APPLICATION OF FINGERPRINT RIDGE DENSITY FOR AGE AND SEX IDENTIFICATION IN NORTH EGYPTIAN POPULATION

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ABSTRACT

Background: Biometric technologies for human identification have recently gained much attention. Because of their unique features of absolute identity and their frequent presence at crime scenes, fingerprints of an individual are considered one of the most important identification tools. The current work **aims to** study the usage of fingerprint ridge density for age and sex identification **Methods:** Fingerprint ridge density was investigated in 233 healthy Egyptian volunteers (130 males and 103 females), aged between 4 and 86 years, and was calculated as the number of ridges in 25 mm^2 areas. Linear regression was applied for age identification and Discriminant function analysis and Roc curve were done for sex identification. **Results:** There is a decrease in ridge density with aging, and we were able to obtain **eight novel equations** to determine the age for each fingerprint density. **Ten novel equations** to determine sex were obtained for each fingerprint density. In addition, we were able to gain **two novel cut-off** values by the Roc curve for sex identification. **Conclusion:** Age and sex differentiation can be applicable based on fingerprint ridge density using linear regression analysis, discriminant function analysis, and Roc curve methods; hence it is recommended to be employed in forensic practice.

KEYWORDS:

Fingerprint ridge density, North Egyptian population, Age, Sex, Linear regression, Discriminant function analysis.

INTRODUCTION

In forensic casework, identification has always been of utmost importance. Because of their unique features of absolute identity and their frequent presence at crime scenes, fingerprinting is a crucial biological feature in forensics and human biology **(Sharma et al., 2021).** Fingerprints can be used to identify offenders and distinguish between amnesiac individuals and unidentified dead bodies. In police investigations, ever-increasing fingerprint control has become essential **(Nayak et al., 2010).**

Early in embryonic development, beginning in the 26th week of pregnancy, epidermal ridges and their order are produced and are completely established by the sixth month of fetal development. Ridge development is influenced by genetic and environmental variables, but once established, these patterns do not vary over time (**Oktem et al., 2015) & (Chavan and Kumar (2020).**

Pattern intensity index, pattern type, and ridge counts are some of the commonly used criteria for identification. Other factors, such as fingerprint ridge density, have not been investigated as extensively as the feature listed above, even though they are of significant importance in definitive personal identification **Gutiérrez et al., 2008).**

The fingerprint ridge density is influenced by two factors: the width of the ridges and the distance between them. Fingerprint-based sex determination has been studied in various populations,

including Spanish, Caucasians, Chinese, Malaysians, and Indians **(Gutiérrez et al., 2008), (Kapoor and Badiye, 2015) & (Gnanasivam and Vijayarajan, 2019).** The use of fingerprint ridge density in sex identification is explained by the fact that female fingers contain more ridges than male digits due to their finer ridge detail. **(Matsuyama and Ito, 2006).** Although aging changes may affect sex-related differences in ridge density, the changes that occur with aging have gained less attention in previous research (**Sánchez-Andrés et al., 2018).**

In this work, we aimed to study the usage of the Linear regression method for age identification, Discriminant function analysis, and ROC curve method for sex identification from fingerprint ridge density of the ten fingers of the North Egyptian population and find out the possibility of its application in forensic practice.

MATERIALS AND METHODS

The current work is a cross-sectional analytical study where fingerprint ridge density was applied for age and sex identification. It was conducted at the Forensic Medicine and Clinical Toxicology Department – Faculty of Medicine, Cairo University, Egypt.

i. Study design:

- **Inclusion criteria:**

Fingerprint samples were collected from 233 healthy Egyptian volunteers (130 males and 103 females), ranging from 4 to 86 years. All included participants gave their informed consent after being informed about the goal and procedures of the study.

- **Exclusion criteria:**

This study excluded subjects with significant deformities such as congenital or acquired permanent scars on fingers, gender identity disorders, chronic skin disease, leprosy-affected fingers, and burned or amputated fingers.

ii. Procedure:

Ten fingerprint cards (TFC) were used to collect fingerprints from each participant. The participants were instructed to wash their hands with soap and water to eliminate all debris, then place the palmer aspect of their fingers on a Forensic fingerprint pad with blue or black ink and roll them on TFCs using the rolling ink print technique keeping their arms relaxed. Care was made to avoid sliding fingers to prevent blurring the print. If the impression was smudged, the technique was repeated on fresh TFC. The participants were then asked to wipe their hands and fingertips **(Binorkar and Kulkarni, 2017).**

A 5 mm × 5 mm square was drawn with a measuring ruler on a transparent sheet, and this square was then applied to the fingerprint samples. The fingerprint ridge density was obtained by counting the number of ridges in this 25 mm2 area using a fingerprint ridge counter (pin) to count the number of ridges along the square's diagonal line (**Acree, 1999).**

iii. Statistical methods:

The data was coded and entered using IBM Corp.'s SPSS version 28 statistical tool for the social sciences (IBM Corp., Armonk, NY, USA). While frequencies (number of cases) and relative frequencies (percentages) were employed for categorical variables, mean and standard deviation were utilized for quantitative variables. The groups were contrasted using the unpaired t-test (**Chan, 2003a).** To compare categorical data, the Chi-square (2) test was employed. When the anticipated frequency was less than 5, the exact test was utilized instead (**Chan, 2003b).** The Pearson correlation coefficient was used to determine correlations between the quantitative variables **(Chan, 2003c).** Different fingerprint densities were used in a linear regression analysis to estimate age **(Chan, 2004).** The test for mean equality between males and females was the first step in the discriminant analysis. The significant predictors required to establish the discriminate function were identified using stepwise statistics. After that, group centroids (group means) were computed; these serve as the cutoff points for separating males and females. It was done to categorize the percentage of cases that

were correctly categorized using the discriminate function **(Chan, 2005).** The best cutoff value of fingerprint density for separating between males and females was discovered using an area under curve analysis and ROC curve construction. Statistics were considered significant for P-values under 0.05.

RESULTS

i. Correlation of fingerprint density with age

Table (1) shows a statistically significant negative correlation between age and density of each fingerprint, except for the right & and left thumb, which show no significant correlation, meaning that a decrease in fingerprint density accompanies increasing age, P-values <0.05 is considered statistically significant.

- Linear regression to detect age

The estimation of age from each fingerprint density is calculated through the regression equations where age equals the multiplication product of the fingerprint density with its corresponding coefficient and subtracting the resultant value from the constant, as follows:

Age=52.810-1.429* Rt Index (Density), 55.321-1.573* Rt Middle (Density), 56.348-1.671* Rt Ring (Density), 49.879-1.182* Rt little (Density), 52.581-1.385* Lt Index (Density), 53.484-1.441* Lt Middle (Density), 3.078-1.424* Lt Ring (Density) & 51.629-1.336* Lt little (Density).

ii. Relation of fingerprint density with sex

There is a statistically significant difference in the mean values of each fingerprint density between the male and female studied groups, with females having higher mean values than males, as shown in **Table 2**.

- Discriminant function analysis to differentiate between males and females:

Discriminant analysis was done to determine sex using each fingerprint density. Sex can be identified using a discriminant score, which is calculated by multiplying each variable by its corresponding coefficient and then adding the resultant value to a constant; considering that negative scores are classified as males and positive scores are classified as females, as follows:

Table 1: Pearson correlation between age and density of each fingerprint within the whole studied sample

	age (years)		
	R	**P value**	**N**
Rt Thumb (Density)	-0.098-	0.135	233
Rt Index (Density)	-0.168-	0.010	233
Rt Middle (Density)	-0.185-	0.005	233
Rt Ring (Density)	-0.205-	0.002	233
Rt little (Density)	-0.135-	0.040	233
Lt Thumb (Density)	-0.103-	0.116	233
Lt Index (Density)	-0.163-	0.013	233
Lt Middle (Density)	-0.180-	0.006	233
Lt Ring (Density)	-0.171-	0.009	233
Lt little (Density)	-0.161-	0.014	233

Discriminant score=-5.137+0.427* Rt Thumb (Density), -4.627+0.388* Rt Index (Density), -4.921+0.396* Rt Middle (Density), -4.576+0.371* Rt Ring (Density), -4.814+0.403* Rt little (Density), -4.983+0.403* Lt Thumb (Density), -4.734+0.390* Lt Index (Density), -4.532+0.368* Lt Middle (Density), -4.634+0.381* Lt Ring (Density), -4.532+0.381* Lt little (Density) with accuracy of 63.5%, 59.2%, 63.1%, 60.1%, 61.8%, 62.2%, 63.9%, 63.1%, 62.7%, 57.5%, respectively.

Table 2: Comparison between fingerprint densities in male and female groups.

	Gender				
	Male		Female		P value
	Mean	SD	Mean	SD	
Rt Thumb (Density)	11.66	2.34	12.50	2.35	0.007
Rt Index (Density)	11.52	2.50	12.47	2.67	0.006
Rt Middle (Density)	11.86	2.36	13.17	2.72	<0.001
Rt Ring (Density)	11.96	2.41	12.79	3.01	0.021
Rt little (Density)	11.48	2.30	12.55	2.69	0.001
Lt Thumb (Density)	11.84	2.25	13.03	2.74	<0.001
Lt Index (Density)	11.68	2.43	12.75	2.73	0.002
Lt Middle (Density)	11.81	2.69	12.94	2.75	0.002
Lt Ring (Density)	11.72	2.50	12.73	2.78	0.004
Lt little (Density)	11.42	2.39	12.49	2.89	0.002

P-value <0.05 is considered statistically significant.

- ROC curve for detection of females:

Table (3) & figure (1) show cut-off values to differentiate between males and females by fingerprint ridge density where values less than **11.5** for Rt Thumb, Rt Index & Rt Little and **12.5** for Rt Middle, Rt Ring, Lt Thumb, Lt Index, Lt Middle, Lt Ring & Lt Little indicates that male

Table 3: Cut-off value between males and females from fingerprint ridge density

	Area Under the Curve	***P value***	***95% Confidence Interval***		***Cut off***	***Sensitivity %***
			Lower Bound	**Upper Bound**		
Rt Thumb (Density)	0.624	0.001	0.551	0.697	11.5	68
Rt Index (Density)	0.619	0.001	0.546	0.692	11.5	65
Rt Middle (Density)	0.677	< 0.001	0.606	0.747	12.5	62.1
Rt Ring (Density)	0.589	0.020	0.514	0.664	12.5	50.5
Rt little (Density)	0.627	0.001	0.554	0.700	11.5	67
Lt Thumb (Density)	0.645	< 0.001	0.572	0.718	12.5	54.4
Lt Index (Density)	0.642	< 0.001	0.569	0.715	12.5	54.4
Lt Middle (Density)	0.637	< 0.001	0.565	0.710	12..5	58.3
Lt Ring (Density)	0.619	0.001	0.546	0.692	12.5	52.4
Lt little (Density)	0.626	0.001	0.553	0.699	12.5	53.4

P-value <0.05 is considered statistically significant.

origin is more likely to be present, and higher values are more likely to be of female origin with significant differences (P-values <0.05).

Many studies have investigated the sex-related differences in epidermal ridge width at different phases of development and among different populations. The effects of aging, on the other hand, are mostly unknown.

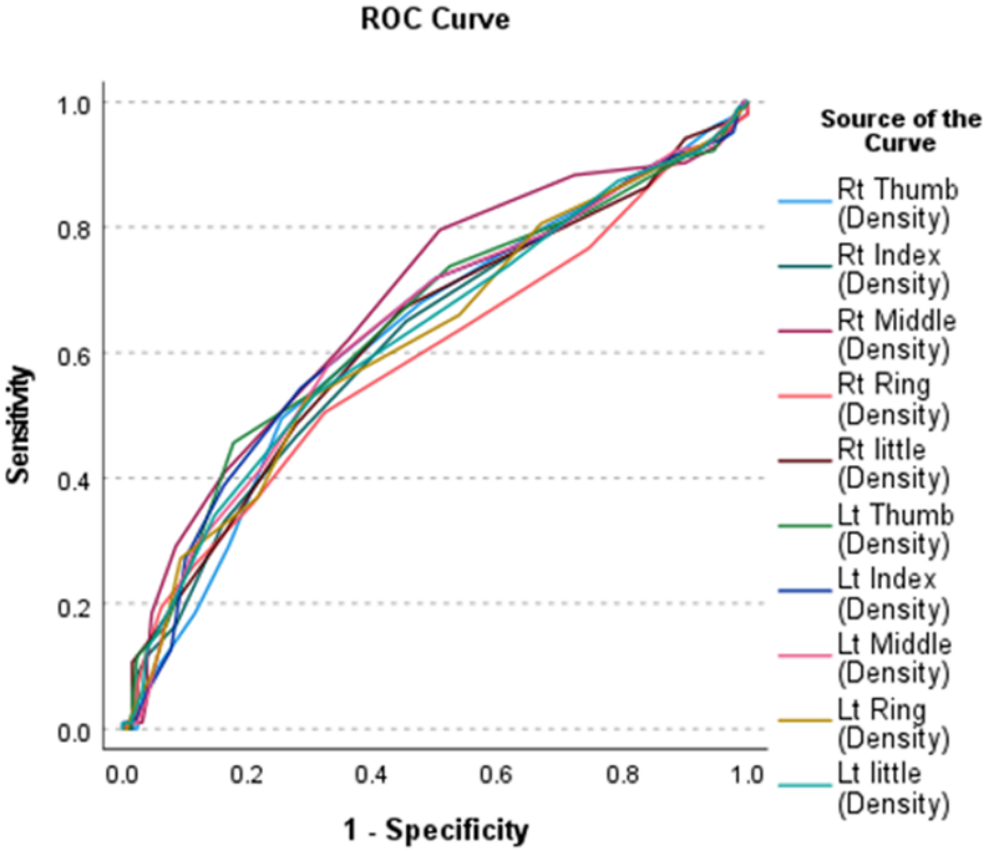

Fig 1: ROC curve for detection of the cut-off value for differentiating sex based on fingerprint ridge density.

DISCUSSION

So, the goal of this research was to the variations in fingerprint density from the ten fingers as regards age and sex in a sample of the North Egyptian population by finding out novel equations and numbers using linear regression method for age identification, discriminant function analysis, and Roc Curve methods for sex identification, and to verify the feasibility to introduce the detected findings in forensic practice.

Regarding age identification, the current study showed a statistically significant.

negative correlation between the ridge density of each fingerprint and age, except for the right & and left thumb, which show no significant correlation, indicating a decrease in fingerprint density with aging.

In comparison, another study done by **Sánchez-Andrés et al., 2018** on a sample of the Spanish native population with two different age groups; 18-30 years old (junior group) and 50-66 years old (senior group), noted that ridge density decreases with aging. They suggested the presence of a relationship between ridge density and hand dimensions changed by aging, which necessitates a more profound knowledge

of epidermal ridge width's topological changes over the life cycle.

In the current study, fingerprint ridge density was analyzed to investigate its relationship with age using the linear regression method, and we were able to obtain **eight novel equations** to determine age from fingerprint density from each finger.

Our results showed a statistically significant difference in the mean values of each fingerprint density of the ten fingers between the male and female studied groups, with females having higher mean values than males concluding **two novel cutoff values** to differentiate between both sexes by fingerprint ridge density which is 11.5 for Rt Thumb, Rt Index & Rt Little and 12.5 for Rt Middle, Rt Ring, Lt Thumb, Lt Index, Lt Middle, Lt Ring & Lt Little where males are more likely to have lower values. In contrast, females are more likely to have higher values.

Females had a much higher ridge density than males, according to the study of **Acree 1999** which was the first to look into sex-related differences in fingerprint ridge density in both Caucasian and African American populations. A fingerprint that has a ridge density of 11 ridges/25 mm2 or less is most likely to have been made by a male, while a fingerprint that has a ridge density of 12 ridges/25 mm2 or more is most likely to have been made by a female. Thereafter, the relationship between fingerprint ridge density and sex was investigated within different populations with almost similar concluded results.

Oktem et al. (2015) observed that in the Turkish young adult population, ridge counts greater than 15 per 25 mm2 in the radial region considerably decrease the probability of being a male and ridge counts less than 14 per 25 mm2 in the radial region significantly decrease the probability of being a female. For the South Indian population, using Baye's theorem indicates that a fingerprint with a ridge density of 14 ridges/25 mm^2 is more likely to have been created by a female **(Nithin et al., 2011) & (Sam, 2014).**

In **2012, Singh** examined the ridge density variations in two Northern Indian communities (Bania and Khatri), and it was discovered that the majority of females have a mean ridge density above 13 & and 14, while the majority of males have a mean ridge density below 13 & 14 in Khatri & Bania populations, respectively. According to the findings, there are considerable disparities in epidermal ridge density between both sexes within each population, as well as significant differences between the two different populations.

Regarding the Malaysian population, it was found that fingerprint ridges of less than 12 ridges/25mm^2 are more likely to belong to a male, while fingerprint ridges of more than 14 ridges/25mm^2 are more likely to belong to a female (**Abdullah et al., 2015).**

It was proposed that the genes encoding for the dermal ridges were situated on the X chromosome, which accounts for why females had more ridges than males, to explain the sex-related differences in fingerprint ridge density. **(Sudesh Gungadin, 2007) & (Oktem et al., 2015).**

To conduct their study on the possibility of ridge density in sex identification, **Chavan and Kumar (2020)** collected fingerprint samples from Marathwada population members ranging in age from 1-70 years. It also investigated how properly defined areas affected the estimate of ridge density's fluctuation. According to their study, there was no discernible change in ridge density because of the chosen region. In terms of age-related variability, it has been discovered that after the age reaches 10 years, ridge density is stable. When the ridge density of male vs. female is calculated, there is a discrepancy of 1-2 ridges that can be attributed to the average over a short database in terms of gender identification.

100 men and 100 women from the South Indian region, ranging in age from 18 to 65, were the subjects of a study by **Kumar et al. (2017)** on 200 people. Males had a ridge density of 13.56 ridges/25 mm2 and females had a ridge density of 16.92 ridges/25 mm2. According to this study, males have less ridge density than females because males have coarser ridges and females have finer ridges.

CONCLUSION

Age and sex differentiation can be applicable based on fingerprint ridge density using linear regression analysis, discriminant function analysis, and Roc curve methods; hence it is ***recommended*** to be employed in forensic practice.

STUDY LIMITATIONS

The number of children less than 10 years old in our study was not sufficient to identify sex (10 children out of 233 participants). More studies with a larger number of children participants are ***recommended*** to identify sex in this age.

ETHICAL APPROVAL

This study was approved by the local ethical committee of the Department of Forensic Medicine and Clinical Toxicology and the ethical committee of the Faculty of Medicine Cairo University, approval number **(N-126-2023).**

ACKNOWLEDGMENTS
None.

FUNDING
No fund was received for this study.

CONFLICTS OF INTEREST
The authors have declared no competing interests or financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Two authors are associate editors in the Egyptian Journal of Forensic Sciences and Applied Toxicology.

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الملخص العربي

تطبيق كثافة بصمات الأصابع لتحديد العمر والجنس في سكان شمال مصر

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اكتسبت تقنيات القياسات الحيوية لتحديد هوية الإنسان اهتمامًا كبيرًا مؤخرًا. نظرًا لسماتهم الفريدة في تحديد الهويه ووجودهم المتكرر في مسرح الجريمة ، وتعتبر بصمات الأصابع من أهم أدوات تحديد الهوية. يهدف العمل الحالي إلى دراسة استخدام كثافة حواف بصمات الأصابع لتحديد العمر والجنس في سكان شمال مصر.
الطريقة: تم فحص كثافة بصمات الأصابع في 233 متطوعًا مصريًا سليمًا (130 ذكرًا و 103 إنثي) تتراوح أعمارهم بين 4 و 86 عامًا ، وتم حسابها على أنها عدد النتوءات في منطقة 25 مم ^{2}. تم تطبيق الانحدار الخطي لتحديد العمر وتحليل الوظيفة التمييزية ومنحنى Roc لتحديد الجنس. **النتائج:** هناك انخفاض في كثافة حواف بصمات الأصابع مع تقدم العمر ، وقد تمكنا من الحصول على ثماني معادلات جديدة لتحديد العمرلكل كثافة بصمة فردية. وايضا تم الحصول على عشر معادلات جديدة لتحديد الجنس لكل كثافة بصمة فردية. بالإضافة إلى ذلك ، تمكنا من الحصول على اثنين من قيم القطع الجديدة من خلال منحنى Roc لتحديد الجنس. الخلاصة: يمكن تمييز العمر والجنس على أساس كثافة بصمات الأصابع باستخدام تحليل الانحدار الخطي ، وتحليل الوظيفة التمييزية ، وايضا عن طريق منحنى Roc ؛ ومن ثم يوصى باستخدامه في الممارسات الطبية الشرعية.

الكلمات المفتاحية:
كثافة بصمات الأصابع ، سكان شمال مصر ، العمر ، الجنس ، الانحدار الخطي ، تحليل الوظيفة التمييزية.