# AXIS SLANT AND ROTATION OF THE CENTRAL RIDGE FOR HAND DETERMINATION (RIGHT-LEFT) IN PLAIN SPIRAL WHORL SINGLE-DIGIT FINGERPRINT PATTERN OBTAINED FROM A SAMPLE OF EGYPTIANS

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## ABSTRACT

**Background:** Fingerprints are the commonest identification tool used for forensic investigation. Identification of the sidedness of the suspect's hand (left or right) is a crucial step for the accurate detection of the suspect by reducing the investigator's effort and time of analysis. **Aim of the work:** This study aimed to evaluate the usefulness of axis slant and rotation of the central ridge to determine whether a single-digit plain spiral whorl print is from a right or left hand in a sample of Egyptians. **Subjects and Methods:** The ten-digit rolled fingerprints were obtained from 128 adult healthy Egyptian participants residing in the Middle Delta region. Out of the 1280 collected prints, 186 plain spiral whorls, including 93 right and 93 left-handed prints, were included and submitted for analysis using (CorelDRAW 2021). Major dermatological injuries or chemotherapy that affects fingerprints were excluded. Axis slant, either right, left, or absent, and rotation of the central ridge, either clockwise or anti-clockwise, were used for the analysis. Chi-square test, Monte Carlo correction, and multivariable binary regression were applied. **Results:** There was a significant association between the hand side and the direction of the axis slant and the rotation of the central ridge. Right axis slant and anticlockwise rotation could suggest the right-handedness of the print. However, left hand print could be suggested from left axis slant and clockwise rotation. **Conclusions:** The axis slant and rotation of the central ridge could be applied to determine whether a single-digit plain spiral whorl pattern print is from a right or left hand.

**Keywords:** *Axis Slant, Rotation of the Central Ridge, Plain Spiral Whorls, Single-digit finger print.*

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## INTRODUCTION

Fingerprints are the distinctive patterns left behind the fingertips (distal phalanges) of the fingers and the thumbs; they are formed by papillary ridges and valleys ***(Sharma et al., 2021; Martins et al., 2024)***.

Fingerprints are unique and remain constant throughout life until death. Even identical twins who share the same DNA profile have different fingerprints ***(Awad, 2012; Win et al., 2020)***.

Any forensic investigation's main objective is to ascertain personal identity. Fingerprints have grown in significance in this field and have become a relative substitute for other conventional authentication techniques. They are among the most crucial pieces of evidence discovered at crime scenes ***(Mandrah and Kanwal, 2016; George and Yassa, 2018; Martins et al., 2024)***.

Additionally, the ridges and furrows in fingerprints combine to create several types of ridge characteristics, which allow producing various parameters and traits that could aid in determining the donor's hand ***(Kapoor et al., 2020$_b$)***. During the court procedures, the side of the hand from which the fingerprint has originated at the crime scene may be questioned ***(Nagesh et al., 2012)***.

One of the most pivotal factors that helps to lessen the investigator's workload and help in the precise identification of the suspect is to detect the hand origin (right or left). However, it is highly challenging due to a lack of available data and decisive standards that are generally acknowledged. Additionally, it is uncommon to find the fingerprints of the whole ten digits. In fact, only one digit or remnant of a print can be frequently traced ***(Kapoor and Badiye, 2015; Mandrah and Kanwal, 2016)***.

By identifying the hand origin of a print (left or right), a researcher can narrow down the group of possible suspects ***(Kapoor et al., 2020$_b$)***.

Also, there are abundant studies that describe different fingerprint features and patterns; however, publications that focus on the identification of the hand origin (either right or left) from a single-digit fingerprint are yet scarce ***(Kapoor and Badiye, 2015; Kapoor et al., 2020$_b$)***.

Based on six parameters, some studies have determined the whorl single-digit fingerprint's origins from either the left or right hand, according to the available literature. These parameters were the ridge count, ridge tracing, perpendicular bisector position on the delta line, angle created at both sides of the core, and the slope of the apex ridges and the rotation of the central ridges ***(Singh et al., 2005; Nagesh et al., 2012)***.

In a subsequent study, three parameters were added: the pattern's direction, the angle between the deltas and the core, and the distance between the deltas and the core. ***(Kapoor and Badiye, 2015)***.

Two studies were done later that proposed the use of axis rotation in the whorl pattern to identify the hand side of a single-digit fingerprint. ***(Brazelle and Brazelle, 2018; Kapoor et al., 2020$_a$)***.

In addition, a recent study determined a new parameter, which was the distance between the core's perpendicular position on the delta line to both deltas ***(Kapoor, 2020)***.

Added to that, some publications are based on suggesting some reliable parameters that determine the origin of the hand (right or left) in single-digit twinned loop fingerprints **(*Singh and Chattopadhyay, 1996; Kralik et al., 2014; Brazelle and Brazelle, 2018; Kapoor, 2020; and Kapoor et al., 2020$_b$)***.

The use of fingerprints as a crucial identification tool has been employed by many Egyptian researchers, resulting in stature detection from fingerprint patterns and age and sex identification from fingerprint ridge density ***(Kholeif, 2023; Alsaeed et al., 2023)***. Sadly, there has been no prior research in Egyptian literature that has examined the identification of the hand side from which the fingerprint originates.

Therefore, in the case of a single-digit fingerprint, it is crucial to confirm certain parameters and assess their accuracy in order to ascertain the hand origin (right or left). This could aid in personal identification, help eliminate some suspects, and reduce the amount of time, money, and effort spent on the inquiry. ***(Kapoor, 2020; Kapoor et al., 2020$_b$)***.

## THE AIM OF THE WORK

This study aimed to evaluate the usefulness of axis slant and rotation of the central ridge and formulate a regression model that could help determine whether a single-digit plain spiral whorl print is from a right or left hand in a sample of Egyptians.

## SUBJECTS AND METHODS

- **Study design and Ethical consideration:**

A cross-sectional study was conducted at the Forensic Medicine and Clinical Toxicology Department, Faculty of Medicine, Tanta University, Tanta, Egypt.

This study has been approved from Local Research Ethical Committee, Quality Assurance Unit, Faculty of Medicine, Tanta University (code number 35641/8/22). Written informed consent was obtained from each participant after clarifying the aim of the study. Confidentiality of the data was maintained by making code numbers for each participant.

- **Duration of the study:**

From the start of September 2022 to the end of February 2023.

- **Sample size calculation:**

Based on ***Singh et al. (2005)*** results, a sample size of 300 whorl pattern finger-prints (minimum of 31 finger-prints for each side in each sub-categories) is the enough required sample size to conduct this diagnostic test accuracy study, assuming level of significance 5% (α error accepted =0.05), and statistical power (1 – β) of 80%, with assumptions of the discrimination level (Area Under the ROC curve (AUC)) of 75% ***(Hanley and mcneil, 1982)***. The calculation of sample size was performed using Medcalc version 14.8.1.

- **Inclusion criteria:**

One hundred and twenty-eight adult Egyptian participants, of whom 48 males and 80 females aged over 18 years (to

ensure constant fingers' size) from the Middle Delta Region (to avoid any ethnic variation in fingerprints), were included in this study.

- **Exclusion criteria:**

After history was taken and fingerprints examination was done, we excluded from the study any case with:

1. Idiopathic absence of fingerprints.
2. Major dermatological injury or disease that affects the fingerprint involves (scar, mechanical abrasion, leprosy, laceration, irritant contact dermatitis, dyshidrotic dermatitis, atopic eczema, psoriasis, amputation, burn, fracture, etc.).
3. Any patient on chemotherapy, as chemotherapy leads to Hand-Foot Syndrome that include redness and swelling on the hands and feet.
4. Any unclear or distorted fingerprints.

- **Sample collection:**

The fingerprints were obtained according to the traditional method ***(Kapoor and Badiye, 2015; Kapoor et al., 2020$_a$)***. First, the participants were instructed to thoroughly wash and dry their hands, and the ink (obtained from the Ministry of Interior) was spread over the fingerprint plate using a roller. Then, the ten-digit fingerprints of each participant were taken by rolling each finger on the plate from nail to nail and were imprinted on the paper sheet in the selected square. Every print was repeated twice or triple, then subjected to analysis to prevent any doubt.

- **Fingerprints analysis:**

The patterns of overall (1280) fingerprints were studied after magnification on-screen using a graphics program (CorelDRAW 2021 (64–Bit)) and classified according to Henry's classification into loops, whorls, and arches ***(Kapoor et al., 2020$_a$)***.

The analysis parameters were applied to 186 plain spiral whorls (93 left- 93 right) and analyzed digitally using this program to determine the side of the hand.

- **The analyses parameters:**

**1- Axis slant**

The axis is an imaginary line that passes from the upper to the lower portion of the pattern crossing its central part which can rotate around it. The axis slant is the direction of the lower portion of this imaginary line. It may be directed towards the right "right slant" or to the left "left slant" or it may be "absent" when the sloping of the whorl axis is neither directed towards the right nor left **(Figure 1)** ***(Kapoor et al., 2020$_a$)***.

**2- Rotation of the central ridge:**

It is the rotation of the innermost ridges around the core that may be clockwise or anti-clockwise **(Figure 2)** ***(Kapoor and Badiye, 2015)***.

**Statistical Analysis:**

Data analysis was performed using the Statistical Package for Social Sciences (IBM SPSS Statistics), version 25 for Windows (Armonk, N.Y: IBM Corp). Descriptive statistics for categorical variables were expressed in the form of numbers and percentages. Associations between categorical variables were assessed by Pearson's chi-square test, which was used to compare categorical variables in 2 x 2 tables. Monte Carlo correction was carried out when indicated (n x m table and >25% expected cells <5) ***(Smith et al., 1996)***. Up to 20% beta error can be tolerated when calculating sample size with a power of study of 80%. An alpha level was set to 5% and a significance level was 95%. Statistical significance was tested at a p value of 0.05 ***(Curran-Everett, 2020)***.

- **Parameter reliability:**

To assess the reliability of the data, 10% of the total plain spiral whorl fingerprints from the right and left sides were randomly selected. These fingerprints were re-examined two months after the first assessment by the same examiner and by two forensic medicine staff members at Faculty of Medicine, Tanta University to test intra-rater and inter-rater reliability. Both intra-raters and inter-raters came to a complete agreement.

**Regression analysis:**

Multivariable binary (binomial) logistic regression analysis was applied to estimate the probability of the binary outcome (sides of the hand) dependent on the two independent predictors (axis slant and rotation of the central ridge). The calibration was assessed by the Hosmer–Lemeshow goodness-of-fit test, where a p-value>0.10 indicates acceptable calibration (***Hosmer et al., 2013)***.

For this logistic regression model with the categorical dependent variable (sides of the hand), pseudo-R square was employed. The log-likelihood of the model was compared to the log-likelihood of a baseline model to get Cox and Snell's R 2. Even with a "perfect" model, it had a theoretical maximum value of less than 1 for the categorical outcome (sides of the hand). A modified version of the Cox and Snell R-square, Nagelkerke's R was applied to encompass the whole range of the statistic's scale from 0 to 1.

The enter method included all independent variables, regardless of their significance or insignificance. However, in forward stepwise selection, the model started with no predictors and successively added significant predictors until reaching the statistical stopping criteria. Odds ratio (OR) and confidence intervals (CI) were presented.

**The following equations of the regression model were used for hand-side prediction:**

- When only one parameter was taken into account,
  Probability (Y) = odds ratio / 1+ odds ratio
- When two or more parameters were taken into account at the same time,
  Predicted logit = ($\beta_0 + \beta_1X_1 + \beta_2X_2 + .... + \beta_kX_k$).
  Odds ratio = exp (predicted logit).
  Probability (Y) = odds ratio / 1+ odds ratio ***(Park, 2013; Boateng and Abaye, 2019; Ebrahimi Kalan et al., 2021)***.
  (Y is the dichotomous outcome, $X_1$, $X_2$, $X_k$ are the predictor variables, $X_1$, $X_2$, $X_k$ are the regression (model) coefficients and $\beta_0$ is the intercept) ***(Boateng and Abaye, 2019)***.

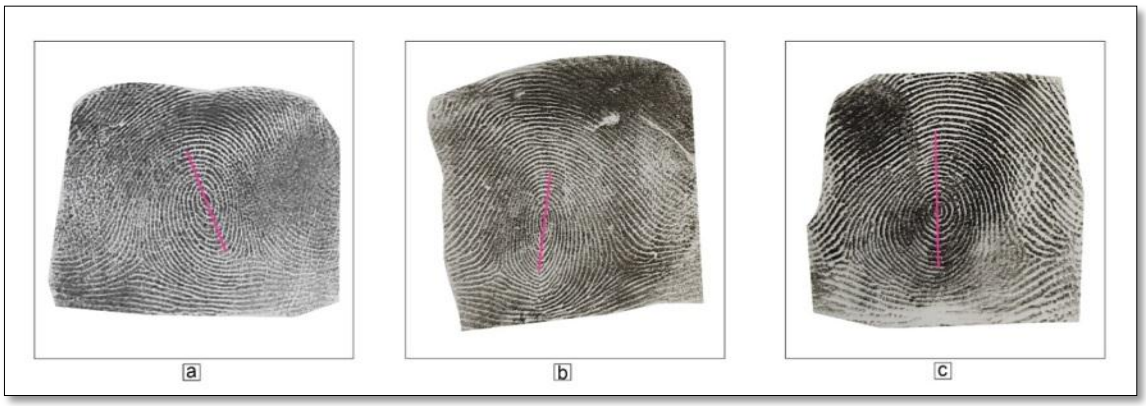


***Figure (1): a, b, c: Axis slant: (a) a plain spiral whorl fingerprint with right axis slant of the right middle finger of a male aged 60 years; (b) a plain spiral whorl fingerprint with left axis slant of the left ring finger of a male aged 28 years; (c) a plain concentric whorl fingerprint with absent axis slant of the right ring finger of a male aged 20 years.***

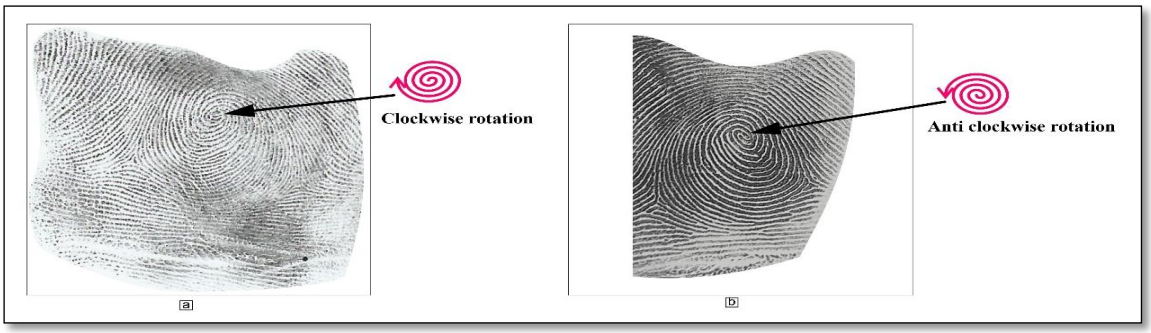


***Figure (2): a, b: Rotation of the central ridge: (a) a plain spiral whorl fingerprint with clockwise rotation of the central ridge of the left thumb of a male aged 35 years; (b) a plain spiral whorl fingerprint with anti-clockwise rotation of the central ridge of the right index finger of a male aged 32.***

## RESULTS

- **Assessment of axis slant and rotation of the central ridge for determination of the side of the hand (right/left) of all studied subjects:**

**1- Axis slant:**

In plain spiral whorls, there was a significant association between the side of the hand and the direction of the axis slant in fingerprints of the total hand and each individual finger ($p<.05$). There was a significant direction of the axis slant towards the right in right-hand fingerprints, and to the left in left-hand fingerprints **(Table 1)**.

**2- Rotation of the central ridge:**

The side of the hand and the rotation of the central ridge in fingerprints of the total hand and each individual finger were significantly associated in plain spiral whorls ($p<.05$). The rotation of the right-hand fingerprints was significantly anti-clockwise, and vice versa in the left-hand fingerprints **(Table 1)**.

- **Regression analysis:**

When the enter method and Forward Stepwise (Likelihood Ratio) were applied, the left axis slant (p=.026) and rotation of the central ridge (clockwise and anti-clockwise) (p=.002) were statistically significant predictors for the hand side. The classification accuracy of the model (block 0) was 50%. Regarding the Forward Stepwise (Likelihood Ratio), two steps were applied in this model, and step 2 (the final step) was described. The included predictors accounted for 61.8%–82.5% variation in the hand side according to the Cox & Snell2 or Nagelkerke R2 methods, respectively. (-2 Log likelihood = 78.66, Cox and Snell 2=0.618, Nagelkerke R2=0.825). The predictive capacity of the model was up to 94.62%. as exhibited in **tables (2, 3, 4, 5)**.

- **In plain spiral whorls, when only one parameter was taken into account for the prediction of the hand side, the probabilities were:**

When controlling the axis slant, anti-clockwise rotation of the central ridge had 12.619 times the chances of being from the right hand (95% CI 2.486–64.057) (p=.002), as shown in **table (3)**, with a 92.66% probability (Odds/(1+Odds) = 12.619/ 13.619 =92.66%).

While the clockwise rotation of the central ridge when controlling the axis slant had 12.619 times the chances of being from the left hand (95% CI 2.486–64.057) (p=.002), as shown in **table (4)**, with a probability of 92.66% (Odds/(1+Odds) = 12.619/ 13.619 = 92.66%). When controlling the rotation of the central ridge, fingerprints with a left axis slant had 7.818 (95% CI 1.285–47.561) times the chances of being from the left hand (p =.026), as shown in **tables (4, 5)**, and an 88.66% probability (Odds/(1+Odds) = 7.818/8.818 = 88.66%).

- **In plain spiral whorls, when more than one parameter were taken into account at the same time, this equation could be used for the prediction of the hand side with the following probabilities:**

The anti-clockwise rotation was the only significant parameter we had to rely on for the right hand prediction. With reference to **table (3)** and after applying the preceding equation; anti-clockwise rotation with a left-axis slant had a 30.29% probability of being from the right hand.

Predicted logit = $B_0 + B_1X_1 + B_2X_2$ = (-1.312) + (- 2.056 x 1) + (2.535 x 1) = -0.833

Odds ratio = exponential (predicted logit) = exponential (-0.833) = 0.434

Probability = Odds/(1+Odds) = 30.29%

However, both the left axis and clockwise rotation were the significant parameters for left-hand prediction. By referring to **table (4, 5)** for the aforementioned parameters and by using the following equation, we obtained two probabilities:

Clockwise rotation with a left-axis slant had a 96.67% probability of being from the left-hand (**Table 4)**.

Predicted logit = $B_0 + B_1X_1 + B_2X_2$ = (-1.223) + (2.056 x 1) + (2.535 x 1) = 3.368

Odds ratio = exponential (predicted logit) = exponential (3.368) = 29.020

Probability = Odds/(1+Odds) = 96.67%

Anti-clockwise rotation with left axis slant had a 69.70% probability of being from the left-hand **(Table 5)**.

Predicted logit = $B_0 + B_1X_1 + B_2X_2$ = (1.312) + (- 2.535 x 1) + (2.056 x 1) = .833

Odds ratio = exponential (predicted logit) = exponential (.833) = 2.300

Probability = Odds/(1+Odds) = 69.70%

**Table (1): Assessment of axis slant & rotation of the central ridge in the studied plain spiral whorl fingerprints (n=186).**

| Axis Slant | Finger name within the side | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thumb | | Index | | Middle | | Ring | | Little | | Total | |
| | N | % | N | % | N | % | N | % | N | % | N | % |
| **Right hand** | | | | | | | | | | | | |
| **Right** | 23 | 88.46% | 18 | 90.00% | 13 | 100.00 % | 19 | 90.48% | 12 | 92.31% | 85 | 91.40% |
| **Left** | 0 | 0.00% | 2 | 10.00% | 0 | 0.00% | 1 | 4.76% | 0 | 0.00% | 3 | 3.23% |
| **Absent** | 3 | 11.54% | 0 | 0.00% | 0 | 0.00% | 1 | 4.76% | 1 | 7.69% | 5 | 5.38% |
| **Left hand** | | | | | | | | | | | | |
| **Right** | 1 | 4.35% | 5 | 20.83% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 6 | 6.45% |
| **Left** | 21 | 91.30% | 16 | 66.67% | 8 | 100.00% | 17 | 89.47% | 17 | 89.47% | 79 | 84.95% |
| **Absent** | 1 | 4.35% | 3 | 12.50% | 0 | 0.00% | 2 | 10.53% | 2 | 10.53% | 8 | 8.60% |
| **Chi-square** | $\chi^2_{(MC)\,(df=2)}$=42.141 | | $\chi^2_{(MC)\,(df=2)}$=21.047 | | $\chi^2_{(df=1)}$=20.000 | | $\chi^2_{(MC)\,(df=2)}$=33.539 | | $\chi^2_{(MC)\,(df=2)}$=29.236 | | $\chi^2_{(MC)\,(df=2)}$=139.714 | |
| **P-value** | P<.0001* | | P<.0001* | | P<.0001* | | P<.0001* | | P<.0001* | | P<.0001* | |
| **Rotation of the central ridge** | **Finger name within the side** | | | | | | | | | | | |
| | **Thumb** | | **Index** | | **Middle** | | **Ring** | | **Little** | | **Total** | |
| | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** |
| **Right hand** | | | | | | | | | | | | |
| **Clockwise** | 0 | 0.00% | 3 | 15.00% | 1 | 7.69% | 1 | 4.76% | 2 | 16.67% | 7 | 7.53% |
| **Anticlockwise** | 26 | 100.00% | 17 | 85.00% | 12 | 92.31% | 20 | 95.24% | 11 | 83.33% | 86 | 92.47% |
| **Left hand** | | | | | | | | | | | | |
| **Clockwise** | 23 | 100.00% | 18 | 75.00% | 8 | 100.0% | 19 | 100.0% | 19 | 100.00% | 87 | 93.55% |
| **Anticlockwise** | 0 | 0.00% | 6 | 25.00% | 0 | 0.00% | 0 | 0.00% | 0 | 0.00% | 6 | 6.45% |
| **Chi-square** | $\chi^2_{(df=1)}$=48.000 | | $\chi^2_{(df=1)}$=15.384 | | $\chi^2_{(df=1)}$=16.410 | | $\chi^2_{(df=1)}$=35.286 | | $\chi^2_{(df=1)}$=22.619 | | $\chi^2_{(df=1)}$=135.927 | |
| **P-value** | P<.0001* | | P=.0001* | | P=.0001* | | P<.0001* | | P<.0001* | | P<.0001* | |

*N: Number of fingerprints df=degree of freedom MC=Monte Carlo*
*$\chi^2$ =Chi-square *: Statistically significant (p<.05).*

**Table (2): Forward Step-wise Likelihood method to predict the right side in the studied plain spiral whorl fingerprints (clockwise rotation and left axis slant).**

| The studied variable(s) | | Block 0 | Cox & Snell2 | Nagelkerke R2 | Predictive capacity | B | S.E. | Wald | df | Sig. | Exp (B) | 95% C.I.for EXP (B) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Lower | Upper |
| **Step 1[a]** | **Rotation of the central ridge (clockwise)** | 50% | 61.8% | 82.5% | 94.62% | -5.183 | .577 | 80.744 | 1 | .000* | .006 | .002 | .017 |
| | **Constant** | | | | | 2.663 | .422 | 39.762 | 1 | .000 | 14.333 | | |
| **Step 2[b]** | **Axis slant** | | | | | | | 15.384 | 2 | .000 | | | |
| | **Axis slant (right)** | | | | | 1.711 | .903 | 3.587 | 1 | .058 | 5.533 | .942 | 32.491 |
| | **Axis slant (left)** | | | | | -2.056 | .921 | 4.983 | 1 | .026* | .128 | .021 | .778 |
| | **Rotation of the central ridge (clockwise)** | | | | | -2.535 | .829 | 9.355 | 1 | .002* | .079 | .016 | .402 |
| | **Constant** | | | | | 1.223 | .879 | 1.938 | 1 | .164 | 3.398 | | |

*a. Variable(s) entered on step 1: Rotation of the central ridge Sig.: Significance *: Statistically significant (p<.05)*
*b. Variable(s) entered on step 2: Axis slant Exp: Exponentiation of B coefficient*
*Exp (B): Odds ratio C.I.: Confidence interval S.E: Standard error df: degree of freedom*

**Table (3): Forward Step-wise Likelihood method to predict the right side in the studied plain spiral whorl fingerprints (anti-clockwise rotation and left axis slant).**

| The studied variable(s) | | Block 0 | Cox & Snell2 | Nagelkerke R2 | Predictive capacity | B | S.E. | Wald | df | Sig. | Exp (B) | 95% C.I.for EXP (B) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Lower | Upper |
| Step 1[a] | Rotation of the central ridge (anti-clockwise) | 50% | 61.8% | 82.5% | 94.62% | 5.183 | .577 | 80.744 | 1 | .000* | 178.143 | 57.522 | 551.700 |
| | Constant | | | | | -2.520 | .393 | 41.142 | 1 | .000 | .080 | | |
| Step 2[b] | Axis slant | | | | | | | 15.384 | 2 | .000 | | | |
| | Axis slant (right) | | | | | 1.711 | .903 | 3.587 | 1 | .058 | 5.533 | .942 | 32.491 |
| | Axis slant (left) | | | | | -2.056 | .921 | 4.983 | 1 | .026* | .128 | .021 | .778 |
| | Rotation of the central ridge (anti clockwise) | | | | | 2.535 | .829 | 9.355 | 1 | .002* | 12.619 | 2.486 | 64.057 |
| | Constant | | | | | -1.312 | .723 | 3.293 | 1 | .070 | .269 | | |

*a. Variable(s) entered on step 1: Rotation of the central ridge* *Sig.: significance* **: Statistically significant (p<.05)*
*b. Variable(s) entered on step 2: Axis slant* *Exp: Exponentiation of B coefficient*
*Exp (B): Odds ratio* *C.I.: Confidence interval* *S.E: Standard error* *df: degree of freedom*

**Table (4): Forward Step-wise Likelihood method to predict the left side in the studied plain spiral whorl fingerprints (clockwise rotation and left axis slant).**

| The studied variable(s) | | Block 0 | Cox & Snell2 | Nagelkerke R2 | Predictive capacity | B | S.E. | Wald | df | Sig. | Exp (B) | 95% C.I.for EXP (B) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Lower | Upper |
| Step 1[a] | Rotation of the central ridge (anti-clockwise) | 50% | 61.8% | 82.5% | 94.62% | 5.183 | .577 | 80.744 | 1 | .000* | 178.143 | 57.522 | 551.700 |
| | Constant | | | | | -2.663 | .422 | 39.762 | 1 | .000 | 0.070 | | |
| Step 2[b] | Axis slant | | | | | | | 15.384 | 2 | | | | |
| | Axis slant (right) | | | | | -1.711 | .903 | 3.587 | 1 | .058 | .181 | 0.31 | 1.061 |
| | Axis slant (left) | | | | | 2.056 | .921 | 4.983 | 1 | .026* | 7.818 | 1.285 | 47.561 |
| | Rotation of the central ridge (anti clockwise) | | | | | 2.535 | .829 | 9.355 | 1 | .002* | 12.619 | 2.486 | 64.057 |
| | Constant | | | | | -1.223 | .879 | 1.938 | .164 | .164 | 294 | | |

*a. Variable(s) entered on step 1: Rotation of the central ridge* *Sig.: significance* **: Statistically significant (p<.05)*
*b. Variable(s) entered on step 2: Axis slant* *Exp: Exponentiation of B coefficient*
*Exp (B): Odds ratio* *C.I.: Confidence interval* *S.E: Standard error* *df: degree of freedom*

**Table (5): Forward Step-wise Likelihood method to predict the left side in the studied plain spiral whorl fingerprints (anti-clockwise rotation and left axis slant).**

| The studied variable(s) | | Block 0 | Cox & Snell2 | Nagelkerke R2 | Predictive capacity | B | S.E. | Wald | df | Sig. | Exp (B) | 95% C.I.for EXP (B) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Lower | Upper |
| Step 1[a] | Rotation of the central ridge (anti-clockwise) | 50% | 61.8% | 82.5% | 94.62% | -5.183 | .577 | 80.744 | 1 | .000* | .006 | .002 | .017 |
| | Constant | | | | | 2.520 | .393 | 41.142 | 1 | .000 | 12.429 | | |
| Step 2[b] | Axis slant | | | | | | | 15.384 | 2 | .000 | | | |
| | Axis slant (right) | | | | | -1.711 | .903 | 3.587 | 1 | .058 | .181 | .031 | 1.061 |
| | Axis slant (left) | | | | | 2.056 | .921 | 4.983 | 1 | .026* | 7.818 | 1.285 | 47.561 |
| | Rotation of the central ridge (anti clockwise) | | | | | -2.535 | .829 | 9.355 | 1 | .002* | .079 | .016 | .402 |
| | Constant | | | | | 1.312 | .723 | 3.293 | 1 | .070 | 3.713 | | |

*a. Variable(s) entered on step 1: Rotation of the central ridge* *Sig.: significance* **: Statistically significant (p<.05)*
*b. Variable(s) entered on step 2: Axis slant* *Exp: Exponentiation of B coefficient*
*Exp (B): Odds ratio* *C.I.: Confidence interval* *S.E: Standard error* *df: degree of freedom*

## DISCUSSION

This current cross section observational study was done on 186 plain spiral whorl fingerprints in order to assess the value of axis slant and rotation of the central ridge and create a regression model that might assist in identifying whether a single-digit plain spiral whorl print belongs to the right or left hand in a sample of Egyptians.

To the author's knowledge, these parameters were evaluated in previous studies such as that were done by ***Kapoor and Badiye (2015)*** and ***Kapoor (2020)***. However, no regression model has been created to predict the hand origin from a single-digit fingerprint. Additionally, there is no available Egyptian study in the literature to investigate the hand side of fingerprints using the studied parameters.

A suspect's identity can be determined in many crimes by discriminating the fingerprints left at the crime scene. That being said, it's frequently challenging because there's always a single-digit print or a portion of a print. The ability to determine the hand origin (left or right) is one of the most important steps in reducing the investigator's effort and aiding in the accurate identification ***(Kapoor and Badiye, 2015; Mandrah and Kanwal, 2016)***.

It has been established that both manual fingerprint identification and the Integrated Automated Fingerprint Identification System (IAFIS) are mutually compatible. It is not possible to rely solely on one of them; it would be very complicated and time-consuming ***(Gao and Pinto, 2016)***.

- **The analysis of plain spiral whorl pattern hand-determining parameters showed that:**

Regarding the axis slant, there was a significant association between the side of the hand and the direction of the axis slant in plain spiral whorl fingerprints; it was slanted to the right side in 91.40% of all right-hand prints. In 84.95% of left-handed prints, the axis slant aligned to the left side. Correspondingly, ***Kapoor (2020)*** recorded the same significant findings; right slant was discovered in 98.61% of right spiral whorl fingerprints, whereas left slant was discovered in 97.63% of left spiral whorl fingerprints.

In consistency with the current study, ***Kralik et al. (2014)*** found that combined plain whorl fingerprints had a significant right axis slant in 90% of the right hands' whorl prints, whereas a significant left axis slant in 80% of the left hands' whorl prints. Additionally**,** ***Kapoor et al. (2020$_a$)*** observed that combined plain spiral and concentric whorl fingerprints had a significant right axis slant in 81.82% of the right hands' whorl prints, whereas a significant left side slant in 80.73% of the left hands' whorl prints.

In this study, the whorl axis in each finger was individually assessed. Most fingers had a significant association between the side of the hand and the direction of the axis slant. As far as we know, preceding research did not document the application of this parameter for each finger.

**Concerning the rotation of the central ridge** in the current study, a significant association between the side of the hand and the rotation of the central ridge was recorded in plain spiral whorl fingerprints. It was rotated anti-clockwise in 92.47% of all right-hand prints, while clockwise rotation was noticed in 93.55% of all left-hand prints. These observations went in harmony with previous significant reports from ***Nagesh et al. (2012); Kralik et al. (2014); Kapoor and Badiye (2015); Mandrah and Kanwal (2016)*** who studied 200 bilateral thumbprints, and ***Kapoor (2020)***. They all declared that the majority of right-hand fingerprints had an anticlockwise rotation, while the majority of left-hand fingerprints had a clockwise rotation.

The current study indicates that anticlockwise rotation is most commonly observed in right thumbprints, followed by right ring fingerprints. In contrast, clockwise rotation was detected in all fingerprints of the left thumb, middle, ring, and little fingers. A comparative study conducted by ***Nagesh et al. (2012)*** found that anticlockwise rotation predominantly occurred in right thumbprints, followed by right little fingerprints, whereas clockwise rotation was primarily noted in left little fingerprints, followed by left thumbprints.

- **Multivariable binary (binomial) logistic regression analysis was the regression model applied in this study for determining the origin of the fingerprints (probability of being from the right or left hand):**

The overall regression model was statistically significant for hand-side prediction. The left axis slant and rotation of the central ridge of plain spiral whorl fingerprints were the statistically significant predictors for the hand side with a predictive capacity of 94.62%.

To the best of the authors' knowledge, this study was the first to predict the fingerprints' hand side using multivariable binary logistic regression analysis, based on the parameters under investigation.

## CONCLUSION

In plain spiral whorl fingerprints; anticlockwise rotation had the highest probability for right hand prediction, however, clockwise rotation with left axis slant had the highest probability of left hand prediction.

## RECOMMENDATIONS

- Axis slant and rotation of the central ridge can be integrated into automated systems to speed up the search and narrow down potential matches.
- In situations where plain spiral whorl fingerprints lifted from the crime scene do not match any in the governmental fingerprint databases, these parameters can be employed during manual examination to narrow down the pool of investigation, as you can focus solely on the matched patterns from either the right or left hand.
- To enhance the validity of these research findings and support the general applicability of these parameters, we suggest conducting a more extensive study with more sub-pattern classification on a larger sample size of different races.
- It is proposed that these parameters can be applied to other fingerprint patterns, such as loops and arches, to evaluate their validity for hand-side determination in these patterns.

**Limitations of the study:**

- Small sample size
- Lack of comparative studies in literature especially Egyptian studies.

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# ميل المحور و دوران الخط البارز المركزي لتحديد اليد (يمنى أو يسرى) من بصمة إصبع واحدة ذات النمط الدوّامي الحلزوني البسيط تم الحصول عليها من عينة من المصريين

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## الملخص العربي

**المقدمة:** بصمات الأصابع هي أداة التعريف الأكثر شيوعا في تحقيقات الطب الشرعي. يعد تحديد جانب اليد منشا البصمة (يسارًا أو يمينًا) خطوة هامة للكشف عن المشتبه به بالإضافه الى تقليل جهد المحقق والوقت المبذول في التحليل .

**الهدف من الدراسة:** هدفت هذه الدراسة إلى تقييم مدى فائدة ميل المحور و دوران الخط البارز المركزي لتحديد جانب اليد (يمنى أو يسرى) من خلال بصمة إصبع واحدة ذات النمط الدوّامي الحلزوني البسيط في عينة من المصريين .

**المشاركين وطرق البحث:** تم الحصول على بصمات العشر أصابع من ١٢٨ مشاركًا مصريًا بالغًا يتمتع بصحة جيدة من منطقة وسط الدلتا. من بين ١٢٨٠ بصمة تم جمعها، تم إشتمال ١٨٦ بصمة ذات النمط الدوّامي الحلزوني البسيط ، بما في ذلك ٩٣ بصمة يمنى و ٩٣ بصمة يسري، وتقديمها للفحص باستخدام (CorelDRAW 2021). تم استبعاد الإصابات الجلدية الكبيرة أو العلاج الكيميائي الذي يؤثر على بصمات الأصابع. تم استخدام ميل المحور، إما لليمين أو اليسار أو الغائب، و دوران الخط البارز المركزي ، إما في اتجاه عقارب الساعة أو عكس اتجاه عقارب الساعة، للتحليل. وتم تطبيق اختبار مربع كاي، وتصحيح مونت كارلو، والانحدار الثنائي متعدد المتغيرات.

**النتائج:** كان هناك ارتباط ذو دلالة إحصائية بين مصدر البصمة (اليد اليمنى أو اليسرى) واتجاه ميل المحور و دوران الخط البارز المركزي. يمكن أن يشير ميل المحور الى اليمين و الدوران في عكس اتجاه عقارب الساعة أن مصدر البصمة هى اليد اليمنى. ومع ذلك، يمكن اقتراح أن اليد اليسرى هى مصدر البصمة من خلال ميل المحور الى اليسار والدوران في اتجاه عقارب الساعة.

**الخلاصة:** يمكن تطبيق ميل المحور و دوران الخط البارز المركزي لتحديد ما إذا كانت بصمة الإصبع الواحدة ذات النمط الدوّامي الحلزوني البسيط هي من اليد اليمنى أو اليسرى.

**الكلمات المفتاحية:** ميل المحور، دوران الخط البارز المركزي، الدوّامات الحلزونية البسيطة، بصمة إصبع واحدة.