

# Ridge Density as an Investigative Tool for Stature

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**Abstract:** It has been reported that epidermal ridge density can be used to determine gender. However, gender determination may not be useful as an investigative tool for solving crimes, because the majority of crimes are committed by males. The current study examines the correlation between stature and epidermal ridge density. Fingerprint cards from 173 African American males aged between 18 and 65 years were analyzed. The epidermal ridge density (ridges/25 mm<sup>2</sup>) was calculated for the radial region of each finger recorded. A statistically significant correlation between stature and epidermal ridge density was found ( $p < 0.01$  for right ring finger,  $p < 0.001$  for all other fingers). The study also generated linear regression equations for stature estimation that were based on epidermal ridge density. The application of the linear regression equations establishes that each increase by one ridge per 25 mm<sup>2</sup> within a fingerprint results in a decrease in predicted stature of 0.50 to 0.74 inches ( $p < 0.01$  for right ring finger,  $p < 0.001$  for all other fingers). The reported data expands the understanding of epidermal ridge density and stature, leading to a new potential investigative tool.

## Introduction

Latent prints that are detected at crime scenes can provide the identity of a donor if a match is found in a database or if a known suspect is compared and a match is found. However, even when latent prints cannot be identified, the information within them can still provide investigative leads.

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The determination of male or female as an investigative tool may be as simple as calculating the thickness of the epidermal ridges or calculating the epidermal ridge density of a latent print. Although this may be difficult in highly distorted latent prints, it can be calculated in latent prints that have little or no distortion. According to Cummins, the first notation that males have “coarser” epidermal ridges was established by A. F. Hecht in 1924. Hecht reported that an epidermal thickness of 0.40 to 0.50 mm was found in women, and an epidermal ridge thickness of 0.50 mm was found in men [1]. However, Hecht’s study lacked statistical analysis to determine whether this difference could lead to gender determination [2]. This data inferred that females tend to have more epidermal ridges in a defined space or higher ridge density than males. This observation set the groundwork for the analysis of epidermal ridge density and gender determination. In 1942, Ohler and Cummins further analyzed the relationship between gender and ridge density. Their data found a statistical difference between males and females, resulting in higher ridge density in females than in males: 23.4 ridges per cm versus 20.7 ridges per cm [2].

In 1999, Acree introduced a likelihood ratio to predict the gender of a fingerprint. The study reported that a ridge density of 11 ridges per 25 mm<sup>2</sup> or less is more likely to be male, and a ridge density of 12 ridges per 25 mm<sup>2</sup> or higher is more likely to be female [3]. The study reported a statistically significant difference between 100 African American females and males in the radial region (the region above the pattern area on the thumb side) of the fingerprints. It found that the average African American female had 12.61 ridges per 25 mm<sup>2</sup> versus the average African American male, who had 10.90 ridges per 25 mm<sup>2</sup>. Furthermore, the study concluded that there was a statistically significant difference between the genders of 100 Caucasian females and males, reporting 13.32 ridges per 25 mm<sup>2</sup> in females and 11.14 ridges per 25 mm<sup>2</sup> in males [3].

Significantly higher epidermal ridge densities for females versus males were reported in Indian [4–8], Spanish [9, 10], Chinese [11], Malaysian [11], Argentinian [12–14], and Filipino [15] populations (Table 1). These studies have led to likelihood ratios that predict gender based on epidermal ridge density of various populations. Furthermore, these studies have created an important investigative tool for latent prints that are detected at a crime scene in which there are no leads. However, because men are more likely to commit a crime, gender determination may not be as helpful as an investigative tool [16].

Population	Reference	Ridge Density Mean (SD) for Radial Area (ridge per 25 mm <sup>2</sup> )	
		Male	Female
European- American (USA)	Acree [3]	10.90 (1.15)	12.61 (1.43)
African American (USA)	Acree [3]	11.14 (1.31)	13.32 (1.24)
South Indian (Karnataka)	Gungadin [4]	12.8 (0.90)	14.6 (0.085)
South Indian (Karnataka)	Nayak et al. [5]	11.05 (1.11)	14.20 (0.63)
South Indian	Nithin et al. [6]	12.57 (1.49)	14.15 (1.68)
North Indian	Krishan et al. [7]	15.84 (1.231)	17.94 (1.232)
Northern India (Delhi)	Dhall and Kapoor [8]	15.96 (1.09)	18.52 (1.32)
Spanish (Madrid)	Gutiérrez-Redomero et al. [9]	16.23 (1.39)	17.91 (1.47)
Spanish	Gutiérrez-Redomero et al. [10]	16.85 (1.76)	19.11 (1.79)
Chinese	Nayak et al. [11]	11.73 (1.066)	14.15 (1.038)
Malaysian	Nayak et al. [11]	11.44 (0.988)	13.63 (0.906)
Argentinian (Mataco-Mataguayo)	Gutiérrez-Redomero et al. [12]	16.62 (2.71)	17.82 (2.87)
Argentinian (Ramal)	Gutiérrez-Redomero et al. [13]	17.04 (1.68)	19.08 (1.84)
Argentinian (Puna-Quebrada)	Gutiérrez-Redomero et al. [13]	16.67 (1.78)	18.47 (1.56)
Argentina (Buenos Aires)	Rivalderia et al. [14]	15.56 (1.49)	17.82 (1.36)
Argentina (Chubut)	Rivalderia et al. [14]	16.08 (1.47)	18.36 (1.83)
Filipino	Taduran et al. [15]	14.57 (1.43)	15.89 (1.69)

*Table 1*

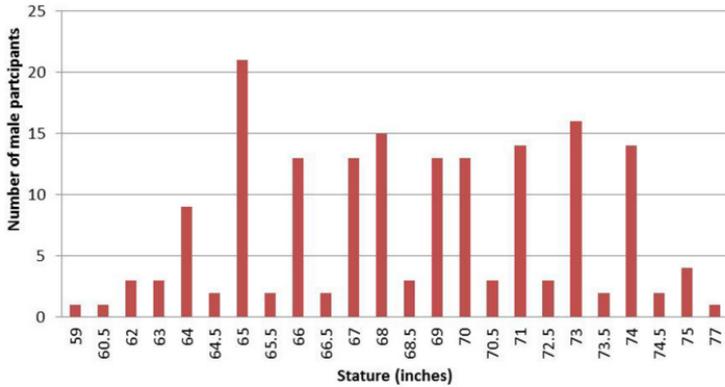
*Descriptive statistics of epidermal ridge density in the radial area of the fingerprint according to sex in various populations.*

In 1941, Cummins et al. also suggested that stature may be another influencing variable in epidermal ridge density values [2, 17–24]. To date, one study by Mundorff et al. has reported a moderate correlation between epidermal ridge breadth (thickness) and stature, indirectly suggesting a correlation between stature and epidermal ridge density in males and females [22]. However, the authors found no direct research that has been conducted to determine whether there is a correlation between epidermal ridge density and stature within a defined population. If such a correlation exists between epidermal ridge density and stature, it could be utilized as an effective investigative tool when a latent print is present. This study examines the correlation between stature and epidermal ridge density in a specific male (African American) population. Furthermore, this study proposes a predictive model for stature that is based on the epidermal ridge density of a fingerprint.

## Materials and Methods

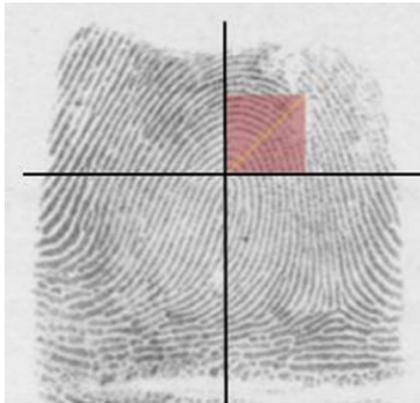
Fingerprints were obtained from the record files of the Columbus County Sheriff's Office in Whiteville, North Carolina. All samples were taken from a standard fingerprint card containing 10 inked fingerprint impressions that were collected from July 1898 through April 1933. For this study, 173 African American male fingerprint cards with a stature distribution between 59 inches to 77 inches were analyzed (Figure 1). Male individuals ranging in age from 18 to 65 were chosen for this study, because epidermal ridge breadth and stature are not established until adulthood [25–27].

The determination of epidermal ridge density was conducted according to the method described by Acree. The fingerprint was divided into four quadrants by placing a vertical line through the core of the print and a horizontal line touching the top of the core. A 5 mm x 5 mm square was drawn in the radial region of the sampled fingerprints. The epidermal ridge count was calculated by counting the number of ridges that intersected a diagonal line drawn within the square [3]. The assessment was done in the radial region of the sampled fingerprints, because the epidermal ridge flow in this region is consistent within all pattern types (Figure 2). Fingerprint cards were scanned using Epson Perfection V500 (Seiko Epson Corporation, Nagano Refecture, Japan ) at 500 ppi and imported into Adobe Photoshop CC (Adobe Systems, San Jose, CA) for analysis. The Adobe Photoshop CC box tool was used to draw the 5 mm x 5 mm square, and the line tool was used to draw all necessary lines for analysis. The diagonal epidermal ridge count within this square is the ridge density value and will be reported as the number of epidermal ridges per 25 mm<sup>2</sup> in this study. It should be noted that not the entire 173 fingerprint cards that were used for this study contained the necessary radial region of each finger or thumb to conduct an analysis, either because of the poor quality of the recording of the fingerprint or an amputation of an individual finger. The portions of the fingerprint cards without the necessary radial region were not used for analysis. The total number of fingerprint cards or fingerprints that were used for each analysis is reflected in the *N* value. Furthermore, for most ridge counts, the analysis was conducted on the rolled fingerprints; however, in cases where the rolled fingerprint was of poor quality, the plain impression fingerprint was used. The population values are noted in tables, where applicable. Stature measurements were taken from the data that were present on the obtained fingerprint cards and were recorded according to the reporting of the individual being fingerprinted.



*Figure 1*

*Stature distribution (in inches) of research participants.*



*Figure 2*

*Radial epidermal ridge count in 5 mm x 5 mm square used in study.*

The collected data were subjected to statistical analyses, which included the mean values and standard deviations for all 10 fingers as well as each hand. For the overall sample mean ridge density statistic, a single ridge density mean was calculated for each individual and was then analyzed. Correlation of the ridge density by finger, by hand, and between stature and ridge density to each finger and by hand were calculated. To determine the statistical significance of each correlation, the correlation *t* test was also performed. Paired sample *t* tests were calculated on the mean difference in ridge densities within each finger and also for each hand. Ordinary Least Squares (OLS) regression equations were developed for stature estimations from ridge density values. For each regression, a residual plot and normal probability plot for the residuals were produced. All statistical analysis was done using Microsoft Excel and Stata. Intra- and inter-observer repeatability tests were not conducted in the current study; however, multiple studies have reported no significant methodological errors [15, 28].

## Results

This study found the mean stature to be 68.73 inches and the mean epidermal ridge density to be 14.66 ridges per 25 mm<sup>2</sup> (Table 2). Table 3 presents the mean epidermal ridge density values by finger. Right and left hands are denoted as R and L, with each finger corresponding to values 1 through 5: 1 is the thumb, 2 is the index finger, 3 is the middle finger, 4 is the ring finger, and 5 is the little finger. In the left hand, the epidermal ridge density increases from the thumb to little finger. In the right hand, the epidermal ridge density increases from the thumb to ring finger, with a slight decrease from the index finger to the little finger. The mean epidermal ridge density is higher in the right hand than in the left hand. This difference is statistically significant for the ring fingers ( $p < 0.05$ ; Table 4) and when all finger measurements are pooled for each hand ( $p < 0.01$ ; Table 4). Correlation coefficients computed for epidermal ridge densities show a strong positive correlation was found when comparing right and left hands for each finger as well as combined, with correlation coefficients for each finger ranging from 0.62 to 0.64 (all  $p < 0.001$ ; Table 4) and the combined hand measurement at 0.64 ( $p < 0.001$ ; Table 4). Figure 3 plots the combined right and left epidermal ridge densities, demonstrating this positive association. The finger-to-finger and hand-to-hand data indicate that ridge densities in one are associated with ridge densities in the other.

Table 5 presents the computed correlation coefficients for the evaluation of stature and epidermal ridge density. The data for each finger show a moderate negative correlation between stature and epidermal ridge density ( $r = -0.26$  to  $-0.37$ ,  $p < 0.01$  for R4, all others  $p < 0.001$ ). A moderate negative correlation is also shown for the combined hand measurement ( $r = -0.30$ ,  $p < 0.001$ ). These data demonstrate that as stature increases, epidermal ridge density decreases.

The linear regression equations for stature estimations that are based on epidermal ridge density of each finger as well as combined hand measurements are shown in Table 6. The combined hand linear regression equation is plotted in Figure 4. All coefficients on epidermal ridge density were found to be statistically significant at conventional levels ( $p < 0.01$  for R4, all others  $p < 0.001$ ), and analyses of the residuals showed that there were no obvious violations of the regression assumptions.

	Stature	Mean Ridge Density
N	173	173
Mean	68.73	14.66
Standard Deviation	3.63	1.50
Standard Error	0.28	0.11
Median	68.50	14.56
Minimum	59.00	11.30
Maximum	77.00	19.44

Table 2

*Descriptive statistics for participant stature (in inches) and mean epidermal ridge density (per 25 mm<sup>2</sup>). The overall mean ridge density was calculated by computing the individual mean ridge density for each fingerprint card then using all fingerprint card values for the descriptive statistics.*

	N	Mean	SD	SE	Median	Minimum	Maximum
R1	165	14.26	1.84	0.14	14	9	21
R2	143	14.48	1.81	0.15	14	10	19
R3	157	14.51	2.01	0.16	14	10	20
R4	159	15.30	1.84	0.15	15	11	20
R5	144	15.29	1.69	0.14	15	10	20
<b>R Total</b>	<b>768</b>	<b>14.76</b>	<b>1.89</b>	<b>0.07</b>	<b>15</b>	<b>9</b>	<b>21</b>
L1	165	14.16	1.87	0.15	14	10	19
L2	143	14.25	1.78	0.15	14	10	20
L3	157	14.30	1.94	0.15	14	10	20
L4	159	14.99	1.90	0.15	15	11	20
L5	144	15.19	1.87	0.16	15	10	22
<b>L Total</b>	<b>768</b>	<b>14.57</b>	<b>1.92</b>	<b>0.07</b>	<b>14</b>	<b>10</b>	<b>22</b>

Table 3

*Descriptive statistics for epidermal ridge density (per 25 mm<sup>2</sup>) by finger and by hand.*

	Mean Difference	SD	t Value	N	p Value	Correlation Coefficient	t Value	p Value
R1-L1	0.10	1.59	0.83	165	0.407	0.6325	10.46	<0.001
R2-L2	0.23	1.57	1.75	143	0.082	0.6151	9.30	<0.001
R3-L3	0.21	1.69	1.56	157	0.121	0.6365	10.31	<0.001
R4-L4	0.31	1.64	2.42	159	0.017	0.6158	9.83	<0.001
R5-L5	0.10	1.57	0.75	144	0.457	0.6189	9.42	<0.001
<b>R-L combined</b>	<b>0.19</b>	<b>1.61</b>	<b>3.29</b>	<b>768</b>	<b>0.001</b>	<b>0.6423</b>	<b>23.31</b>	<b>&lt;0.001</b>

Table 4

*Epidermal ridge density paired sample t test comparison and correlation coefficients between fingers individually and pooled.*

	N	Correlation Coefficient	t Value	p Value
R1	169	-0.3518	-4.87	<0.001
R2	158	-0.3745	-5.06	<0.001
R3	168	-0.2888	-3.90	<0.001
R4	169	-0.2597	-3.49	0.001
R5	161	-0.2989	-3.96	<0.001
L1	169	-0.2709	-3.65	<0.001
L2	153	-0.3357	-4.39	<0.001
L3	161	-0.3224	-4.31	<0.001
L4	163	-0.2709	-3.58	<0.001
L5	156	-0.3370	-4.46	<0.001
<b>Combined</b>	<b>1627</b>	<b>-0.3011</b>	<b>-12.73</b>	<b>&lt;0.001</b>

Table 5

*Correlation coefficients between epidermal ridge density and stature for all fingers individually and pooled.*

	N	Regression Equation	p Value	Adj R <sup>2</sup>	Model SE
R1	169	Y = -0.68X + 78.48	<0.001	0.118	3.34
R2	158	Y = -0.74X + 79.38	<0.001	0.135	3.32
R3	168	Y = -0.53X + 76.41	<0.001	0.078	3.50
R4	169	Y = -0.50X + 76.30	0.001	0.062	3.53
R5	161	Y = -0.65X + 78.57	<0.001	0.084	3.45
L1	169	Y = -0.52X + 76.01	<0.001	0.068	3.50
L2	153	Y = -0.70X + 78.60	<0.001	0.107	3.50
L3	161	Y = -0.60X + 77.41	<0.001	0.098	3.42
L4	163	Y = -0.51X + 76.40	<0.001	0.068	3.46
L5	156	Y = -0.64X + 78.53	<0.001	0.108	3.42
<b>Combined</b>	<b>1627</b>	<b>Y = -0.57X + 77.06</b>	<b>&lt;0.001</b>	<b>0.091</b>	<b>3.44</b>

Table 6

*Linear regression equation for stature estimation from epidermal ridge density of fingers. Y = stature (inches); X = epidermal ridge density (per 25 mm<sup>2</sup>).*

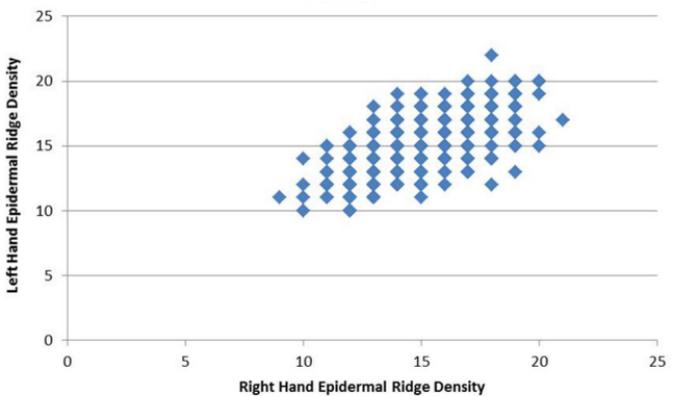


Figure 3

Scatter plot of combined right epidermal ridge densities (per 25 mm<sup>2</sup>) versus left combined epidermal ridge densities (per 25 mm<sup>2</sup>).

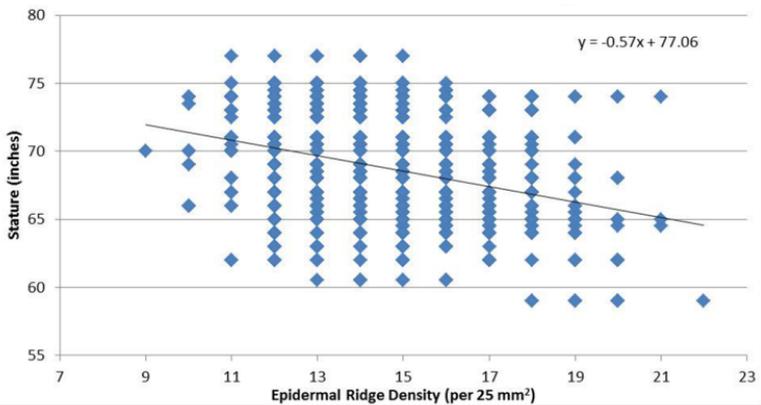


Figure 4

Scatter plot of stature (in inches) versus combined epidermal ridge density (per 25 mm<sup>2</sup>). The plot represents all data used to generate the combined linear regression equation in Table 6.

## Discussion

The mean epidermal ridge density in this study was reported as 14.66 ridges per 25 mm<sup>2</sup> for African American males (Table 2). This mean was greater than Acree's reported 10.90 ridges per 25 mm<sup>2</sup> for the same population [3]. The differences found between the studies may be due to the placement of the measurements taken. This study calculated the epidermal ridge density starting slightly closer to the core, or the pattern center, than the Acree study. Thicker epidermal ridges are located in the distal or tip area of fingerprints; this is especially true of the thumbs, which may affect epidermal ridge density calculations if taken further from the core [29]. However, it is more likely that the difference between this study and the Acree study is the stature distribution. In the current study, a broader range of statures were analyzed. There is no data in the Acree study that shows the distribution of stature that was used in the study's sampling. It may be that the Acree population was distributed with statures within the average African American population and missed higher and lower statures within the calculations. This would lead to an overall difference between the two studies. Although this study's mean epidermal ridge density did not agree with Acree's reported mean epidermal ridge density, it did fall within the range reported by Acree: 7.90 to 14.70 ridges per 25 mm<sup>2</sup> [3].

The 2014 study by Mundorff et al. reported a moderate correlation between ridge breadth (thickness) and stature. The study reported correlation coefficients for the left hand as 0.39 to 0.43 and right hand as 0.36 to 0.40 [22]. The reported correlation by Mundorff et al. for ridge breadth further confirms that a component of epidermal ridge formation is affected by an individual's stature. Because ridge breadth is inversely related to epidermal ridge density, Mundorff's data can be directly interpreted as a moderate negative correlation between epidermal ridge density and stature. The reported correlation is in agreement with the current study that found correlation coefficients for the left hand to be -0.27 to -0.34 ( $p < 0.001$ ) and for the right hand to be -0.26 to -0.37 ( $p < 0.01$  for R4, all others  $p < 0.001$ ; Table 5).

This study is the first study to generate linear regression equations for stature estimation from ridge density for any population. By using the linear regression equation generated for combined fingers, presented in Table 6, it is predicted that an African American male with a ridge density of 12 ridges per 25 mm<sup>2</sup> is 5 foot 10.22 inches, and an African American male with a ridge density of 13 ridges per 25 mm<sup>2</sup> is 5 foot

9.65 inches. This is a difference of 0.57 inches, leading to the conclusion that each increase by one ridge per 25 mm<sup>2</sup> within a fingerprint results in a decrease in predicted stature of 0.57 inches ( $p < 0.001$ ). This study establishes that each increase by one ridge per 25 mm<sup>2</sup> results in a decrease in predicted stature of 0.51 to 0.70 inches in left fingers and a decrease in predicted stature of 0.50 to 0.74 inches in right fingers for an African American male population ( $p < 0.01$  for R4, all others  $p < 0.001$ ). Further interpretation of the linear regression equation for pooled fingers would predict that an epidermal ridge density of 12 ridges per 25 mm<sup>2</sup> or less is more likely a person who is 5 foot 10 inches or taller, and an epidermal ridge density of 13 ridges per 25 mm<sup>2</sup> or greater is more likely a person who is 5 foot 9 inches or shorter. It should be noted that the minimum epidermal ridge density that was observed in the study was 9 ridges per 25 mm<sup>2</sup>, and the maximum epidermal ridge density that was observed was 22 ridges per 25 mm<sup>2</sup>.

Interestingly, in the past it has been reported that epidermal ridge count or density is subject to sex chromosome dosage effects [30]. These effects are manifest in an individual's physical stature, which provides additional confirmation that epidermal ridge density is correlated to stature. A closer look at the data from each chromosomal anomaly is worth further discussion.

Turner syndrome (monosomy X) is a chromosomal anomaly in that the second X chromosome is either altered or missing, causing a female to have only one functioning X chromosome [31, 32]. This condition affects the development of a female. Short stature is the most common feature of Turner syndrome, with the average untreated female reported as 4 foot 8 inches [32]. By applying the correlation between epidermal ridge density and stature reported in this study, it is expected that a short female would have a higher ridge density (higher ridge count) than other unaffected individuals. Kobylansky et al. reported that epidermal ridge counts increased in Turner syndrome females when compared to control individuals (170.98 ridges in Turner syndrome females, 152.27 ridges in control males, and 140.93 ridges in control females) [33]. Jantz and Brehme also reported higher ridge counts in Turner syndrome females in the interdigital region of the palms [34].

Triple X syndrome (47,XXX) is a chromosomal anomaly in which females have an additional X chromosome. Many females with this condition are slightly above the average stature of 5 foot 7 inches [35]. Saldaña-Garcia reported that the epidermal ridge counts decreased for Triple X females, reporting 104.94 ridges for Triple X females versus 126.97 ridges for control females [36].

Jacob's syndrome (47,XYY) is a chromosomal anomaly where males have an extra Y chromosome. Males with this condition have an average stature of 6 foot 3 inches [37]. In 1973, Hubbell et al. reported that Jacob's syndrome males have a lower total finger epidermal ridge count, 128.88 ridges, than control males, 135.29 ridges [38]. This trend was also reported by Borgaonkar and Mules [39], Penrose [40], and Saldana-Garda [41], reporting Jacob's syndrome males with total finger ridge counts of 109.85, 133.60, and 124.00, respectively, and control males with total finger ridge counts of 135.29, 145.00, 135.00, respectively.

In both Triple X syndrome and Jacob's syndrome, individuals reportedly have lower epidermal ridge counts, meaning there are fewer ridges per a defined space or a lower epidermal ridge density. The reported data for Triple X syndrome and Jacob's syndrome agree with the current study: it would be expected that individuals with these anomalies would be taller than the average population and would have a lower ridge density.

## **Conclusion**

This study has demonstrated the existence of a relationship between epidermal ridge density and stature in the African American male population. The data revealed that taller individuals have a lower ridge density than shorter individuals within the same population. Thus, using epidermal ridge density to predict stature may be useful as a tool for investigations when an unidentified latent print is present.

It must be noted that the findings in this study are correlations and linear regression equations that are based on the studied population and cannot be applied to general populations. However, further study of different populations, including both genders and different ethnicities, could confirm the forensic importance of epidermal ridge density as a predictor of stature.

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