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ORIGINAL ARTICLE

Determination of sex difference from fingerprint ridge density in northeastern Thai teenagers

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KEYWORDS

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Abstract: Although, there has already been much research on the differences between sexes in fingerprint ridge density and its variability in the Thai population, such studies have not included native northeastern Thais aged between 14 and 24 who are descended from northeastern Thai ancestry. This study intends to determine the topological, age-grouping and sexual differences in fingerprint ridge density (RD) in such populations. Fingerprints were collected from 353 unrelated volunteers (191 males and 162 females) and classified into three groups, that is, group A (total subjects), group B (14–18 years old) and group C (18–24 years old). RD was assessed for two topological areas, radial and ulnar. Significant differences between genders and age groups were obtained in both counting areas. Females exhibit higher RD i.e. narrower ridges, than males. A decrease in RD values with increasing age was also detected. The RD threshold for discrimination of sexes, computed based on Bayes' theorem, was achieved in all groups and counting areas, enabling its use in forensic investigation.

1. Introduction

Fingerprints, composed of ridges and furrows, are one of the dermatoglyphic traits that can be used for identification of an individual. The formation of the ridges is governed by a multitude of genes and the environment of the embryo during its first month of development, in other words the content of the amniotic fluid.[1,2] Once created, the ridges do not transform anymore throughout the lifetime except in cases of injury. Although the ridge number in a fingerprint is not age-dependent, the ridges grow further apart with an increasing age as the body size increases.[3–6] Generally speaking, the study of dermatoglyphics is either qualitative or quantitative. Qualitative dermatoglyphics focuses on, among other things, patterns of fingerprints and types of minutiae; while, ridge count and finger ridge density (RD) are examples of the fingerprints' quantitative study.

Fingerprints are unique in each individual even in identical twins they are not identical.[7] Thus, fingerprint pattern types and various specific characteristics have been utilized worldwide for personal identification. Latent fingerprints are a primary evidence that investigating officers need to collect at the crime scene.

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The study of RD has been incessantly reported in multiple populations for forensic applications.[8–16] One study reported RD evaluation in the northeast of Thailand[17]; however, teens were not among its subject groups. Based on reports in 2013 by the Department of Juvenile Observation and Protection, as they have been involved in a large number of cases in Thailand (36,763 cases), there is an urgent need for RD evaluations among the teenagers. The term teenager is one that, the World Health Organization defines as those who are aged between 15 and 24, while the Thai Royal Act and the Thai Royal Institute Dictionary defines as those whose ages range from 15 to 18 and 14 to 18, respectively.[18] Combining all three definitions, we set the age group of the teenagers in this study as between 14 and 24 years.

Our main objectives in this study are to compare the RD difference between male and female teenagers and within the same sex if RD differs between the younger group of 14–18 years old and the older one of over 18 up to 24 years of age. We also compared our RD results to the existing database of other populations.[17] Although ridge formation was determined by genes and the content of the amniotic fluid, ridge number has been proven to be highly genetically inherited, with as much as 90–95% contribution by the genes.[19,20] Consequently, if populations are genetically distinct, RD is likely different between then.

2. Materials and methods

Since the present study involved underaged individuals, on top of the informed consent, those under 18 years of age must have their participation approved by their parents. To qualify as a Northeasterner for our study, unrelated individuals (by at least two generations) must be descended from the northeastern Thai ancestry and they must come from a family where all members are able to speak the northeastern Thai dialect. This research protocol was approved by the Khon Kaen University Ethics Committee for Human Research. In total, fingerprints from all fingers of 353 subjects (191 males and 162 females) were obtained, using an ink pad and rolled ink print technique.[21]

Generally, fingerprint ridge density is acquired from a number of ridges over an area of $5 \times 5\ \text{mm}^2$ based on the method of Acree.[8] Our study slightly modified this method[8] and that of the counting portion described by Gutierrez-Redomero et al.[6] We constructed two squares of $5 \times 5\ \text{mm}^2$ each and placed them on the second ridge above the central core in both the radial and ulnar areas (Fig. 1). In each square ridges were counted from one corner to the diagonally opposite corner. Dots were not counted, while forks and lakes were counted as two ridges. To count the ridges[22], each fingerprint on a collected fingerprint card was scanned to an image format file. The image was then superimposed on the two squares of $5 \times 5\ \text{mm}^2$, each with one diagonal line, which were constructed on a spreadsheet using the Microsoft Word program. The superimposed images were enlarged five times for more precise ridge counting.

In the statistical analyses, the RD values for the radial and ulnar areas of all 10 fingers were calculated means in each subject were used to compute the mean for each area and each hand in both sexes. The mean RD for each area for all 10 fingers was also computed. The comparison of means for the radial and ulnar areas in each hand and means for all 10 fingers among genders was executed using independent t-test as embedded in SPSS version 17.0.[23]

The probability density in male (C) and female (C') in each given RD density was calculated by observed RD and then these two values in each given RD density were used to compute the likelihood ratio (LR). Let RD be the ridge density, C the male donor, and C' the female donor:

$$\text{LR} = \frac{\text{probability of the observing a given ridge density that belongs to male contributor}\,(C)\,\text{or}\,P(\text{RD}/C)}{\text{probability of the observing a given ridge density that belongs to female contributor}\,(C')\,\text{or}\,P(\text{RD}/C')}$$

The strength of support for one of the hypotheses: C or C' was indicated by LR value. Posterior probabilities i.e. $P(C/\text{RD})$ and $P(C'/\text{RD})$ were computed using Bayes' theorem as expressed in the following equation.

$$\text{Posterior probability} = \frac{P(C) \times P(\text{RD}/C)}{P(C) \times P(\text{RD}/C) + P(C') \times P(\text{RD}/C')}$$

Figure 1 Two squares of $5 \times 5\ \text{mm}^2$ each were placed just above the core of a fingerprint image. For each square, a diagonal line was constructed. Ridges passing through the line were counted for the calculation of ridge density.

Let $P(C)$ and $P(C')$ are prior probability of male and female, respectively. This study employed two sets of $P(C)$ and $P(C')$ to calculate the posterior probability. Assuming equal likelihood for both sexes to commit a crime, the prior probabilities for males and females are equal at 0.5. However, based on the crimes committed by teenagers in Thailand in 2013, males were found to be involved in about 90 percent of the cases.[24] As a result, the second set of the prior probabilities were 0.9 for $P(C)$ and 0.1 for $P(C')$.

In addition, due to epidermal RD change during pubertal growth[25], all analyses mentioned above were done in total RD data as well as in each categorizing groups based on age (less than and over 18 years old). Briefly, three groups were statistically analyzed for RD: group A (total 14–24 years old), group B (14–18 years old) and group C (18–24 years).

3. Results and discussion

3.1. Differences in RD by counting area and gender

Table 1 shows sex wise distribution of fingerprint RD from all groups in radial and ulnar areas. The similar pattern of distribution of RD in both areas was observed in all groups. In group A, the RD in radial and ulnar areas ranges from 12 to 18 ridges/25 mm^2 and 12 to 20 ridges/25 mm^2 among males and 14 to 20 ridges/25 mm^2 and 13 to 21 ridges/25 mm^2 among females, respectively. In group B, the RD distribution ranges from 13 to 18 ridges/25 mm^2 (radial) and 14 to 20 ridges/25 mm^2 (ulnar) of males and 15 to 20 ridges/25 mm^2 (radial) and 15 to 21 ridges/25 mm^2 (ulnar) of female, while in group C the ranges were from 12 to 17 ridges/25 mm^2 (radial) and 12 to 18 ridges/25 mm^2 (ulnar) in male and from 14 to 19 ridges/25 mm^2 (radial) and 13 to 20 ridges/25 mm^2 (ulnar) in female.

Descriptive statistics for RD in all fingers together in each designated area of three groups is shown in Table 2. It is apparent that the difference of RD values between male and female is statistically significant in both counting areas and in all groups ($p < 0.001$). The radial area ($t = -10.078$, -9.36 and -8.06 in group A, B and C, respectively) exhibited a larger sex difference than the ulnar area ($t = -4.438$, -5.54 and -4.89 in group A, B and C, respectively). Distribution of RD in both areas from 3 groups is in Fig. 2.

Finger to finger, the mean RD in each area and each group is shown in Fig. 3 is higher in females than in males. Our results were concordant with the existing literature.[26] The higher RD in female than in male is attributed to the fact that males have larger epidermal ridge breadth than females.[27,28] Approximately 10% of the difference in ridge breadth was observed between males and females and the increment of ridge density is related to the number of X-chromosome.[29] In addition, the presence of the Y-chromosome is associated with the increase of distance between ridges. The narrowest ridge breadth was observed in the patients with Turner's syndrome (X), while the subjects of XYY males had the widest ridge breadth.[5,30,31] Therefore, not only the number of ridges among females is higher than males but also ridges in females are packed more densely in a given area than males.[26] In addition, Gutiérrez-Redomero et al.[6] stated that epidermal ridge breadth varies considerably among different dermatoglyphic topological regions and between the sexes, and that there is a relationship between ridge breadth and hand size. Since males have larger body size than females, the equal number of ridges on a larger surface area means males have a lower fingerprint ridge density.[32]

Earlier studies reported that there was no significant difference in the mean of ridge breadth in the second interdigital area between males and females up to the age of 12 years, whereas in older children, the difference between the two sexes was significant.[4,6] In agreement with those reports, since our studied samples are aged between 14 and 24 years old, it is not surprising that we observed the difference between sexes. Surprisingly, this study divided sampled groups based on age 18 years old, therefore, when mean RD value was compared among age-related grouping, group B (14–18 years old) has higher mean RD than group C (19–24 years old) in both counting areas with statistical significance ($t = 2.930$ and $t = 6.650$ in radial and ulnar areas, respectively, $P < 0.01$), and group A has intermediated value. A reduction in RD values from both radial and ulnar areas with increasing age is clearly visible (Fig. 3). It might be explained by biological factors involved in body growth and development. Teenagers

Table 1 Group wise and sex wise distribution of fingerprint ridge density in radial and ulnar areas.

RD	Radial area						Ulnar area					
	A		B		C		A		B		C	
	M	F	M	F	M	F	M	F	M	F	M	F
12	0.3	0.0	0.0	0.0	0.64	0.0	0.6	0.0	0.0	0.0	1.27	0.0
13	0.3	0.0	1.5	0.0	3.18	0.0	3.6	0.9	0.0	0.0	7.64	1.91
14	7.1	0.6	7.1	0.0	7.01	1.27	6.5	3.5	4.6	0.0	8.92	7.64
15	17.6	6.2	18.4	1.02	16.56	12.74	13.5	9.3	16.8	1.53	10.19	19.11
16	17.8	13.6	25	7.14	7.64	21.66	13.3	11.8	20.4	9.7	4.46	14.65
17	7.4	12.7	11.2	9.2	2.55	17.2	8.3	7.2	12.2	7.14	3.82	7.01
18	2.3	9.3	4.1	10.2	0.0	8.28	5.7	7.3	9.2	7.7	1.27	6.37
19	0.0	2.5	0.0	3.6	0.0	1.27	2.1	3.4	3.6	4.6	0.0	1.91
20	0.0	0.8	0.0	1.5	0.0	0.0	0.3	2.6	0.51	1.5	0.0	3.82
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.0

RD = finger ridge density; A = age group 14–24 years old; B = age group 14–18 years old; C = age group 18–24 years old.

Table 2 Descriptive statistics and sex differences of fingerprint ridge density on radial and ulnar areas in all analyzed age groups.

Sex	Statistics	Radial area			Ulnar area		
		A	B	C	A	B	C
Male	*n*	191	132	59	191	132	59
	Mean	15.98	16.21	15.46	16.23	16.7	15.17
	S.D	1.16	1.12	1.07	1.54	1.33	1.49
	Range	12–18	13–18	12–17	12–20	14–20	12–18
	Median	15	18	15	15	16	15
Female	*n*	162	64	98	162	64	98
	Mean	17.23	17.81	16.85	16.99	17.81	16.44
	S.D	1.17	1.12	1.071	1.64	1.29	1.63
	Range	14–20	15–20	14–19	13–21	15–21	13–20
	Median	16	18	16	16	16	15
t-test		−10.08	−9.36	−8.06	−4.42	−5.54	−4.89
p-value		0.001	0.001	0.001	0.001	0.001	0.001

A = age group 14–24 years old; B = age group 14–18 years old; C = age group 18–24 years old.

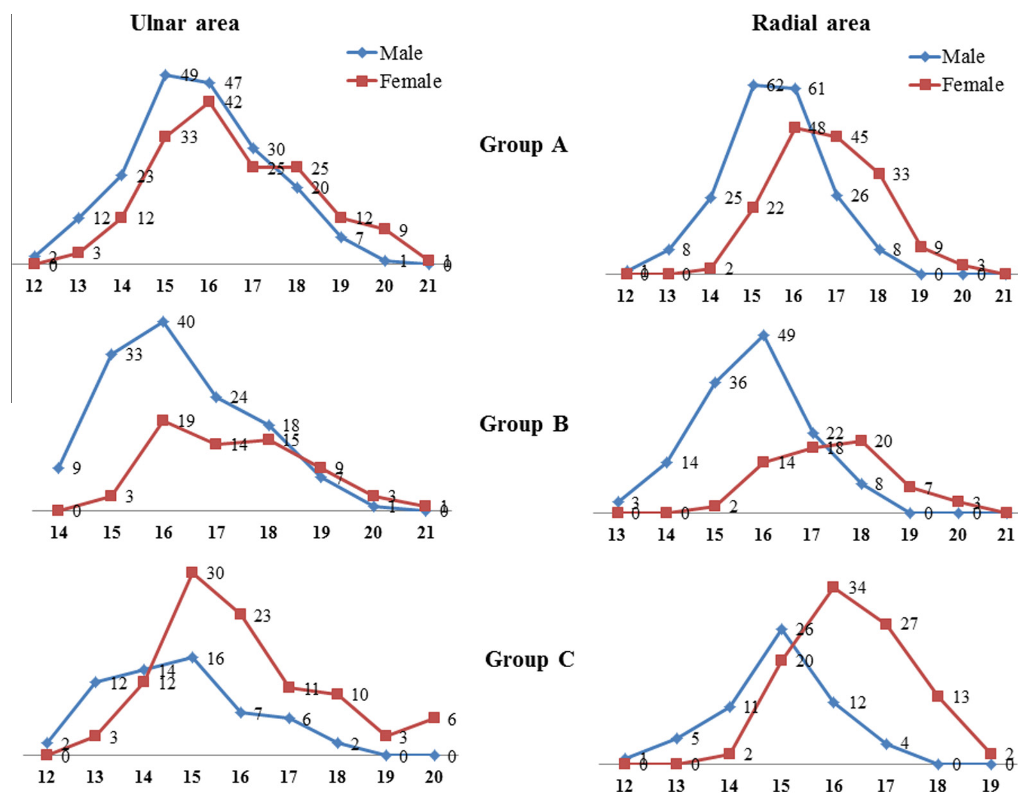
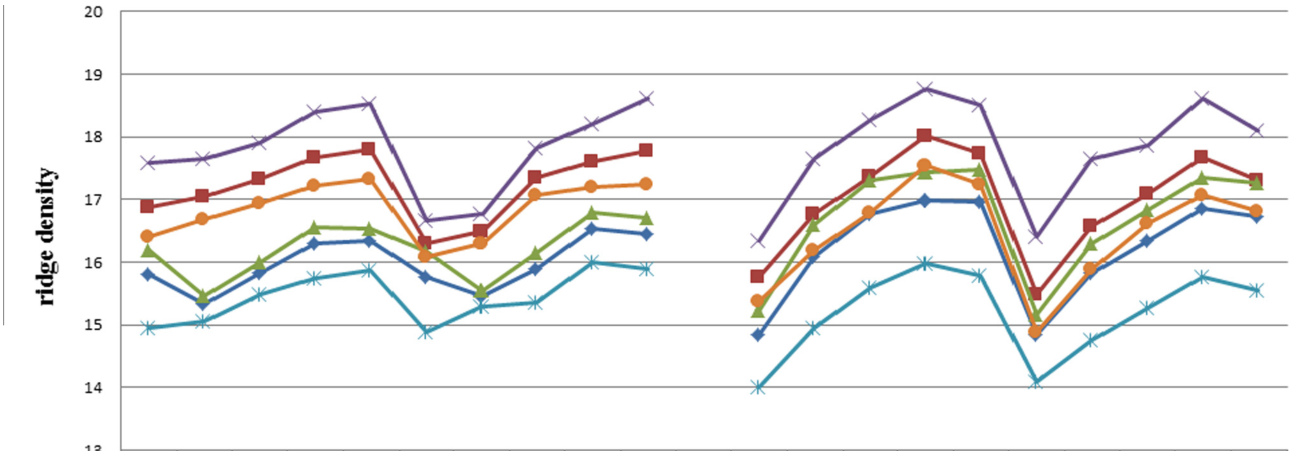


Figure 2 Frequency distribution of fingerprint ridge density in the radial and ulnar areas of a fingerprint.

whose age was lower than 18 might have pubertal growth less than the other group.[18,33]

3.2. RD comparison among population

Since RD has been reported as one of the genetically quantitative traits in human populations[26], this RD difference might reflect population variation. Fingerprint ridge density in this study was compared to different studies for radial and ulnar areas in males and females (Table 3). Females have a higher RD than males in all populations, indicating sexual dimorphism in this trait of various human populations. In addition, a universal RD heterogeneity was observed. The northeastern Thai population exhibited a higher RD than Indian and sub-Saharan populations, whereas the RD from northeastern Thailand was lower than populations from Argentina and Spain. Actual population variations sourced from genetically diverse origins might cause these differences. In addition methodological differences in fingerprint collection and position of the counting area might also play a role in RD difference among populations.



	1R	2R	3R	4R	5R	6R	7R	8R	9R	10R	1U	2U	3U	4U	5U	6U	7U	8U	9U	10U
A Male	15.81	15.34	15.84	16.31	16.34	15.77	15.47	15.9	16.54	16.46	14.85	16.09	16.78	16.99	16.96	14.84	15.83	16.35	16.86	16.73
A Female	16.87	17.06	17.33	17.68	17.8	16.31	16.49	17.36	17.6	17.79	15.77	16.77	17.37	18.02	17.74	15.49	16.59	17.1	17.68	17.31
B Male	16.197	15.47	15.992	16.561	16.545	16.167	15.546	16.152	16.788	16.712	15.235	16.606	17.311	17.447	17.485	15.174	16.311	16.833	17.356	17.265
B Female	17.578	17.656	17.906	18.391	18.531	16.672	16.766	17.813	18.219	18.625	16.344	17.641	18.266	18.766	18.5	16.406	17.656	17.859	18.609	18.094
C Male	14.949	15.051	15.492	15.746	15.881	14.898	15.305	15.356	16	15.898	14	14.949	15.593	15.983	15.797	14.085	14.763	15.271	15.763	15.542
C Female	16.408	16.684	16.949	17.214	17.337	16.082	16.306	17.071	17.204	17.245	15.388	16.204	16.786	17.541	17.245	14.898	15.888	16.612	17.071	16.806

Figure 3 Mean ridge density in each area for the ten fingers according to sex and age groups. Group A (total data), group B (14–18 years old) and group C (18–24 years old), R: radial, U: ulnar, 1, 2, 3, 4, 5: thumb, index, medium, ring, and little of right hand and 6, 7, 8, 9, 10: thumb, index, medium, ring, and little of left hand.

Table 3 Fingerprint ridge density by radial and ulnar areas among males and females in various studies.

Sample	Age (years)	RD mean (standard deviation)			
		Radial		Ulnar	
		Male	Female	Male	Female
Afro-American (USA)[8]	18–67	10.90 (1.15)	12.61 (1.43)	–	–
Caucasian-American (USA)[8]	18–67	11.14 (1.31)	13.32 (1.24)	–	–
Malaysian[12]	18–25	11.44 (0.98)	13.63 (0.90)	–	–
Chinese[12]	18–25	11.73 (1.06)	14.15 (1.03)	–	–
Southern Indian[9]	18–60	12.80 (0.90)	14.60 (0.08)	–	–
Southern Indian[11]	18–25	11.05 (1.11)	14.20 (0.63)	–	–
Southern Indian[13]	18–65	12.57 (1.49)	14.15 (1.68)	–	–
Northern Indian[26]	18–25	15.84 (1.23)	17.94 (1.23)	15.51 (1.08)	17.11 (1.207)
Sub-Saharan[16]	18–48	14.33 (1.22)	–	14.51 (1.29)	–
Argentina (Mataco-Mataguayo)[6]	6–25	16.62 (2.71)	17.82 (2.87)	16.54 (2.80)	17.29 (1.76)
Argentina (Puna-Quebrada)[15]	–	16.67 (1.78)	18.47 (1.56)	16.39 (1.75)	17.62 (1.62)
Argentina (Ramal)[15]	–	17.04 (1.68)	19.08 (1.84)	16.10 (1.61)	17.75 (1.69)
Spanish[33]	18–34	16.85 (1.76)	19.11 (1.79)	15.38 (1.49)	16.84 (1.58)
Central Thais[34]	20–60	15.81 (1.28)	16.58 (1.35)	–	–
Northeastern Thais[17]	20–30	14.72 (1.21)	16.53 (1.18)	14.77 (1.24)	16.36 (1.17)
Northeastern Thais[22]	10–12	15.89 (1.90)	16.19 (1.48)	15.84 (1.96)	16.00 (1.44)
Northeastern Thais*	14–24	15.97 (1.16)	17.23 (1.17)	16.23 (1.54)	16.98 (1.64)

* Present study.

3.3. A threshold of sex differentiation

The distribution of the ridge density frequency used for calculation of the likelihood ratio and posterior probabilities are shown in Tables 4 and 5. In ulnar area (Table 4), the results of group A when assuming equal prior probability ($P(C) = P(C') = 0.5$) showed that a fingerprint possessing up to 15 ridges/25 mm^2 has a probability of being from male while 18 ridges/25 mm^2 or more is most likely to be of female origin. The RD ranging from 16 to 17 ridges/25 mm^2 failed to determine sex owing to equal posterior probability in both sexes. Presuming men are 9 times more likely to commit a crime than females ($P(C) = 0.9$, $P(C') = 0.1$), the threshold of sex determination changed to 19–20 ridges/25 mm^2 by which a count of fewer than 20 is most likely to be of male origin, and greater ($\geqslant 20$ ridges/25 mm^2) of female.

Table 4 Data of probability densities, likelihood ratios, and posterior probabilities derived from observed ridge densities in ulnar area. Values in parentheses represent posterior probabilities.

Group A (14–24 years old)

RD	Probability densities M	Probability densities F	L_M	L_F	Posterior probabilities a	Posterior probabilities b
≤12	0.01	0	NA	0	M (1) > F (0)	M (1) > F (0)
13	0.06	0.02	3.00	0.33	M (0.77) > F (0.23)	M (0.97) > F (0.03)
14	0.12	0.07	1.71	0.58	M (0.62) > F (0.38)	M (0.94) > F (0.06)
15	0.26	0.2	1.30	0.77	M (0.56) > F (0.44)	M (0.92) > F (0.08)
16	0.25	0.26	0.96	1.04	M (0.49) < F (0.51)	M (0.90) > F (0.10)
17	0.16	0.15	1.06	0.94	M (0.50) = F (0.50)	M (0.90) > F (0.10)
18	0.1	0.15	0.66	1.5	M (0.40) < F (0.60)	M (0.86) > F (0.14)
19	0.04	0.07	0.57	1.75	M (0.33) < F (0.67)	M (0.82) > F (0.18)
20	0.01	0.06	0.17	6	M (0.09) < F (0.91)	M (0.46) < F (0.54)
21	0	0.01	0	NA	M (0) < F (1)	M (0) < F (1)

Group B (14–18 years old)

RD	Probability densities M	Probability densities F	L_M	L_F	Posterior probabilities a	Posterior probabilities b
≤12	–	–	–		–	–
13	–	–	–		–	–
14	0.07	0	NA	0	M (1) > F (0)	M (1) > F (0.01)
15	0.25	0.05	5.00	0.20	M (0.84) > F (0.16)	M (0.98) > F (0.02)
16	0.30	0.30	1.00	1.00	M (0.51) > F (0.49)	M (0.90) > F (0.10)
17	0.18	0.22	0.82	1.22	M (0.45) < F (0.55)	M (0.88) > F (0.12)
18	0.14	0.23	0.60	1.64	M (0.37) < F (0.63)	M (0.84) > F (0.16)
19	0.05	0.14	0.36	2.80	M (0.27) < F (0.73)	M (0.77) > F (0.23)
20	0.01	0.05	0.20	5.00	M (0.14) < F (0.86)	M (0.41) < F (0.59)
≥21	0.00	0.02	0	NA	M (0) < F (1)	M (0) < F (1)

Group C (18–24 years old)

RD	Probability densities M	Probability densities F	L_M	L_F	Posterior probabilities a	Posterior probabilities b
≤12	0.03	0	NA	0	M (1) > F (0)	M (1) > F (0)
13	0.20	0.03	6.67	0.15	M (0.87) > F (0.13)	M (0.98) > F (0.02)
14	0.24	0.12	2.00	0.50	M (0.66) > F (0.34)	M (0.95) > F (0.05)
15	0.27	0.31	0.87	1.15	M (0.47) < F (0.53)	M (0.89) > F (0.11)
16	0.12	0.23	0.52	1.92	M (0.34) < F (0.66)	M (0.82) > F (0.18)
17	0.10	0.11	0.90	1.10	M (0.48) < F (0.52)	M (0.89) > F 0.11)
18	0.03	0.10	0.30	0.33	M (0.25) < F (0.75)	M (0.75) > F (0.25)
19	0.00	0.03	0.00	NA	M (0) < F (1)	M (0) < F (1)
20	0.00	0.06	0.00	NA	M (0) < F (1)	M (0) < F (1)
–	–	–	–		–	–

M is Probability densities of Male $P(RD/C)$; F is Probability densities of female = $P(RD/C')$;
L_M is Likelihood ratio for male $P(RD/C)/ P(RD/C')$; L_F is Likelihood ratio for female $P(RD/C')/P(RD/C)$;
a is prior probability of male ($P(C)$) and female (($P(C')$) at 0.50; b is prior probability of male ($P(C)$) at 0.9 and female (($P(C')$) at 0.10.

Table 5 Data of probability densities, likelihood ratios, and posterior probabilities derived from observed ridge densities in radial area. Values in parentheses represent posterior probabilities.

RD	Group A (14–24 years old)						Group B (14–18 years old)							Group C (18–24 years old)						
	Probability densities		L_M	L_F	Posterior probabilities		RD	Probability densities		L_M	L_F	Posterior probabilities		RD	Probability densities		L_M	L_F	Posterior probabilities	
	M	F			a	b		M	F			a	b		M	F			a	b
≤12	0.01	0	NA	0	M (1) > F (0)	M (1) > F (0)	≤12	–	–	–	–	–	–	≤12	0.02	0	NA	0	M (1) > F (0)	M (1) > F (0)
13	0.04	0	NA	0	M (1) > F (0)	M (1) > F (0)	13	0.02	0	NA	0	M (1) > F (0)	M (1) > F (0)	13	0.08	0	NA	0	M (1) > F (0)	M (1) > F (0)
14	0.13	0.01	13.00	0.08	M (0.91) > F (0.09)	M (0.99) > F(0.01)	14	0.11	0	NA	0	M (1) > F (0)	M (1) > F (0)	14	0.19	0.02	9.50	0.11	M (0.90) > F (0.10)	M (0.99) > F (0.01)
15	0.32	0.14	2.29	0.44	M (0.71) > F (0.29)	M (0.96) > F(0.08)	15	0.27	0.03	9.00	0.11	M (0.90) > F (0.10)	M (0.99) > F (0.01)	15	0.44	0.20	2.20	0.45	M (0.68) > F (0.32)	M (0.95) > F (0.05)
16	0.32	0.30	1.06	0.94	M (0.52) > F (0.48)	M (0.91) > F(0.09)	16	0.37	0.22	1.68	0.59	M (0.63) > F (0.37)	M (0.94) > F (0.06)	16	0.20	0.35	0.57	1.75	M (0.37) < F (0.63)	M (0.84) > F (0.16)
17	0.14	0.28	0.50	2.00	M (0.33) < F (0.67)	M (0.82) > F(0.18)	17	0.17	0.28	0.61	1.65	M (0.37) < F (0.63)	M (0.84) > F (0.16)	17	0.07	0.28	0.25	4.00	M (0.20) < F (0.80)	M (0.69) > F (0.31)
18	0.04	0.20	0.20	5.00	M (0.17) < F (0.83)	M (0.65) > F(0.35)	18	0.06	0.31	0.19	5.17	M (0.16) < F (0.84)	M (0.64) > F (0.36)	18	0.00	0.13	0.00	NA	M (0) < F (1)	M (0) < F (1)
19	0	0.06	0	NA	M (0) < F (1)	M (0) < F (1)	19	0.00	0.11	0.00	NA	M (0) < F (1)	M (0) < F (1)	19	0.00	0.02	0.00	NA	M (0) < F (1)	M (0) < F (1)
20	0	0.02	0	NA	M (0) < F (1)	M (0) < F (1)	≥20	0.00	0.05	0.00	NA	M (0) < F (1)	M (0) < F (1)	–	–	–	–		–	–

M is Probability densities of Male $P(RD/C)$; F is Probability densities of female = $P(RD/C')$;
L_M is Likelihood ratio for male $P(RD/C)/P(RD/C')$; L_F is Likelihood ratio for female $P(RD/C')/P(RD/C)$;
a is prior probability of male ($P(C)$) and female (($P(C')$) at 0.50; b is prior probability of male ($P(C)$) at 0.9 and female (($P(C')$) at 0.10.

In groups B and C, with equal prior probability, the threshold of 16–17 ridges/25 mm^2 and 14–15 ridges/25 mm^2 was obtained, respectively. Furthermore, if the prior probabilities were changed to $P(C) = 0.9$ and $P(C') = 0.1$, the thresholds increased (19–20 ridges/25 mm^2 in group B and 18–19 ridges/25 mm^2 in group C).

Likewise, in the radial area (Table 5), with equal prior probability in both genders, a count of 16–17 ridges/25 mm^2 was determined as the threshold for group A and B while a threshold of 15–16 ridges/25 mm^2 was achieved in group C. When prior probabilities to commit crime of male and female are 0.9 and 0.1, respectively, the thresholds moved to 18–19 ridges/25 mm^2 in group A and B and 17–18 ridges/25 mm^2 in group C.

3.4. Implications

More details are considered in young and old teenagers (group B and C) from the greater posterior probabilities coupled with the greater likelihood ratios (L_M and L_F) to select the appropriate cutoff point RD for most likely being sex origin. In the ulnar area, group B maintains 15 ridges/25 mm^2 to be most likely being male at either equal or 0.9:0.1 prior probabilities (posterior probabilities = 0.84 and 0.98, respectively; $L_M = 5.0$), while 20 ridges/25 mm^2 for female at each prior probability ($L_F = 5.0$). Group C obtains 13 ridges/25 mm^2 to be likely male at either equal or 0.9:0.1 prior probability (posterior probabilities = 0.87 and 0.98, respectively; $L_M = 6.67$), while 16 ridges/25 mm^2 for female at equal prior probability (posterior probability = 0.66; $L_F = 1.92$) and 19 ridges/25 mm^2 at 0.9:0.1 prior probability with 1.0 posterior probability.

In the radial area, group B shows 15 ridges/25 mm^2 to be most likely male at each prior probability, (posterior probabilities = 0.90 and 0.99, respectively; $L_M = 9.0$) while 18 ridges/25 mm^2 to be most likely female (posterior probabilities = 0.84; $L_F = 5.17$), then increased to 19 ridges/25 mm^2 at equal and 0.9:0.1 prior probabilities, respectively. Group C also shows a pattern similar to that of group B that the RD 14 ridges/25 mm^2 to be most likely male at equal and 0.9:0.1 prior probabilities (posterior probabilities = 0.90 and 0.99, respectively; $L_M = 9.5$), and increasing RD from 18 to 19 ridges/25 mm^2 for being most likely female at equal and 0.9:0.1 prior probabilities, respectively.

Regarding RD mean differences between male and female in both of group B and C as seen in Table 2, it shows that the radial RD of group B obtained 1.60 ridges/25 mm^2 compared to 1.11 in ulnar RD. Similarly in group C its RD difference in the ulnar area is only 1.33 ridges/25 mm^2 while 1.39 ridges in radial RD. The higher mean RD differences of the radial area than those of the ulnar area are in accordance with results from a previous study[10] which showed 1.67 and 1.07 ridges/25 mm^2 in the radial and ulnar areas, respectively among subjects aged 20–30 years old. It implies that the radial RD exhibited a greater RD than that of ulnar area. For the reason, the radial RD should be applied in forensic task for helping a fingerprint examiner to investigate the most likely sex of criminals. As it is known results based on posterior probabilities and on likelihood ratios calculated using Bayes' theorem are inferences according to an assumption of prior probabilities that occurred in the studied subjects. Thus an application in forensics should be based on the statistics on crime committed by teenagers in Thailand on the latest year of which 90 percentage of the cases were male teenagers in the year 2013. We recommend the radial RD cutoff point at the prior probability of 0.9:0.1 for determination of the most likely sex from examined latent fingerprints collected at the crime scene. For example, the latent fingerprints collected at the crime scene had an average RD of 15 ridges/25 mm^2 it could differentiate as most likely from male origin aged less than 18 years. And if the RD is 14 ridges/25 mm^2, male could be differentiated as the most likely sex aged over 18 years. However, the size of latent fingerprint and breadth of epidermal ridge should be considered with the radial RD cutoff point. As this is not only the report of sex differentiation by fingerprint ridge density but also comparing among young and old Thai teenagers, a future research on an accuracy of using the recommended radial RD at 0.9:0.1 prior probability for sex and age differentiation is essential.

4. Conclusions

Concordant with previous studies, we found that females have significantly higher fingerprint RD, i.e. finer ridge, than males for both radial and ulnar areas. Group of subjects with ages less than 18 years old has higher fingerprint RD than the older group aged 18–24 years old. Comparing fingerprint RD of the studied population to other population's worldwide, ethnic variation exists. A threshold of sex differentiation calculated from RD was observed in both counting areas and all analyzed groups. This finding suggests that the fingerprint RD might be relevant and useful for inferring the donor's sex from latent fingerprints of unknown origin. However, to improve sex identification, RD counting from other topological areas, for example the proximal region, as well as from fingerprints which are collected by plain print method needs to be evaluated in the future study.

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Conflict of interest

None declared.

Informed consent

Informed consent was obtained from the participants of the study.

Ethical approval

Necessary ethical approval was obtained from the institute ethics committee.

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