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SEXUAL DIMORPHISM IN FINGERPRINT RIDGE DENSITY: A STUDY IN SURABAYA, INDONESIA

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ABSTRACT

Fingerprints are considered the primary human identifier and a gold standard in forensic identification. However, the application of fingerprints for sex estimation in Indonesia remains limited. This study aimed to evaluate sex-related differences in fingerprint ridge density among young adults and to develop a population-specific discriminant formula for sex classification. Fingerprints of all ten digits were collected from 90 participants (45 males and 45 females), aged 17–21 years. Fingerprints' ridge density was quantified in three anatomical regions (radial, ulnar, and proximal) and statistically analyzed using SPSS version 23.0. Discriminant function analysis was employed to identify the most informative digits for sex prediction and to develop a predictive classification model. The present study found that females consistently exhibited significantly higher ridge densities than males across all ten digits ($p < 0.001$). Four digits—the right thumb, right index finger, right little finger, and left index finger—were identified as the most reliable predictors for sex differentiation. The derived discriminant function achieved an overall classification accuracy of 97.2% in cross-validation and 94.4% in the test sample. These findings confirm that fingerprint ridge density is a robust indicator for sex estimation in the Surabaya population. This study highlights the importance of developing population-specific sex-determination formulas for forensic identification. Further studies with larger, more diverse samples are recommended to validate and improve the generalizability of this model for routine forensic casework.

Keywords: Biometric identification, Fingerprints, Human identification, Legal identity, Sexual dimorphism

1 INTRODUCTION

Sex prediction is a critical component of forensic identification, particularly in cases involving mass disasters, unidentified remains, and criminal investigations. Fingerprints remain among the most widely used biometric identifiers in forensic practice and are classified by Interpol, along with DNA and dental analysis, as primary human identifiers in Disaster Victim Identification (DVI).(Interpol 2023) Fingerprints are widely regarded as highly individual and stable biometric features, supported by extensive empirical evidence, though their absolute uniqueness remains a practical assumption rather than a scientifically testable fact (Saharan et al. 2021).

In recent years, the scope of fingerprint analysis has expanded beyond pattern classification to include the study of dermatoglyphic variables that may support sex estimation. Several fingerprint characteristics—such as ridge density, ridge count, pattern frequency, and minutiae distribution—have been shown to exhibit sexual dimorphism and have therefore attracted increasing research interest (Sharma et al. 2021). Among these features, fingerprint ridge density is one of the most frequently analyzed parameters. Defined as the number of ridges within a specific fingerprint area (Acree 1999). Ridge density has demonstrated consistent sex-related differences in numerous populations, with females generally presenting higher ridge densities than males. These findings have been reported in Indian, Turkish, Filipino, Malaysian, Thai, and Argentine populations (Nayak et al. 2010; Abdullah et al. 2015; Oktem et al. 2015; Rivaldería et al. 2016; Taduran et al. 2016; Soanboon et al. 2016).

As the literature has expanded, the need for population-specific reference data has become increasingly evident. Variations in genetic, environmental, and ethnic factors may influence ridge density patterns. Despite Indonesia's substantial ethnic diversity and its relevance in regional forensic practice, studies on fingerprint ridge density for sex prediction remain scarce. To date, no comprehensive research has been conducted in Surabaya, an urban area characterized by considerable demographic heterogeneity. Establishing population-specific data for this region is therefore essential to improve the reliability and applicability of fingerprint ridge density analysis in Indonesia. Accordingly, this study aimed to assess sex-related differences in fingerprint ridge density and develop a classification formula to assist in sex estimation within this population.

2 MATERIALS AND METHODS

This study received ethical approval from the Institutional Ethical Committee (approval number: 0580/HRECC.FODM/VI/2024) and was conducted in accordance with the Declaration of Helsinki. A total of 90 subjects (45 males and 45 females), aged 17–21 years, voluntarily participated in this study after providing informed consent. Of these, 80% (36 males and 36 females) were allocated to the primary analysis, while the remaining 20% (9 males and 9 females) served as an independent validation sample.

Fingerprint patterns were recorded using a simple ink-staining method. Materials included black ink, a stamp pad, white paper, acetate sheets, a ruler, a pen, and a magnifying lens. The distal phalanges of all ten fingers were stained using an ink pad, covering both the radial and ulnar sides, as well as the distal joint lines. Each impression was carefully transferred onto a recording sheet for subsequent assessment, following the principles described by Cummins and Midlo 1961.

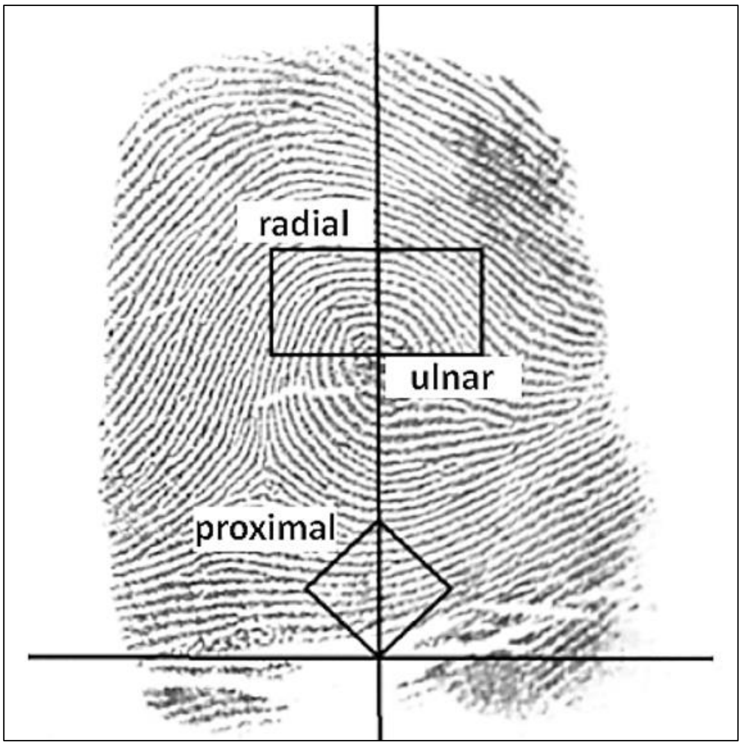

Figure 1: Anatomical segmentation of a left-hand fingerprint into radial, ulnar, and proximal regions following the method of Gutiérrez-Redomero et al. (2008). Standardized 25 mm^2 boxes indicate the measurement zones used to calculate ridge density.

Fingerprint ridge density assessment was performed using the Acree method, with modifications introduced by Gutiérrez-Redomero et al. (2008). Each fingerprint was divided into three anatomical regions—radial, ulnar, and proximal (Figure 1). Two perpendicular axes were drawn to segment the print into four sectors. A horizontal reference line was positioned parallel to the interphalangeal joint, and two 5 × 5 mm^2 counting boxes were placed along the second line above the pattern core (Gutiérrez-Redomero et al. 2008). Ridge density for each region was calculated as the number of diagonal ridges within the designated boxes, and all values were entered into Microsoft Excel for tabulation.

Discriminant function analysis was used to identify the fingerprint regions and fingers that contributed most strongly to sex differentiation and to derive a classification formula. All statistical analyses were performed using SPSS Statistics version 23.0.

3 RESULTS

A total of 72 subjects were included in the primary analysis to develop the discriminant formula for sex prediction. Descriptive statistics of fingerprint ridge density across the radial, ulnar, and proximal regions are shown in Table 1. Among females, the highest ridge density in the radial section was observed on the right thumb (16.69 ± 1.12), while the highest density in the ulnar section was recorded on the right ring finger (15.72 ± 1.11), and in the proximal section on the right thumb (12.47 ± 1.75). In males, the highest ridge density in the radial section was found on the left ring finger (13.61 ± 1.15), while the highest density in the ulnar section was observed on the right ring finger (13.75 ± 1.32), and in the proximal section on the right thumb (11.58 ± 1.36). Overall ridge density was highest on the right ring finger in males (12.67 ± 0.69) and on the right thumb in females (14.77 ± 0.71). We then used the overall densities of each finger as input variables in discriminant function analysis.

All ten fingerprint ridge densities differed significantly between males and females ($p < 0.001$). Box's M test indicated that the covariance matrices did not differ significantly between groups ($p = 0.264$), supporting the assumption of equal covariance matrices. Stepwise discriminant analysis retained four of ten variables—right thumb, right little finger, right index finger, and left index finger—as the strongest predictors, minimizing Wilks' Lambda. Each variable entered the model, leading to a significant decrease in Wilks' Lambda ($p < 0.001$), and the final function exhibited strong discriminatory ability (Wilks' Lambda = 0.167, Chi-square = 121.532, $p < 0.001$).

Table 1: Descriptive statistics of fingerprint ridge density (mean ± SD per 25 mm²) measured on the radial, ulnar, and proximal regions of all participants, presented separately for males and females.

Finger	Sex	Fingerprint ridge density /25mm² (mean ± SD)				Sig.
		Radial	Ulnar	Proximal	Overall	
Right hand						
Thumb	M	12.75±1.32	12.22±1.48	11.58±1.36	12.19±0.84	<0.001*
	F	16.69±1.12	15.14±0.96	12.47±1.75	14.77±0.71	
Index	M	12.75±1.30	12.53±1.40	10.97±1.59	12.08±0.98	<0.001*
	F	15.50±1.03	15.19±0.75	11.92±1.57	14.20±0.67	
Middle	M	13.11±1.43	13.39±1.61	10.69±1.51	12.40±0.87	<0.001*
	F	15.67±1.10	15.39±1.15	11.89±1.49	14.31±0.64	
Ring	M	13.56±1.18	13.75±1.32	10.69±1.56	12.67±0.69	<0.001*
	F	15.61±1.29	15.72±1.11	11.94±1.45	14.43±0.78	
Little	M	13.31±1.35	13.25±1.08	10.56±1.36	12.37±0.70	<0.001*
	F	15.75±0.97	15.47±1.42	11.69±1.55	14.31±0.83	
Left hand						
Thumb	M	12.67±1.33	12.05±1.49	11.28±1.23	12.00±0.99	<0.001*
	F	15.64±1.10	15.25±1.96	11.89±1.58	14.26±0.77	
Index	M	13.17±1.25	12.86±1.36	10.92±1.20	12.31±0.77	<0.001*
	F	15.33±0.93	15.19±0.75	11.92±1.59	14.15±0.62	
Middle	M	13.50±1.28	13.28±1.39	10.64±1.57	12.47±0.95	<0.001*
	F	15.61±1.27	15.50±0.88	11.50±1.50	14.20±0.80	
Ring	M	13.61±1.15	13.61±1.64	10.64±1.42	12.62±0.91	<0.001*
	F	15.81±1.01	15.36±1.51	11.89±1.51	14.35±0.93	
Little	M	13.25±1.18	13.44±1.25	10.58±1.34	12.43±0.85	<0.001*
	F	15.11±1.01	15.44±1.48	11.36±1.40	13.97±0.91	

*indicates statistically significant difference between males and females; M= Males; F= Females

Table 2: Results of the discriminant function analysis, including the structure matrix, standardized canonical coefficients, group centroids, and discriminant function strength. These parameters summarize each fingerprint region's contribution to sex differentiation.

Finger	Structured matrix	Constant (A)	Coefficient (B)	Centroids (C)	Chi-square sig.	CC
Right hand		−26.905		Male (n=36) −2.199 Female (n=36) 2.199	<0.001	0.912
Thumb	0.754		0.746			
Index finger	0.574		0.322			
Little finger	0.576		0.453			
Left hand						
Index finger	0.595		0.497			

The canonical correlation was 0.912, indicating a strong relationship between the discriminant function and sex prediction, accounting for 83.17% of the variance. The chi-square test also confirmed a statistically significant difference in ridge density between males and females across the four selected fingers ($p < 0.001$).

The structure matrix showed that the right thumb (0.754) contributed most significantly to the discriminant function, followed by the left index finger, right little finger, and right index finger (Table 2). The resulting discriminant formula for sex prediction was:

$$Z = 0.746(R\_Tm) + 0.322(R\_In) + 0.453(R\_Li) + 0.497(L\_In) - 26.905$$

Z: discriminant score

- R_Tm: overall fingerprint ridge density of the right thumb
- R_In: overall fingerprint ridge density of the right index finger
- R_Li: overall fingerprint ridge density of the right little finger
- L_In: overall fingerprint ridge density of the left index finger

Group centroids were distinctly separated, with values of –2.199 for males and +2.199 for females, demonstrating strong discriminative ability. The cut-off score was determined using the group means and sample sizes:

$$Z_C = \frac{n_M.C_M + n_F.C_F}{n_M + n_F} \quad \Rightarrow \quad Z_C = \frac{(36 \text{ x } (-2.199) + (36 \text{ x } (2.199))}{36 + 36} = 0.00$$

- Z_C: Cutting Score
- n_M: Male Sample Size
- n_F: Female Sample Size
- C_M: Centroids in Male Sample
- C_F: Centroids in Female Sample

A Z score above 0 classified an individual as female, while a score below 0 classified an individual as male. The discriminant formula was cross-validated on the entire study sample and then tested on the remaining 20% of subjects. The classification results for the test samples showed an overall accuracy of 94.4%, as shown in Table 3. Table 4 provides detailed ridge density profiles, discriminant scores, and sex predictions for all test samples.

Table 3: Classification accuracy of the derived discriminant function, showing both original, cross-validated, *and testing dataset* classifications for male and female subjects. The table indicates the proportion of correctly classified cases and the model's predictive performance.

	Sex	**Prediction**				**Total Correct Predictions**	
		Male		**Female**			
		n	**%**	**n**	**%**	**n**	**%**
Original	Male	36	100	0	0	71	98.6
	Female	1	2.8	35	97.2		
Cros-validated	Male	35	97.2	1	2.8	70	97.2
	Female	1	2.8	35	97.2		
Testing	Male	8	88.9	1	11.1	17	94.4
	Female	0	0.00	9	100.0		

Table 4: Fingerprint ridge density values, computed discriminant scores, and resulting sex predictions for the independent testing samples.

No.	Overall ridge density				Z score	Prediction
	R_Tm	R_In	R_Li	L_In		
Male						
1	13.67	14.00	12.00	12.67	-0.470	M
2	12.00	11.33	12.00	13.67	-2.075	M
3	12.33	12.33	11.67	13.33	-1.821	M
4	12.67	12.67	12.33	12.33	-1.660	M
5	14.33	14.00	12.33	13.00	0.344*	F*
6	13.67	11.33	11.00	12.33	-1.948	M
7	12.33	13.33	13.67	13.00	-0.759	M
8	12.00	11.33	12.33	12.00	-2.753	M
9	13.00	13.33	12.67	13.00	-0.715	M
Female						
1	13.33	14.33	14.00	14.00	0.957	F
2	15.67	13.67	14.67	14.00	2.785	F
3	15.33	15.67	13.67	13.33	2.396	F
4	13.33	14.00	13.00	16.00	1.391	F
5	15.00	14.67	13.00	15.33	2.517	F
6	16.33	13.67	14.33	15.33	3.794	F
7	15.33	15.33	13.67	14.33	2.786	F
8	14.67	13.33	14.00	16.00	2.624	F
9	14.00	14.33	14.33	14.67	1.937	F

*indicates misclassification; R_Tm= right thumb; R_In= Right index finger; R_Li= Right little finger; L_In= Left index finger; M= male; F= female

4 DISCUSSION

Fingerprint ridge density analysis has become an important biometric method for supporting sex prediction in forensic investigations. Since fingerprints are unique, permanent, and easily obtainable, their application in forensic science extends beyond personal identification to include demographic profiling (Kaushal and Kaushal 2011). The present study examined sex-based differences in fingerprint ridge density and developed a discriminant function for sex classification. The results demonstrated statistically significant differences between males and females, supporting previous findings that females tend to exhibit higher ridge densities than males (Acree 1999; Gutiérrez-Redomero et al. 2008; Nayak et al. 2010; Eshak et al. 2013).

In this study population, males generally had fewer than 13 ridges/25 mm^2, whereas females commonly had more than 14 ridges/25 mm^2. These values closely align with a study by Soanboon et al. (2016) in Northeast Thailand, which reported significantly higher ridge densities in females, averaging more than 14 ridges/25 mm^2. In contrast, males generally had fewer than 14 ridges/25 mm^2 in the radial and ulnar regions (Soanboon et al. 2016). Similar trends were observed in the Buenos Aires population, where males showed ridge densities of ≤14.96 in the ulnar region and ≤15.56 in the radial region, compared with 7.00 and ≥17.82 in females (Rivaldería et al. 2016). Correspondingly, South Indian data indicate that ridge densities below 13 ridges/25 mm^2 are more characteristic of males, while counts above 14 ridges/25 mm^2 tend to indicate females (Nithin et al. 2011). Table 5 presents comparative findings from a few studies.

Table 5: Summary of reported fingerprint ridge density values (mean ± SD per 25 mm²) across multiple populations, showing radial, ulnar, and proximal segment measurements for males and females as described in previous studies and in the present Indonesian sample.

Reference	Population	Age Range	Ridge Density /25 mm² (Mean±SD)					
			Radial		Ulnar		Proximal	
			Male	Female	Male	Female	Male	Female
Acree (1999)	Afro-American	18-67	10.90±1.15	12.61±1.43				
	Caucasian-American		11.14±1.31	13.32±1.24				
Nithin et al. (2011)	Southern Indian	18-65	12.57±1.49	14.15±1.68				
Gutiérrez-Redomero et al. (2014)	Spain	18-34	16.85±1.76	19.11±1.79	15.38±1.49	16.84±1.58	12.62±1.45	13.76±1.52
Soanboon et al. (2016)	Northeastern Thais	14-24	15.97±1.16	17.23±1.17	16.23±1.54	16.98±1.64		
Rivaldería et al. (2016)	Argentinean (Buenos Aires)	>18	15.56±1.49	17.82±1.36	14.96±1.55	17.00±1.68	13.27±1.11	14.27±1.18
	Argentinean (Chubut)		16.80±1.47	18.36±1.83	14.65±1.48	16.58±1.68	14.07±1.42	14.78±1.34
Present study (2026)	Indonesian (Surabaya)	17-21	13.23±1.29	15.67±1.20	13.14±1.50	15.39±1.31	10.88±1.47	11.75±1.55

This study also found that ridge densities in the radial and ulnar regions were comparable, whereas those in the proximal region were distinctly lower. Previous studies have attributed this pattern to the structural characteristics of proximal ridges, which tend to be thicker and more widely spaced, resulting in lower ridge density (Gutiérrez-Redomero et al. 2008; Oktem et al. 2015). This study observed a statistically significant difference in ridge density across all three regions between males and females. These findings align with previous studies conducted in the North Indian (Krishan et al. 2013), Turkish (Oktem et al. 2015), and Argentinean (Rivaldería et al. 2016) populations. Population variability, however, remains an important consideration. In the Sudanese population, for instance, females exhibited smoother ridge surfaces and higher ridge densities, whereas some African populations, such as Kenyan and Tanzanian groups, have shown the opposite trend, with males having higher ridge densities (Ahmed and Osman 2016). These differences underscore the influence of genetic, environmental, and functional factors on ridge morphology (Acree 1999).

Using ridge density data from each finger, this study applied discriminant function analysis and identified four fingers—the right thumb, right index finger, right little finger, and left index finger—as the most discriminative for sex prediction. The resulting discriminant function ($Z = 0.746(R\_Tm) + 0.322(R\_In) + 0.453(R\_Li) + 0.497(L\_In) - 26.905$) produced high classification accuracy, achieving 97.2% in cross-validation and 94.4% in the test dataset. These findings are comparable to those reported by Dhall and Kapoor (2016), who observed accuracies exceeding 95% using both discriminant function analysis and logistic regression (Dhall and Kapoor 2016). Similarly, a study in Northern India achieved an overall accuracy of 84.4% using multivariate discriminant analysis, with the radial area of the left hand identified as the most predictive region (Kaur et al. 2020).

Beyond traditional statistical approaches, emerging computational techniques have further enhanced fingerprint-based sex classification. Gnanasivam and Muttan (2012) introduced an innovative approach using discrete wavelet transform (DWT) and singular value decomposition (SVD), achieving classification accuracies ranging from 88% to 95% depending on the finger analyzed (Gnanasivam and Muttan 2012). Later, Gnanasivam and Vijayarajan (2019) examined ridge count and fingertip size, reporting a maximum accuracy of 90.11% for the right ring finger in young adults

(Gnanasivam and Vijayarajan 2019). A machine-learning approach to sex prediction was also applied to the German Caucasian population. The best results were obtained for the ulnar area in combination with the left thumb's fingerprint size, with F1-scores of 0.84 for KNN, 0.833 for Support Vector Machine (SVM), and 0.817 for logistic regression (Mohaupt et al. 2021).

This study has several limitations that should be considered when interpreting its findings. First, the sample size was relatively modest and restricted to individuals aged 17–21 years, limiting the ability to generalize the results to broader age groups. The study population was also geographically confined to Surabaya, which may not fully represent Indonesia's genetic and ethnic diversity. In addition, ink-based fingerprint collection, although practical, may introduce minor variations in ridge clarity and print quality that can affect ridge counts, particularly in individuals with dry, wet, or worn fingertips.

The findings of the present study emphasize the importance of carefully selecting and consistently defining fingerprint regions in ridge density analysis. Unlike traditional identity verification, which relies on matching known fingerprints, sex estimation requires standardized measurement approaches to ensure comparability and reproducibility. Although ridge density remains a promising parameter for sex prediction, further work is needed to explore population-specific variation, refine area-calculation methods, and assess potential influences such as age, genetics, environmental exposure, and hand function. Additionally, interpreting partial or low-quality fingerprints remains a challenge in forensic settings. Future studies, including larger, more heterogeneous samples, will be essential to validate and generalize the sex-classification formula developed in this study.

5 CONCLUSION

This study demonstrates that fingerprint ridge density can serve as a reliable indicator of sex, with females generally exhibiting higher ridge density than males. The right thumb, right index finger, right little finger, and left index finger showed the best ability to distinguish between sexes and were included in the final discriminant model. The resulting formula may assist forensic investigations, especially in cases involving unidentified or damaged remains. However, because ridge density can vary among populations, further studies are needed to validate and expand the applicability of this formula for broader forensic use.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflict of interest.

Statement of ethical approval

This study received ethical approval from the Institutional Ethical Committee (approval number: 0580/HRECC.FODM/VI/2024) and was conducted in accordance with the Declaration of Helsinki.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

REFERENCES

[1] Abdullah SF, Rahman AFNA, Abas ZA (2015) Classification Of Gender By Using Fingerprint Ridge Density In Northern Part Of Malaysia. J Eng Appl Sci, 10(22):10722–10726.

[2] Acree MA (1999) Is there a gender difference in fingerprint ridge density?. Forensic Sci Int, 102(1):35–44.

[3] Ahmed AA, 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.

[4] Cummins H, Midlo C (1961) Finger Prints, Palms And Soles: An Introduction to Dermatoglyphics. Dover Publications Inc., New York

[5] Dhall JK, Kapoor AK (2016) Fingerprint Ridge Density as a Potential Forensic Anthropological Tool for Sex Identification. J Forensic Sci, 61(2):424–429.

[6] Eshak GA, Zaher JF, Hasan EI, El-Azeem EWIS AA (2013) Sex identification from fingertip features in Egyptian population. J Forensic Leg Med, 20(1):46–50.

[7] Gnanasivam P, Muttan S (2012) Fingerprint Gender Classification using Wavelet Transform and Singular Value Decomposition. Int J Comp Sci, 9(2).

[8] Gnanasivam P, Vijayarajan R (2019) Gender classification from fingerprint ridge count and fingertip size using optimal score assignment. Complex & Intelligent Systems, 5(3):343–352.

[9] Gutiérrez-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 Sci Int, 180(1):17–22.

[10] Interpol (2023) Disaster Victim Identification (DVI) Guide. https://www.interpol.int/en/How-we-work/Forensics/Disaster-Victim-Identification-DVI. Accessed 21 Feb 2025.

[11] Kaur M, Kaur M, Yangchan J (2020) Identification of sex using discriminant function analysis of fingerprint ridge density at three topological areas among North Indian population. Anthropol Rev, 83(4):349–361.

[12] Kaushal N, Kaushal P (2011) Human Identification and Fingerprints: A Review. J Biom Biostat, 2(4):123.

[13] 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.

[14] Mohaupt M, Stoeter S, Labudde D (2021) Automated Determination of Fingerprint Ridge Density and Fingerprint Size to Detect Sex Differences. In: Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft fur Informatik (GI). pp 847–856

[15] Nayak VC, Rastogi P, Kanchan T, Lobo SW, Yoganarasimha K, Nayak S, Rao NG, Pradeep KG, Suresh KSB, Menezes RG (2010) Sex differences from fingerprint ridge density in the Indian population. J Forensic Leg Med, 17(2):84–86.

[16] Nithin MD, Manjunatha B, Preethi DS, Balaraj BM (2011) Gender differentiation by finger ridge count among South Indian population. J Forensic Leg Med, 18(2):79–81.

[17] Oktem H, Kurkcuoglu A, Pelin IC, Yazici AC, Aktaş G, Altunay F (2015) Sex differences in fingerprint ridge density in a Turkish young adult population: A sample of Baskent University. J Forensic Leg Med, 32:34–38.

[18] Rivaldería N, Sánchez-Andrés Á, Alonso-Rodríguez C, Dipierri JE, Gutiérrez-Redomero E (2016) Fingerprint ridge density in the Argentinean population and its application to sex inference: A comparative study. HOMO 67(1):65–84.

[19] Saharan S, Yadav AK, Yadav B (2021) Forge fingerprints: Fabrication, development, and detection techniques. Int J Med Toxicol Legal Med, 24(3):189–194.

[20] Sharma S, Shrestha R, Krishan K, Kanchan T (2021) Sex estimation from fingerprint ridge density. A review of literature. Acta Biomed, 92(5): e2021366.

[21] Soanboon P, Nanakorn S, Kutanan W (2016) Determination of sex difference from fingerprint ridge density in northeastern Thai teenagers. Egypt J Forensic Sci, 6(2):185–193.

[22] Taduran RJO, Tadeo AKV., Escalona NAC, Townsend GC (2016) Sex determination from fingerprint ridge density and white line counts in Filipinos. HOMO, 67(2):163–171.