 https://doi.org/10.34836/pk.2021.313.1

Sex determination from plain fingerprint ridge density in Filipinos

Regine Ynez H. De Mesa[1*], Ysabella Bernice D.J. Yapchiongco[2], Carmela A. Evangelista[3], Maria Olivia M. Alcantara[3], Konika D. Kub-ao[3], and Richard Jonathan O. Taduran[3,4]

[1] Center for Integrative and Development Studies, University of the Philippines Diliman
[2] Ateneo School of Medicine and Public Health
[3] Department of Anthropology, University of the Philippines Diliman, Quezon City, Philippines
[4] College of Humanities and Social Sciences, University of the Philippines Mindanao
* Corresponding author: rhdemesa@up.edu.ph

Summary

Fingerprints are integral in establishing individuality in forensic cases. This study derived sex discrimination formulas using the radial ridge density of plain fingerprints in a sample of 150 male and 150 female Filipinos. Laterality, interfinger differences, and associations between ridge density, height, and weight were examined. Ridge density was found to be sexually dimorphic ($p < 0.001$), with an average of 17 ridges / 25 mm^2 recorded among males and 20 ridges / 25 mm^2 among females. Most prints were revealed to be laterally distinct with statistically significant interfinger differences among the sexes. While results confirm that radial ridge density is sexually dimorphic within the sample, comparably higher ridge estimation thresholds were reported in this study than in existing literature – potentially due to the use of plain prints for measuring ridge density. Given representational inequities in forensic research, this study diversifies existing thresholds using a viable yet cost-effective method for estimating sex.

Key words: ridge density, sex determination, sex estimation, plain fingerprints, fingerprint analysis, Filipino population

Introduction

Background of the Study

Establishing individuality is at the cornerstone of crime scene and forensic investigations. Fingerprint analysis is integral in drawing individuality, given that each fingerprint is unique and immutable throughout an individual's lifetime (Barua et al., 2011; Soanboon et al., 2016). Sex differentiation through the examination of dermatoglyphic traits hinges on the variation between male and female epidermal ridges, where the former typically exhibits coarser ridges than the latter (Cummins et al., 1941; Ohler, Cummins, 1942). Following this observation, fingerprint analysis has since utilized either epidermal ridge thickness or epidermal ridge densities as the primary method for estimating sex (Brazelle et al., 2017). However, despite a growing consensus that fingerprints are sexually dimorphic, sectioning points that provide a threshold for estimating sex have been shown to vary across populations.

Gutiérrez-Redomero et al. (2008) defines ridge density as the ridge counts situated within a pre-defined fingerprint area, one that is "determined by two parameters: 1) ridge width and 2) distance between ridges" (p. 17). Gender differentiation thresholds estimate a ridge count of ⩽ 11 to be likely male and ⩾ 12 to be likely female within a 5 × 5 mm^2 surface area (Acree, 1999). Sexual dimorphism in fingerprint RD has since been found across numerous groups. These include Spanish populations (Gutiérrez-Redomero et al., 2008), Indian (Kapoor, Badiye, 2015; Kaur, 2019; Patil et al., 2018), Egyptian (Eshak et al., 2013), Malaysian and Chinese (Nayak et al., 2010), Nigerian (Adamu et al., 2016), Thai (Soanboon et al., 2016), Filipino (Taduran et al., 2016), Emirati (Singh et al., 2019), among many others. The general tendency for female ridge densities to exceed male averages has been attributed to increased ridge breadth among men and body size differentials between men and women (Soanboon et al., 2016). Furthermore, as women exhibit finer ridges than men (Acree, 1999), ridge density can generally be expected to be higher among women across populations.

While fingerprint ridge densities were observed to be higher among female prints in the aforementioned studies, standardized methodologies for examining ridge characteristics also remain lacking. Types of impressions procured (e.g. rolled prints and plain prints), methods for counting ridges, fingerprint regions examined, and tools employed for documenting prints differ across studies. Inevitably, ridge counts and likelihood ratios obtained from the array methods employed exhibit some degree of variation (Gutiérrez-Redomero et al., 2008, 2014; Jain, Feng, 2011; Nadgir, Ross, 2006). In a survey of studies examining sexual dimorphism in fingerprint ridge density, the greater focus has been directed towards exploring rolled impressions over plain prints (Dhall, Kapoor, 2016; Kapoor, Badiye, 2015; Kaur, 2019; Krishan et al., 2013; Patil et al., 2018; Singh et al., 2019; Wahdan, Khalifa, 2017). Within the Filipino population, associations between sex and fingerprint ridge density have only been examined in Taduran et al. (2016) and have only been limited to rolled impressions. Given that plain impressions are the most common type of fingerprints obtained from crime scenes (Feng et al., 2009), exploring the viability of ridge density as a predictor of sex in plain prints is of paramount value especially for matching latent prints with existing databases.

Study Objectives

The objectives of this study are to: 1) examine sexual dimorphism in fingerprint ridge characteristics within a Filipino sample; 2) determine ridge estimation thresholds between male and female prints; and 3) explore the viability of ridge density as an investigative tool for sex estimation among plain prints.

Materials and methods

Data Collection and Processing

Fingerprint samples of 150 males and 150 females were obtained from volunteers at the University of the Philippines Diliman in Metro Manila. Participants were adults aged 18–40 years old and were assisted by a researcher with imprinting plain finger impressions onto standard ten-print cards. These impressions were then digitally scanned and uploaded onto Adobe Photoshop to measure ridge counts. Following Acree (1999), a 5 mm x 5 mm square with a diagonal line was superimposed onto an enlarged image of the radial area of each fingerprint (Figure 1). Ridge density (RD) was calculated by counting the number of ridges that intersect the diagonal line within the pre-determined square. Ensuring a Frankfurt position was maintained, height was measured in centimeters (cm) against a flat wall. Belongings, shoes, and other accessories were removed by participants before standing onto a standard digital weighing scale to obtain their weight in kilograms (kg). Verbal and written consent was elicited from all participants prior. To their participation in the study. Furthermore, all participant data were anonymized upon encoding and analysis.

Figure 1. Example of radial ridge count area on a plain fingerprint.

Statistical Analysis

Data were recorded using Microsoft Excel and analyzed using R Statistical Software. Digits were encoded from 1 to 5, with digit 1 corresponding to the thumb and digit 5 for the little finger respectively (Figure 2). Descriptive statistics inclusive of the mean, standard deviations, and correlation coefficients of variation were calculated. Data analyses were conducted using the Student's t-test for assessing sexual dimorphism, paired t-tests for determining lateral differences, and ANOVA for measuring interfinger variation. Frequency distributions of mean ridge densities for both sexes were calculated alongside probability densities P(RD|C), P(RD|C'), likelihood ratios, and odds ratios. Sectioning points were established to estimate thresholds for sex classification. Lastly, Pearson's correlation coefficients were obtained to examine potential associations between RD, stature, and weight. *P*-values < 0.05 were considered statistically significant for this study.

Results

Table 1 shows a comparison of mean RDs between sexes and across digits. Male RDs and female RDs were identified to have significant differences in all ten fingers. For males and females, mean RD was found to be significantly greater for left fingers. Female mean RD was statistically higher than male mean RD ($p < 0.001$). Male and female RDs were found to be sexually distinct across all ten fingers.

Paired t-test results between left and right digits reveal significant side differences in all-female digits and most male digits in males (see Table 2). Mean differences for the left and right sides of thumb, index, middle, and little digits were significant in males. Among females, all digits exhibited significant side differences. Differences between L4 and R4 were the least pronounced for both males and females.

Mean differences and sectioning points between male and female digits are presented in Table 3. Identified thumb and index prints with < 18 ridges were determined male, while prints with > 18 ridges were determined to be of female origin. Sectioning points for the middle, ring, and little digits were estimated to be between 19.07–19.62 ridges. As such, < 19 ridges were classified male and > 19 ridges were classified female.

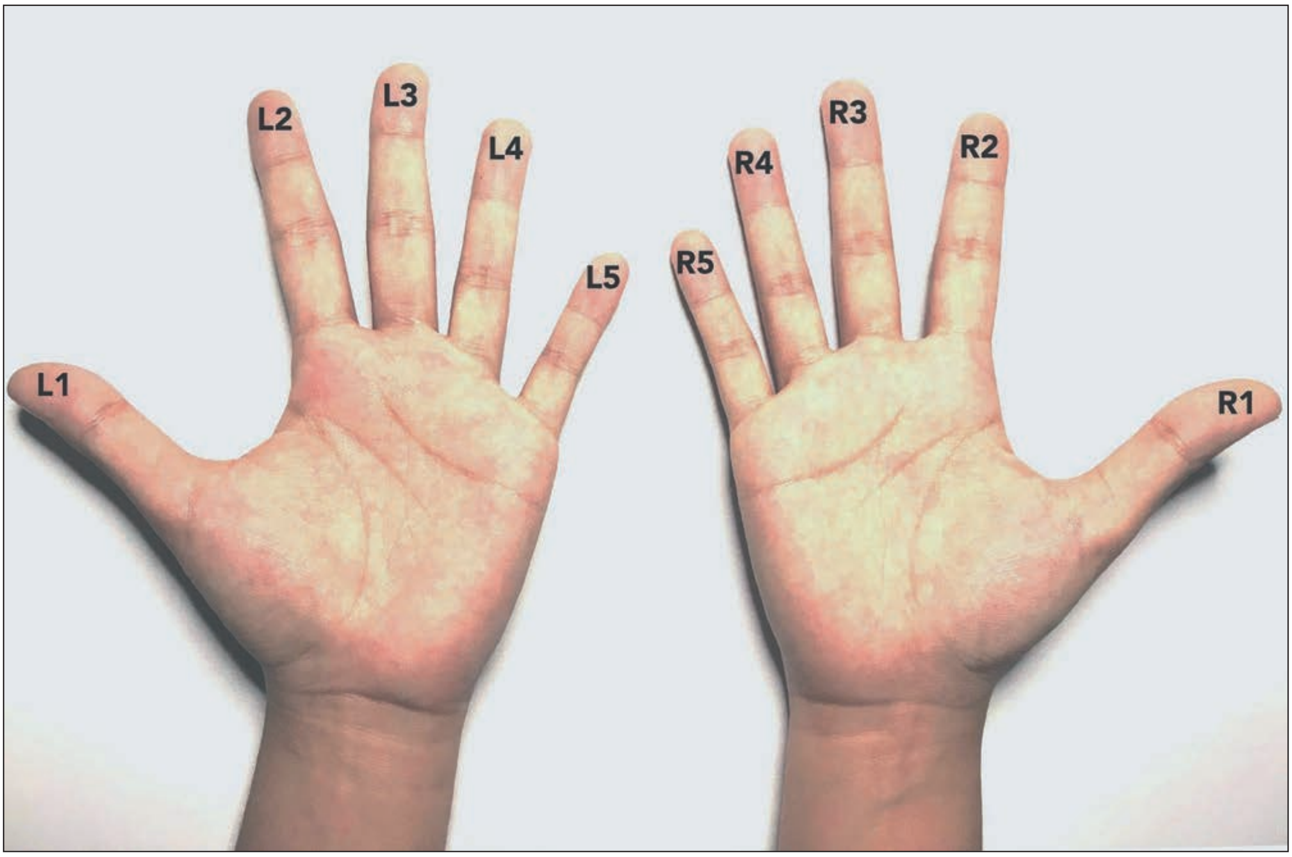

Figure 2. Hand diagram of labeled digits.

Table 1. Student's t-test comparisons for male and female fingerprint ridge densities.

Digit	Male			Female			Mean difference
	Mean	SD	CV %	Mean	SD	CV %	
L1	17.9	2.16	12.05	19.43	2.33	11.97	1.53*
L2	17.40	1.96	11.25	19.32	2.10	10.85	1.92*
L3	18.70	2.12	11.35	20.53	2.32	11.28	1.83*
L4	19.00	2.10	11.03	20.78	2.24	10.79	1.78*
L5	18.80	2.18	11.58	20.61	2.01	9.73	1.81*
R1	17.00	2.05	12.08	18.39	2.05	11.12	1.39*
R2	17.00	1.88	11.07	18.64	1.93	10.35	1.64*
R3	17.50	1.92	10.95	19.57	2.27	11.58	2.07*
R4	18.60	1.94	10.41	20.22	2.26	11.17	1.62*
R5	18.10	2.02	11.16	19.71	2.18	11.06	1.61*
Left	18.40	1.65	8.99	20.13	1.70	8.43	1.73*
Right	17.60	1.52	8.66	19.31	1.64	8.51	1.71*
Combined	18.00	1.49	8.28	19.72	1.58	8.01	1.72*

** Significant at < 0.05.*

Table 2 Paired t-test comparisons between left and right digits in male and female prints.

Digit Comparison	Male		Female	
	Mean difference	P-value	Mean difference	P-value
L1–R1	0.95	< 0.001*	1.04	< 0.001*
L2–R2	0.42	< 0.01*	0.68	< 0.001*
L3–R3	1.15	< 0.001*	0.96	< 0.001*
L4–R4	0.31	0.051	0.56	< 0.01*
L5–R5	0.76	< 0.001*	0.90	< 0.001*

* Significant *at $p < 0.05$.*

Table 3. Mean differences and sectioning points of Filipino ridge densities per digit.

Digit	Male		Female		Mean difference	Sectioning point
	Mean	SD	Mean	SD		
Thumb	17.47	1.77	18.91	1.91	1.44	18.19
Index	17.24	1.69	18.98	1.76	1.74	18.11
Middle	18.09	1.76	20.05	1.98	1.96	19.07
Ring	18.80	1.78	20.43	2.12	1.63	19.62
Little	18.44	1.86	20.09	1.93	1.65	19.27
Combined	18.00	1.49	20.26	1.58	2.26	19.13

Sectioning points for combined or unspecified prints were reported at the same thresholds, with < 19 ridges to be likely male and > 19 ridges to be likely female.

Table 4 presents interfinger differences in male and female prints. With the present sample exhibiting significant differences in RD between sexes, interfinger differences were analyzed independently for each sex. Results reveal that most fingers demonstrate statistically significant interfinger variation, suggesting that one digit can be distinguished from the other through their ridge counts. Males exhibited significant interfinger differences for all fingers, whereas females were shown to have significant RD differences among all fingers were significant except between thumb and index, and between middle and little.

Table 5 presents the frequency distributions, probability densities, and likelihood ratios of mean ridge densities by sex. In the radial area, 74% of males had a mean RD below 19.00, while 67% of females had above 19.00. With a mean radial ridge count of 17 ridges / 25 mm^2, a print is more likely classified male (p = 0.67) and a mean ridge count of 20 ridges / 25 mm^2 likely classified female (p = 0.79). A mean ridge count of 14 or less was determined to have a high probability of being of male origin (p = 1.00), whereas, a mean ridge count of 23 or more ridges were found highly likely to be of female origin (p = 1.00).

Weight and RD were determined to have a weak negative correlation for most fingers. All female digits were found to be negatively correlated with weight. Male RD for individual digits were negatively correlated with weight, except for L3, L4, and R3. For laterally unspecified or combined digits, radial RD was reported to be correlated with weight among males (r = 0.27) and females (–0.37). No relationship between RD and height was established within the sample.

Discussion

Existing literature supports the prevalence of sexual dimorphism in fingerprint ridge characteristics through ridge density. However, likelihood ratios and mean ridge counts have demonstrated considerable variation across existing studies, populations, and methodologies applied. Fingerprint ridge density was found to be sexually dimorphic and laterally distinct, with pronounced interfinger differences in the Filipino sample examined in this study. In the only prior assessment conducted on the sample population (Taduran et al., 2016), mean ridge counts for the radial region were observed at 15.89 ridges per 25 mm^2 for women and 14.57 ridges per 25 mm^2 for men. Furthermore, Taduran et al. (2016) estimates mean ridge counts ⩽ 13 ridges / 25 mm^2 to likely be of male origin and counts ⩾ 16 ridges / 25 mm^2 to likely be of female origin. This study reports mean ridge counts at 18 and 19.72 ridges per mm^2 for males and females respectively. As such, the resulting threshold estimate was reported to be considerably higher at ⩽ 17 ridges / 25 mm^2 for males and ⩾ 20 ridges / 25 mm^2 for females. Contrasted with mean ridge densities reported across different populations (Acree, 1999; Nayak et al., 2010) and within the same population (Taduran et al., 2016), the present

Table 4. ANOVA results for interfinger differences of Filipino ridge densities.

		Thumb	Index	Middle	Ring	Little	
	Thumb	**0.000**	$p = 0.049$*	$p < 0.001$*	$p < 0.001$*	$p < 0.001$*	
	Index	$p = 0.602$	**0.000**	$p = 0.179$	$p < 0.001$*	$p < 0.001$*	
Female	**Middle**	$p < 0.001$*	$p < 0.001$*	**0.000**	$p < 0.001$*	$p = 0.0041$*	**Male**
	Ring	$p < 0.001$*	$p < 0.001$*	$p = 0.006$*	**0.000**	$p < 0.001$*	
	Little	$p < 0.001$*	$p < 0.001$*	$p = 0.74$	$p = 0.013$*	**0.000**	

* *Significant at $p < 0.05$.*

Table 5. Frequency distributions of mean radial fingerprint ridge densities in Filipinos.

Mean RD	Frequency distribution		Probability density		Likelihood ratio		Odds
	Male	Female	Male (C)	Female (C')	C:C'	C':C	Male : Female
⩽ 14	1	0	0.01	0.00	-	-	1.00 > 0.00
15–15.99	10	1	0.07	0.01	10.00	0.10	0.91 > 0.09
16–16.99	24	2	0.16	0.01	12.00	0.08	0.92 > 0.08
17–17.99	41	20	0.27	0.13	2.05	0.49	0.67 > 0.33
18–18.99	35	27	0.23	0.18	1.30	0.77	0.56 > 0.44
19–19.99	25	33	0.17	0.22	0.76	1.32	0.43 < 0.57
20–20.99	10	37	0.07	0.25	0.27	3.70	0.21 < 0.79
21–21.99	1	18	0.01	0.12	0.06	18.00	0.05 < 0.95
22–22.99	3	8	0.02	0.05	0.40	2.50	0.28 < 0.72
23–23.99	0	3	0.00	0.02	-	-	0.00 < 1.00
⩾ 24	0	1	0.00	0.01	-	-	0.00 < 1.00
TOTAL	150	150					

study also reports higher ridge counts and likelihood ratios for both males and females relative to previous estimates. This suggests that factors associated with ridge count variation must be considered when applying pre-determined sex estimation thresholds even within the same population.

Variation in reported ridge counts and likelihood ratios has been attributed to two reasons: 1) differences in the frequencies of fingerprint patterns (Sharma et al., 2007; Namouchi, 2011); and 2) variability in data elicitation methods. Studies on ridge density have employed an array of methods for procuring prints, mainly through the use of rolled impressions (Dhall, Kapoor, 2016; Soanboon et al., 2016) or plain inked prints (Htun et al., 2017). Other technologies employed for documenting ridge density include the use of fingerprint scanners (Omidiora et al., 2012) and live scanners (Adamu et al., 2016). Dissimilarities in print procurement methods are a likely contributory factor in the reported variation in mean ridge counts and likelihood ratios (Gutiérrez--Redomero et al., 2014; Jain, Feng, 2011; Nadgir, Ross, 2006). While existing evidence posits that these differences result from distortion and increased minutiae (Feng et al., 2009), the expanded surface area occupied by rolled impressions has also been cited as a potential source for variation (Gutiérrez-Redomero et al., 2014). This suggests that when situated within a 5 mm x 5 mm area, reported ridge density decreases among rolled impressions as distal lines tend to be spaced further apart relative to plain impressions. Given that the present study reports higher thresholds than existing estimates within the same population (Taduran et al., 2016), differences in fingerprint pattern frequencies may have had less of an impact on the elevated ridge counts reported.

Bilateral structures in the human body generally tend to develop as mirror images of one another (Shen, Pedersen, 2004). However, these structures are rarely found perfectly symmetrical even in cases assumed to have the same genetic input (Potter, 1976). A study conducted among Tunisian males and females revealed that ridge counts were laterally distinct, with higher counts on the right hand than the left for both sexes (Namouchi, 2011). Similarly-conducted assessments across other populations describe the opposite phenomenon, wherein digits on the left hand exhibit finer ridges than in the right (Gutiérrez-Redomero et al., 2008). Patterns on interfinger ridge count differences also vary across populations. Radial and ulnar ridge counts among Spanish Caucasians tend to increase from the thumb to the ring finger (Gutiérrez-Redomero et al., 2008). These interfinger differences were likewise noted in the present research, except among female thumb-index and ring-little pairs. Lateral and interfinger variation can be attributed to an array of factors, ranging from the aggregation of the finest ridges along the anatomical axis of the hand to testosterone levels. Jamison et al. (1993) report that individuals with higher testosterone levels revealed higher left-hand ridge counts among males and higher right-hand ridge counts among females. While this hypothesis may be better supported in other contexts, the present study suggests an auxiliary contributory factor for variation as both males and females exhibited higher radial ridge density on the left hand. Parallel to existing findings (Gutiérrez--Redomero et al., 2008) likewise examining plain prints, methodological differences in print procurement and analysis may have had greater influence over other factors.

Albeit sparse, associations between fingerprint features, stature, and weight, have been explored by several studies in recent years. Where Brazelle et al. (2017) reports that African American males exhibit significantly lower RDs than shorter males, Kaur and Sharma (2016) assert that ridge density remains altogether independent from stature. Mundorff et al.'s (2014) study examining ridge breadth also forwards the possibility of correlating fingerprint features with stature and weight. While their study reports that taller and heavier individuals tend to demonstrate higher ridge breadth than others, the strongest associations were found between ridge breadth and weight. The results of the present study support the findings of Kaur and Sharma (2016) and Mundorff et al. (2014), given that no statistically significant association was established between ridge density and stature and only a weak negative correlation was observed between ridge density and weight. This may be attributed to the use of plain prints alongside possible cross-ethnic variation in finger size (Davies et al., 1980). Despite inconclusive results, the potential for eliciting relationships among ridge density, stature, and weight is not unfounded. Studies on finger length ratios (Krishan et al., 2012; L. Kumar et al., 2014; S. S. Kumar et al., 2014), ridge breadth (Mundorff et al., 2014), as well as fingerprint length (Nataraja Moorthy, Zulkifly, 2016), have reported favorable results for stature and/or weight estimation using dermatoglyphic or fingerprint analysis. Sexual dimorphism in height has been explored within the Philippine context (Taduran et al., 2017), thus providing a substantial basis for the development of stature estimation in future studies (Go, 2018).

In sum, mean ridge density remains significantly higher among females than males across all comparisons conducted in this study. Paralleling the existing findings on sexual dimorphism in ridge density, the present analysis forwards that ridge density can be a viable tool for sex determination. However, given the lack of homogeneity in fingerprint procurement methods and population characteristics, fingerprint analyses must factor in cross-methodological and cross-cultural variation. With the majority of fingerprint impressions being latent in crime scenes (Feng et al., 2009), differences in sex-estimating thresholds for rolled and plain prints must therefore be considered.

Conclusion

This study was conducted to describe fingerprint ridge characteristics within a Filipino sample, examine the viability of ridge density as a tool for sex estimation, and determine specific thresholds for estimating sex within the target sample. Results reveal that females tend to have significantly higher ridge densities than males. Interfinger differences and differences in laterality were also found to be predominantly significant within the sample. As such, this study forwards that the epidermal ridge density of plain prints can serve as a reliable predictor of biological sex. Specifically, ridge counts of $\leqslant 17$ ridges / 25 mm^2 were found more likely to be of male origin and ridge counts of $\geqslant 20$ ridges / 25 mm^2 were likely to be of female origin. While the findings of this study coincide with existing literature conducted within and outside the population examined, the present study reveals higher ridge counts and likelihood ratios for both sexes. This suggests that methodological disparities alongside the limited impact of pattern variation may factor into the reported ridge counts and their resulting threshold estimates. As research on fingerprint ridge density maintains to be a recent milieu, future studies may explore age, gene pool diversity, and ethnicity as other potential sources for variation.

Acknowledgments

The authors would like to extend their gratitude to the participants of this study and the University of the Philippines Diliman Department of Anthropology for assisting in gathering data.

Sources of figures and table: authors

Bibliography

1. Acree, M.A. (1999). Is there a gender difference in fingerprint ridge density?. *Forensic Science International*, *102*(1), https://doi.org/10.1016/S0379-0738(99)00037-7.
2. Adamu, L., Ojo, S., Danborno, B., Adebisi, S., Taura, M. (2016). The potential of thumbprint profiles in prediction of body mass index among Hausa ethnic group of Nigeria. *Bayero Journal of Biomedical Sciences*, *1*(1).
3. Barua, K., Bhattacharya, S., Mali, K. (2011). Fingerprint identification. *Global Journal of Computer Science & Technology*, *11*(6).

4. Brazelle, S., Carbone, A., Fleming, K. (2017). Ridge density as an investigative tool for stature. *Journal of Forensic Identification*, *67*(4).
5. Cummins, H., Waits, W.J., McQuitty, J.T. (1941). The breadths of epidermal ridges on the finger tips and palms: A study of variation. *American Journal of Anatomy*, *68*(1), https://doi.org/10.1002/aja.1000680106.
6. Davies, B., Abada, A., Benson, K., Courtney, A., Minto, I. (1980). A comparison of hand anthropometry of females in three ethnic groups. *Ergonomics*, *23*(2), https://doi.org/10.1080/0014013800 8924731.
7. Dhall, J.K., Kapoor, A.K. (2016). Fingerprint ridge density as a potential forensic anthropological tool for sex identification. *Journal of Forensic Sciences*, *61*(2), https://doi.org/10.1111/1556-4029.12959.
8. Eshak, G.A., Zaher, J.F., Hasan, E.I., El-Azeem Ewis, A.A. (2013). Sex identification from fingertip features in Egyptian population. *Journal of Forensic and Legal Medicine*, *20*(1), https://doi.org/10.1016/j.jflm.2012.04.038.
9. Feng, J., Yoon, S., Jain, A. (2009). Latent fingerprint matching: Fusion of rolled and plain fingerprints. *International Conference on Biometrics*.
10. Go, M.C. (2018). Appraising forensic anthropology in the Philippines: Current status and future directions. *Forensic Science International*, *288*, https://doi.org/10.1016/j.forsciint.2018.04.035.
11. 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 Science International*, *180*(1), https://doi.org/10.1016/j.forsciint.2008.06.014.
12. Gutiérrez-Redomero, E., Rivaldería, N., Alonso--Rodríguez, C., Sánchez-Andrés, Á. (2014). Assessment of the methodology for estimating ridge density in fingerprints and its forensic application. *Science & Justice*, *54*(3), https://doi.org/10.1016/j.scijus.2013.11.004.
13. Htun, K.S., Hlaing, K.H., Zaw, T., Hlaing, T.M. (2017). Stereomicroscopic gender determination from fingerprint ridge density and fingerprint patterns. *24th Myanmar Military Medical Conference*.
14. Jain, A.K., Feng, J. (2011). Latent fingerprint *matching*. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *33*(1), https://doi.org/10.1109/TPAMI.2010.59.
15. Jamison, C.S., Meier, R.J., Campbell, B.C. (1993). Dermatoglyphic asymmetry and testosterone levels in normal males. *American Journal of Physical Anthropology*, *90*(2), https://doi.org/10.1002/ajpa.1330900205.
16. Kapoor, N., Badiye, A. (2015). Sex differences in the thumbprint ridge density in a central Indian population. *Egyptian Journal of Forensic Sciences*, *5*(1), https://doi.org/10.1016/j.ejfs.2014.05.001.
17. Kaur, M. (2019). Fingerprint ridge density of convicted male and female prisoners: A pilot study. *Brazilian Journal of Forensic Sciences, Medical Law and Bioethics*, *8*(4), https://doi.org/10.17063/bjfs8(4)y2019226.
18. 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*, https://doi.org/10.1016/j.jflm.2016.10.011.
19. Krishan, K., Kanchan, T., Asha, N. (2012). Estimation of stature from index and ring finger length in a North Indian adolescent population. *Journal of Forensic and Legal Medicine*, *19*(5), https://doi.org/10.1016/j.jflm.2011.12.036.
20. Krishan, K., Kanchan, T., Ngangom, C. (2013). A study of sex differences in fingerprint ridge density in a North Indian young adult population. *Journal of Forensic and Legal Medicine*, *20*(4), https://doi.org/10.1016/j.jflm.2012.09.008.
21. Kumar, L., Agarwal, S., Garg, R., Dixit, A.P. (2014). Correlation between index finger and stature in Uttarakhand population. *The Anthropologist*, *17*(3), https://doi.org/10.1080/09720073.2014.11891481.
22. Kumar, S.S., Shetty, P., Shankar (2014). Estimation of stature from middle finger length-in Salem region. *Indian Journal of Forensic Medicine & Toxicology*, *8*(2), https://doi.org/10.5958/0973-9130.2014.00 676.8.
23. Mundorff, A.Z., Bartelink, E.J., Murad, T.A. (2014). Sexual dimorphism in finger ridge breadth measurements: A tool for sex estimation from fingerprints. *Journal of Forensic Sciences*, *59*(4), https://doi.org/10.1111/1556-4029.12449.
24. Nadgir, R., Ross, A. (2006). *Roll versus Plain Prints: An Experimental Study Using the NIST SD 29 Database*. West Virginia University.
25. Namouchi, I. (2011). Anthropological significance of dermatoglyphic trait variation: An intra-Tunisian population analysis. *International Journal of Modern Anthropology*, *1*(4), https://doi.org/10.4314/ijma.v1i4.1.
26. Nataraja Moorthy, T., Zulkifly, N. (2016). Determination of stature from fingerprints in Malaysian Malays by regression analysis. *Malaysian Applied Biology Journal*, *45*(2).
27. Nayak, V.C., Rastogi, P., Kanchan, T., Yoganarasimha, K., Kumar, G.P., Menezes, R.G. (2010). Sex differences from fingerprint ridge density in Chinese and Malaysian population. *Forensic Science International*, *197*(1–3), https://doi.org/10.1016/j.forsciint.2009.12.055.
28. Ohler, E.A., Cummins, H. (1942). Sexual differences in breadths of epidermal ridges on fingertips and palms. *American Journal of Physical Anthropology*, *29*(3), https://doi.org/10.1002/ajpa.13302 90302.
29. Omidiora, E., Ojo, O., Yekini, N., Tubi, T. (2012). Analysis, design and implementation of human

fingerprint patterns system towards age & gender determination, ridge thickness to valley thickness ratio (RTVTR) & ridge count on gender detection. *International Journal of Advanced Research in Artificial Intelligence*, *1*(2), https://doi.org/10.14569/IJARAI.2012.010210.
30. Patil, A., Malik, A., Shirole, T. (2018). Finger print ridge density a tool for gender determination. *IOSR Journal of Dental and Medical Sciences*, *17*(8).
31. Potter, M. (1976). Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory*, *2*(5).
32. Sharma, P.R., Gautam, A.K., Tiwari, P.K. (2007). Dermatoglyphic variations in five ethno-geographical cohorts of Indian populations: A pilot study. *The Internet Journal of Biological Anthropology, 2*.
33. Shen, M., Pedersen, RA. (2004). Developmental origins of the mammalian body plan. In: C. Epstein, R. Erickson, A. Wynshaw-Boris (ed.), *Inborn Errors of Development: The Molecular Basis of Clinical Disorders of Morphogenesis*. Oxford–New York: Oxford University Press.
34. Singh, N., Chand, D., Hussain, M.K., Bakri, M. (2019). Gender identification of Emirati population using finger prints. *Eurasian Journal of Analytical Chemistry*, *14*(2).
35. Soanboon, P., Nanakorn, S., Kutanan, W. (2016). Determination of sex difference from fingerprint ridge density in northeastern Thai teenagers. *Egyptian Journal of Forensic Sciences*, *6*(2), https://doi.org/10.1016/j.ejfs.2015.08.001.
36. Taduran, R.J.O., Tadeo, A.K. v., Escalona, N.A.C., Townsend, G.C. (2016). Sex determination from fingerprint ridge density and white line counts in Filipinos. *HOMO*, *67*(2), https://doi.org/10.1016/j.jchb.2015.11.001.
37. Taduran, R.J.O., Tan, M.L., Townsend, G.C. (2017). Different methods for estimating height in a Filipino sample: Forensic implications. *Australian Journal of Forensic Sciences*, *49*(1), https://doi.org/10.1080/00450618.2015.1122081.
38. Wahdan, A., Khalifa, H. (2017). The study of fingerprint ridge density in a sample of Egyptian population and its application for sex identification. *Mansoura Journal of Forensic Medicine and Clinical Toxicology*, *25*(1), https://doi.org/10.21608/mjfmct.2018.47259.