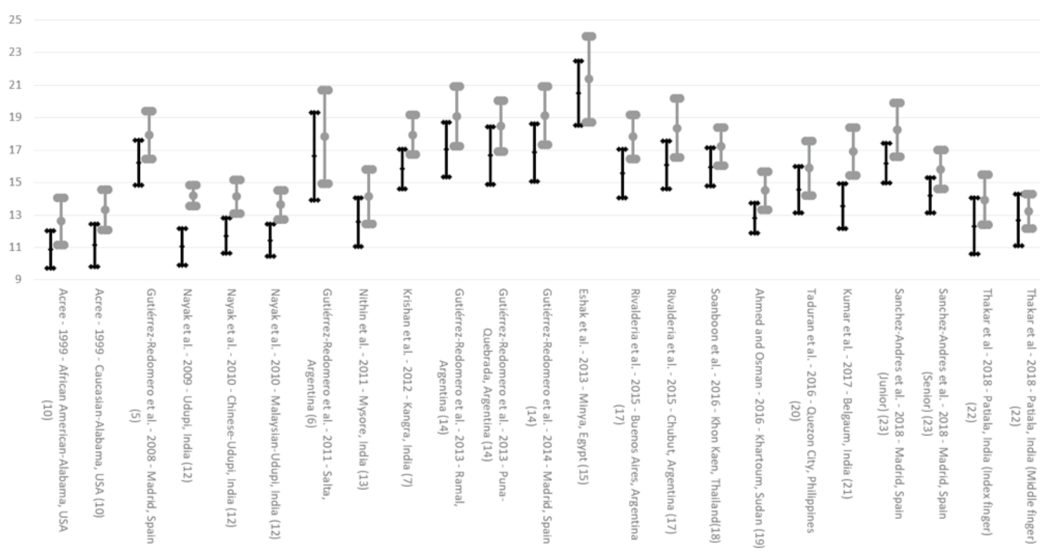

Figure 1. Mean and standard deviation for FPRD in radial areas among males and females

is a greater degree of overlap within the population. The ulnar ridge density in males varied from 13.02 /25 mm^2 in Sudanese Population to 16.54/25 mm^2 in (Salta) Argentine population. In female, ridge density varied between 14.22/25 mm^2 in Sudanese population to 17.75/25 mm^2 in (Ramal) Argentine population. Males demonstrated higher variability in the ulnar ridge density as well, varying from a low standard deviation of 0.90/25 mm^2 in Egyptian population to a high standard deviation of 1.75/25 mm^2 in (Puna-Quebrada) Argentine population. The standard deviation in females varied from 1.207/25 mm^2 in (Kangra) Indian population to 1.76/25 mm^2 in (Salta) Argentine population. (Table 2 and Graph 2)

Table 2. Mean and standard deviation for FPRD in ulnar areas among males and females

No.	Author/ Year/ Population	Male		Female	
		Mean	SD	Mean	SD
1.	Gutiérrez-Redomero et al. - 2008 - Madrid, Spain (5)	15.31	1.32	16.38	1.47
2.	Gutiérrez-Redomero et al. - 2011 - Salta, Argentina (6)	16.54	2.80	17.29	1.76
3.	Krishan et al. - 2012 - Kangra, India (7)	15.51	1.081	17.11	1.207
4.	Gutiérrez-Redomero et al. - 2013 - Ramal, Argentina (14)	16.10	1.61	17.75	1.69
5.	Gutiérrez-Redomero et al. - 2013 - Puna-Quebrada, Argentina (14)	16.39	1.75	17.62	1.62
6.	Gutiérrez-Redomero et al. - 2014 - Madrid, Spain (14)	15.38	1.32	16.84	1.46
7.	Rivalderia et al. - 2015 - Buenos Aires, Argentina (17)	14.96	1.55	17.00	1.68
8.	Rivalderia et al. - 2015 - Chubut, Argentina (17)	14.65	1.48	16.58	1.68
9.	Soanboon et al. - 2016 - Khon Kaen, Thailand(18)	16.23	1.54	16.98	1.64
10.	Ahmed and Osman - 2016 - Khartoum, Sudan (19)	13.02	0.90	14.73	1.25
11.	Taduran et al. - 2016 - Quezon City, Philippines (20)	13.10	1.27	14.22	1.51
12.	Sanchez-Andres et al. - 2018 - Madrid, Spain (Junior) (23)	14.63	1.20	16.44	1.40
13.	Sanchez-Andres et al. - 2018 - Madrid, Spain (Senior) (23)	12.81	1.08	14.25	1.24

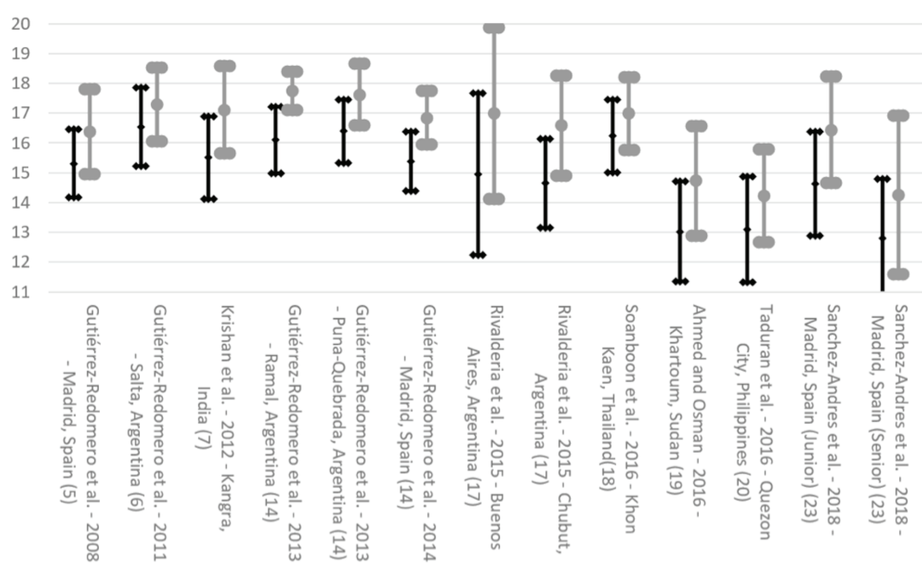

Figure 2. Mean and standard deviation for FPRD in ulnar areas among males and females

With regards to the proximal region as well, the results were found to be similar, with males having lower ridge density with a higher than females. The lowest proximal ridge density was found to be 9.75/25 mm^2 in Sudanese population, while the highest was found to be 14.33/25 mm^2 in (Puna-Quebrada) Argentine population. In case of females, the lowest mean proximal FPRD was found to be 10.80/25 mm^2 in Sudanese population, increasing to a maximum of 16.13/25 mm^2 in (Puna-Quebrada) Argentine population. With regards to the variability, the standard deviation varied from a low range of 0.80/25 mm^2 in Sudanese males to a high of 2.01/25 mm^2 in (Salta) Argentine males. The standard deviation in females ranged from 0.87/25 mm^2 in (Kangra) Indian population to 1.70/25 mm^2 in Filipino population as seen in the (Table 3 and Figure 3).

Table 3. Mean and standard deviation for FPRD in proximal areas among males and females

No.	Author/ Year/ Population	Male		Female	
		Mean	SD	Mean	SD
1.	Gutiérrez-Redomero et al. - 2008 - Madrid, Spain (5)	11.87	1.37	11.96	1.06
2.	Gutiérrez-Redomero et al. - 2011 - Salta, Argentina (6)	14.20	2.01	14.63	1.42
3.	Krishan et al. - 2012 - Kangra, India (7)	11.29	1.108	12.05	0.87
4.	Gutiérrez-Redomero et al. - 2013 - Ramal, Argentina (14)	14.08	1.30	15.12	1.4
5.	Gutiérrez-Redomero et al. - 2013 - Puna-Quebrada, Argentina (14)	14.33	1.31	16.13	1.54
6.	Gutiérrez-Redomero et al. - 2014 - Madrid, Spain (14)	12.62	1.37	13.76	1.05
7.	Rivalderia et al. - 2015 - Buenos Aires, Argentina (17)	13.27	1.11	14.27	1.18
8.	Rivalderia et al. - 2015 - Chubut, Argentina (17)	14.07	1.42	14.78	1.34
9.	Ahmed and Osman - 2016 - Khartoum, Sudan (19)	9.75	0.80	10.80	0.93
10.	Taduran et al. - 2016 - Quezon City, Philippines (20)	11.36	1.54	11.97	1.70
11.	Sanchez-Andres et al. - 2018 - Madrid, Spain (Junior) (23)	12.25	1.11	13.27	1.10
12.	Sanchez-Andres et al. - 2018 - Madrid, Spain (Senior) (23)	12.07	1.23	13.05	0.95

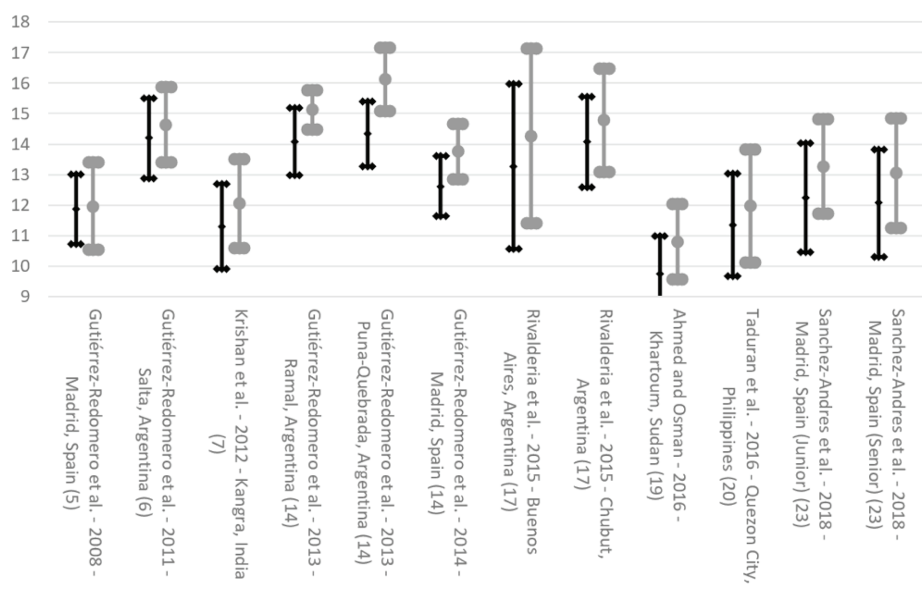

Figure 3. Mean and standard deviation for FPRD in proximal areas among males and females

Conclusions and future directions

The present study recommends the use of fingerprint considering their presence in the crime scene for estimating sex. Fingerprints are extremely valuable in identification of the individuals based on the examination of an individual's variation. However, positive identification of fingerprint requires matching of the fingerprint obtained from the crime scene, with a known database or with the fingerprint of a suspect. The examination of the FPRD is therefore a viable alternative to estimate the sex of the individual in cases without any suspects.

The results of this study show that while there is considerable statistically significant sexual dimorphism in the fingerprint ridge density, the mean density is extremely variable between populations. Therefore, population specific models need to be developed to estimate the sex of individuals based on fingerprint ridge density. This can then be used to help law enforcement agencies involved in medico-legal processes, crime scene investigations and disaster victim identification especially involving mutilated and fragmented remains.

Future research on FPRD can examine the ethnic variations in India, in its association with diseases including alcoholism (25), diabetes (26), caries (27), hypertension (28), Wilson's disease (29) as well as its use in screening for leukaemia (30). Studies need to be conducted on ethnic variations and develop population-specific databases for India. Similarly, research on factors affecting the sexual differences in ridge density should examine the genetic influences on ridge density, possibly based on genes located on the X-chromosome as well as other autosomal chromosomal anomalies (31).

Further research is also warranted on the influence of socio-economic factors on fingerprint ridge density. One of the important factors affecting finger ridge density has been proposed to be historical division of labour between the sexes. Fowler et al. studied the division of labour and learning about pottery making in the early Bronze age (32). This study provided an insight into the manufacturing of the wares in the Early Bronze age. In this specific study the archaeological sample was taken in to consideration so the calculation was divided into the density value of 2% and 6%... Intensive manual labour could lead to gross changes in the structure of epidermis on the hands. Therefore, future research in effects of occupation on FPRD could be important (32-34). Future research on sexual dimorphism of FPRD must examine the intra-population variations between the sexes as well as inter-population variations (31,35). Some other factors that should be examined include stature of an individual, body morphology, and anthropometry (36).

FPRD is, therefore, an important biological trait that has significant forensic implications. These can also help scientists understand the biological variations and help classify populations. FPRD can also be used to predict the risk of diseases in an individual and can be a useful screening tool in clinical medicine. Further research is needed to establish population specific data on FPRD and its uses.

Acknowledgements: Siddharatha Sharma acknowledges the Basic Science Research fellowship from University Grants Commission, New Delhi, India. Kewal Krishan is supported by a DST PURSE Grant and UGC Center of Advanced Study (CAS II) awarded to the Department of Anthropology, Panjab University, Chandigarh, India.

Conflicts of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Funding: This work is a part of the PhD research of Siddharatha Sharma (A Study of FPRD in a Rajput Population of Shimla and Solan Districts of Himachal Pradesh: Forensic and Anthropological Aspects) which was supported by the University Grants Commission (UGC) fellowship.

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Received: 17 March 2021
Accepted: 7 April 2021
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