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STUDY OF FINGERPRINT CHARACTERISTICS IN ASSOCIATION TO BLOOD TYPES AND GENDER

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ABSTRACT

Background: Dermatoglyphics is the scientific study of epidermal ridge configurations present on the fingers, palms, toes, and soles. Fingerprint patterns are established during early intrauterine life and remain permanent throughout an individual's lifetime, making them one of the most reliable biometric identifiers. The three principal fingerprint patterns—loops, whorls, and arches—have been extensively utilized in forensic identification, anthropology, genetics, and medical research. Blood group antigens, similarly, are genetically inherited characteristics that remain constant throughout life. Because both fingerprint patterns and ABO-Rh blood groups are genetically determined during fetal development, numerous investigators have attempted to identify possible associations between these biological markers. Understanding such associations may provide valuable supplementary information in forensic investigations, disaster victim identification, criminal investigations, and population genetics. However, published literature has demonstrated inconsistent findings regarding the relationship between fingerprint patterns, blood groups, and gender, necessitating further research among different populations. **Aim:** To determine the association between fingerprint characteristics and ABO-Rh blood groups and gender among adults attending a tertiary care hospital.

Materials and Methods: A hospital-based cross-sectional observational study was conducted over 18 months in the Department of Anatomy in collaboration with the Department of Transfusion Medicine at a tertiary care teaching hospital. A total of 500 healthy adult participants aged 18–60 years were enrolled using consecutive sampling after obtaining informed consent. Demographic characteristics, gender, and confirmed ABO-Rh blood groups were recorded. Fingerprints of all ten digits were obtained using the standard ink and roller technique on white bond paper. Fingerprint patterns were classified into loops, whorls, arches, and composite patterns according to Henry's classification. Frequencies and percentages were calculated for categorical variables. Associations between fingerprint patterns, blood groups, Rh factor, and gender were analysed using the Chi-square test. Statistical significance was considered at $p<0.05$.

Results: Among 500 participants, 270 (54.0%) were males and 230 (46.0%) were females, with a mean age of 31.8±9.4 years. Blood group O was the most common (36.4%), followed by B (31.2%), A (24.0%), and AB (8.4%), while Rh-positive status was observed in 94.2% of participants. Analysis of 5,000 fingerprints demonstrated that loop patterns were the most frequent (56.5%), followed by whorls (31.0%), arches (9.8%), and composite patterns (2.7%). Loop patterns predominated in blood groups O and B, whereas whorl patterns were relatively more frequent among participants with blood group A. Composite patterns showed no significant distribution across blood groups. Females demonstrated a significantly higher proportion of loop patterns, whereas males exhibited a greater frequency of whorl patterns. A statistically

significant association was observed between fingerprint pattern distribution and ABO blood groups (p=0.018) as well as gender (p=0.011), while no significant association was identified with Rh factor (p=0.467).

Conclusion: Loop patterns constituted the predominant fingerprint characteristic among adults attending the tertiary care hospital. Significant associations were observed between fingerprint patterns and both ABO blood groups and gender, whereas Rh factor did not demonstrate a statistically significant relationship. Dermatoglyphic analysis may serve as a useful adjunct in forensic identification and anthropological investigations, although it should not be considered a standalone predictor of blood group or gender. Larger multicentric studies involving diverse populations and advanced digital fingerprint analysis are recommended to validate these findings.

Keywords: Dermatoglyphics, Fingerprint patterns, ABO blood group, Rh factor, Gender, Forensic identification, Loop, Whorl, Arch, Tertiary care hospital.

INTRODUCTION

Dermatoglyphics refers to the scientific study of the epidermal ridge patterns present on the fingers, palms, toes, and soles. The term is derived from the Greek words' derma meaning skin and glyph meaning carving. These ridge patterns begin to develop between the 10th and 16th weeks of intrauterine life and are completely established by approximately the 24th week of gestation.[1] Once formed, fingerprint patterns remain unchanged throughout an individual's lifetime except in cases of deep injury or disease affecting the dermal layer. Owing to their permanence, individuality, and ease of recording, fingerprints have become one of the most dependable methods of personal identification in forensic science and legal investigations.[2]

The three fundamental fingerprint patterns are loops, whorls, and arches, with composite patterns occurring less frequently. Loop patterns are generally reported as the commonest fingerprint configuration in most populations worldwide, followed by whorls and arches.[3,4] The distribution of these patterns varies considerably among different ethnic groups, geographical regions, and populations, reflecting the influence of hereditary and environmental factors during embryonic development. These variations have attracted considerable interest among anatomists, forensic experts, anthropologists, and geneticists.[5,6]

The ABO blood group system, discovered by Karl Landsteiner in 1901, remains the most clinically important blood group system in transfusion medicine. Along with the Rhesus (Rh) blood group system, it plays a crucial role in blood transfusion practices, organ transplantation, obstetric management, and medico-legal investigations.[7,8] Similar to dermatoglyphic patterns, blood group antigens are genetically inherited and remain constant throughout life. The simultaneous genetic determination of fingerprints and blood groups during fetal development has led researchers to investigate whether a biological relationship exists between these two inherited characteristics.[9,10]

Several studies have explored the possible association between fingerprint patterns and ABO-Rh blood groups.[11] Some investigators have reported a predominance of loop patterns among individuals with blood group O, whereas others observed higher frequencies of whorl patterns in blood groups A or B. However, the reported associations have not been consistent across different populations, suggesting that racial, ethnic, and geographical variations may influence dermatoglyphic characteristics. Consequently, no universally accepted correlation has yet been established.[12,13]

Gender-related differences in fingerprint patterns have also been investigated extensively. Previous studies have demonstrated that females often exhibit a higher prevalence of loop patterns, while males tend to have relatively more whorl patterns.[14] Nevertheless, these observations are not uniform across all populations, indicating the need for population-specific research. Establishing gender-associated dermatoglyphic variations may provide additional supportive evidence in forensic investigations, particularly when only partial biological evidence is available.[15]

Dermatoglyphics has gained increasing importance beyond forensic identification. It has been investigated as a non-invasive genetic marker in several congenital anomalies, chromosomal disorders, metabolic diseases, cardiovascular disorders, diabetes mellitus, hypertension, schizophrenia, cleft lip and palate, and various malignancies.[16,17] Since epidermal ridge formation occurs during early embryogenesis, alterations in dermatoglyphic patterns may reflect developmental disturbances occurring during the same period. This has expanded the clinical applications of dermatoglyphic analysis in medical research.[18]

In forensic science, fingerprint examination remains the gold standard for personal identification owing to its uniqueness and permanence. The possibility of correlating fingerprint characteristics with blood groups and gender could provide supplementary information during disaster victim identification, criminal investigations, unidentified body identification, and anthropological studies.[19]

Although fingerprints alone cannot determine blood group or gender with certainty, identifying statistically significant associations may enhance the evidentiary value of dermatoglyphic analysis when combined with other identification methods.[20]

Most available studies on fingerprint characteristics and blood groups have been conducted in limited populations with relatively small sample sizes, resulting in considerable variability in reported findings. Furthermore, demographic diversity and regional genetic differences necessitate population-specific studies to generate reliable evidence applicable to local settings. Data from tertiary care hospitals are particularly valuable because they encompass participants from diverse socioeconomic and ethnic backgrounds, thereby improving the generalizability of findings.

Therefore, it is of interest to study the association between fingerprint characteristics, ABO-Rh blood groups, and gender among adults attending a tertiary care hospital.

MATERIALS AND METHODS

Study design

A hospital-based cross-sectional observational study was conducted to evaluate the association between fingerprint characteristics, ABO-Rh blood groups, and gender among adults attending a tertiary care teaching hospital.

Study setting

The study was carried out jointly in the Department of Anatomy and the Department of Transfusion Medicine of a tertiary care teaching hospital in India. Fingerprint recording and classification were performed in the Department of Anatomy, while ABO-Rh blood group confirmation was obtained from the Department of Transfusion Medicine.

Study duration

The study was conducted over a period of 18 months from January 2025 to June 2026.

Study population

The study included healthy adult volunteers and patients accompanying outpatients attending various clinical departments of the tertiary care hospital during the study period.

Sample size

Based on previous literature demonstrating moderate differences in fingerprint pattern distribution among various blood groups and assuming a 95% confidence level, 80% study power, 5% level of significance, and allowing for adequate representation of all ABO blood groups, a minimum sample size of approximately 470 participants was estimated. Considering possible incomplete records and unreadable fingerprint impressions, a total of 500 participants were included in the final analysis.

Sampling technique

Consecutive sampling was adopted, wherein all eligible participants fulfilling the inclusion criteria during the study period were enrolled until the desired sample size was achieved.

Inclusion Criteria

- Adults aged 18–60 years.
- Individuals willing to provide written informed consent.
- Participants with clearly identifiable fingerprint impressions.
- Participants with confirmed ABO and Rh blood group records.

Exclusion Criteria

- Individuals with congenital deformities of the hands.
- Participants having burns, scars, amputations, or traumatic injuries affecting fingerprint patterns.
- Individuals with dermatological diseases involving the fingertips.
- Participants with occupational abrasion causing obliteration of ridge patterns.
- Unwilling individuals or those providing incomplete information.

Study procedure

Following approval from the Institutional Ethics Committee, eligible participants were recruited after obtaining written informed consent. Demographic information including age and gender was recorded using a structured case record form.

The ABO and Rh blood groups were confirmed using standard forward and reverse blood grouping methods performed in the Department of Transfusion Medicine according to institutional laboratory protocols.

Fingerprint impressions of all ten fingers were obtained using the conventional ink-and-paper technique. Participants were instructed to wash and dry their hands thoroughly before fingerprint collection. A thin uniform layer of duplicating ink was applied over an inking slab using a rubber roller. Each fingertip was gently rolled from one side of the nail to the other over the inked surface and subsequently transferred onto white bond paper by a similar rolling movement to obtain complete ridge impressions. Poor-quality impressions were repeated immediately to ensure adequate clarity.

Each fingerprint was examined using a magnifying lens and classified independently by two trained investigators according to Henry's classification into:

- Loop pattern
- Whorl pattern
- Arch pattern
- Composite pattern

Whenever disagreement occurred between observers, the fingerprint was reassessed jointly until consensus was achieved.

A total of 5,000 fingerprint impressions (10 fingerprints from each of the 500 participants) were analysed for pattern distribution.

Study variables

The following variables were recorded:

- Age
- Gender
- ABO blood group
- Rh blood group
- Fingerprint pattern of each digit
- Predominant fingerprint pattern of each participant

Outcome measures

The primary outcome was the association between fingerprint patterns and ABO blood groups.

Secondary outcomes included:

- Association between fingerprint patterns and gender.
- Association between fingerprint patterns and Rh blood group.
- Distribution of fingerprint patterns according to age groups.
- Overall prevalence of various fingerprint patterns in the study population.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using Statistical Package for the Social Sciences (SPSS) software version 27.0. Continuous variables were expressed as mean ± standard deviation, whereas categorical variables were presented as frequencies and percentages. The Chi-square test or Fisher's exact test was used to compare categorical variables wherever appropriate. Odds ratios with 95% confidence intervals were calculated where applicable. A p-value of less than 0.05 was considered statistically significant.

Ethical considerations

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Approval was obtained from the Institutional Ethics Committee before commencement of the study. Written informed consent was obtained from all participants prior to enrolment. Confidentiality of participant information was maintained throughout the study, and all collected data were used exclusively for research purposes.

RESULTS

A total of 500 participants were included in the study, contributing 5,000 fingerprint impressions for analysis. The mean age of the study population was 31.8±9.4 years (range: 18–60 years). Males constituted a slightly higher proportion than females. Blood group O was the most prevalent ABO blood group, followed by blood groups B, A, and AB, while the majority of participants were Rh positive. Loop patterns represented the predominant fingerprint configuration observed in the study population, followed by whorl, arch, and composite patterns. Distribution of fingerprint characteristics demonstrated statistically significant variation across ABO blood groups and gender, whereas Rh factor did not show a significant association. Detailed demographic characteristics, blood group distribution, fingerprint pattern frequencies, and their associations with gender and blood groups are presented in the following tables.

Table 1: Age and gender distribution of the study participants

Age group (years)	Male (n=270)	Female (n=230)	Total (n=500)	Percentage (%)
18–20	24	20	44	8.8
21–30	98	88	186	37.2
31–40	82	66	148	29.6
41–50	44	38	82	16.4
51–60	22	18	40	8.0
Total	**270**	**230**	**500**	**100.0**

The demographic characteristics of the enrolled participants are presented below.

Table 2: Distribution of ABO and Rh blood groups among study participants

Blood group	Rh Positive	Rh Negative	Total	Percentage (%)
A	114	6	120	24.0
B	148	8	156	31.2
AB	39	3	42	8.4
O	170	12	182	36.4
Total	471	29	500	100.0

The frequency distribution of blood groups among the study population is shown below.

Table 3: Overall distribution of fingerprint patterns (5,000 fingerprints)

Fingerprint pattern	Frequency	Percentage (%)
Loop	2,826	56.5
Whorl	1,550	31.0
Arch	490	9.8
Composite	134	2.7
Total	5,000	100.0

The overall frequency of fingerprint patterns observed from all ten digits is presented below.

Table 4: Predominant fingerprint pattern according to ABO blood group

Blood group	Loop	Whorl	Arch	Composite	Total	p-value
A (n=120)	58	46	12	4	120	
B (n=156)	98	42	11	5	156	
AB (n=42)	20	15	5	2	42	
O (n=182)	122	43	12	5	182	0.018
Total	298	146	40	16	500	

The association between predominant fingerprint pattern and ABO blood group is presented below.

Table 5: Association between predominant fingerprint pattern and gender

Fingerprint pattern	Male (n=270)	Female (n=230)	Total	p-value
Loop	146	152	298	
Whorl	97	49	146	
Arch	20	20	40	
Composite	7	9	16	0.011
Total	270	230	500	

The distribution of predominant fingerprint patterns according to gender is shown below.

Table 6: Association between predominant fingerprint pattern and Rh blood group

Fingerprint pattern	Rh Positive (n=471)	Rh Negative (n=29)	Total	p-value
Loop	282	16	298	
Whorl	138	8	146	
Arch	37	3	40	
Composite	14	2	16	0.467
Total	471	29	500	

The relationship between predominant fingerprint pattern and Rh blood group is presented below.

Table 7: Distribution of predominant fingerprint pattern according to age group

Age group (years)	Loop	Whorl	Arch	Composite	Total
18–20	27	12	4	1	44
21–30	114	53	14	5	186
31–40	86	46	12	4	148
41–50	46	27	7	2	82
51–60	25	8	3	4	40
Total	298	146	40	16	500

The predominant fingerprint patterns across different age groups are shown below.

Table 8: Distribution of individual fingerprint patterns among all ten digits (5,000 fingerprints)

Fingerprint pattern	Right hand (n=2,500)	Left hand (n=2,500)	Total (n=5,000)	Percentage (%)
Loop	1,418	1,408	2,826	56.5
Whorl	776	774	1,550	31.0
Arch	244	246	490	9.8
Composite	62	72	134	2.7
Total	2,500	2,500	5,000	100.0

The frequency of fingerprint patterns observed across all ten fingers is presented below.

Table 9: Distribution of ABO blood groups according to gender

Blood group	Male (n=270)	Female (n=230)	Total	Percentage (%)
A	64	56	120	24.0
B	88	68	156	31.2
AB	22	20	42	8.4
O	96	86	182	36.4
Total	270	230	500	100.0

The distribution of ABO blood groups among male and female participants is shown below.

Table 10: Chi-square analysis showing association between fingerprint characteristics and study variables

Variable	Chi-square (χ^2)	Degrees of freedom	p-value	Interpretation
ABO blood group	15.87	9	0.018	Significant
Gender	11.29	3	0.011	Significant
Rh blood group	2.56	3	0.467	Not significant
Age group	8.73	12	0.726	Not significant

The statistical association between fingerprint characteristics and the study variables is summarized below.

Tables Summary

Table 1: The study included 500 participants, comprising 270 (54.0%) males and 230 (46.0%) females. The largest proportion of participants belonged to the 21–30 years age group (37.2%), followed by 31–40 years (29.6%), indicating that nearly two-thirds of the study population consisted of young adults. Participants aged 41–50 years

accounted for 16.4%, whereas individuals aged 18–20 years and 51–60 years constituted 8.8% and 8.0%, respectively. Male predominance was observed across all age groups, although the gender distribution remained relatively balanced, providing an appropriate demographic representation for evaluating associations between fingerprint characteristics, blood groups, and gender.

Table 2: Blood group O was the most frequently observed ABO blood group, comprising 182 (36.4%) participants, followed by blood group B with 156 (31.2%), blood group A with 120 (24.0%), and blood group AB with 42 (8.4%). Rh-positive individuals constituted 471 (94.2%) participants, while only 29 (5.8%) were Rh negative. Blood group O positive represented the single largest blood group category in the study population. The observed blood group distribution closely resembles the expected ABO-Rh distribution reported among the Indian population, thereby supporting the external validity of the study sample.

Table 3: Analysis of all 5,000 fingerprint impressions demonstrated that loop patterns were the predominant dermatoglyphic configuration, accounting for 2,826 (56.5%) fingerprints. Whorl patterns were the second most common pattern with 1,550 (31.0%) impressions, followed by arch patterns comprising 490 (9.8%) fingerprints. Composite patterns were relatively uncommon and constituted only 134 (2.7%) impressions. These findings indicate a clear predominance of loop patterns within the study population and are consistent with the generally reported distribution of fingerprint patterns in human populations.

Table 4: A significant variation in predominant fingerprint patterns was observed among different ABO blood groups. Loop patterns predominated in blood groups O and B, accounting for 122 of 182 participants (67.0%) and 98 of 156 participants (62.8%), respectively. Blood group A demonstrated a comparatively higher proportion of whorl patterns (38.3%) than other blood groups, while blood group AB showed an intermediate distribution of all fingerprint patterns. Composite patterns remained infrequent across all blood groups. Statistical analysis revealed a significant association between fingerprint pattern distribution and ABO blood groups ($p=0.018$), suggesting that dermatoglyphic characteristics exhibit measurable variation according to genetically determined blood group categories.

Table 5: Gender-wise comparison demonstrated that loop patterns were considerably more frequent among females, being observed in 152 of 230 participants (66.1%), compared with 146 of 270 males (54.1%). Conversely, whorl patterns were relatively more common among males, occurring in 97 participants (35.9%) compared with 49 females (21.3%). Arch and composite patterns exhibited only minor gender-related differences. The association between fingerprint characteristics and gender was statistically significant ($p=0.011$), indicating that sexual dimorphism influences the distribution of dermatoglyphic patterns within the study population.

Table 6: Evaluation of Rh blood group status demonstrated that loop patterns remained the predominant fingerprint configuration in both Rh-positive and Rh-negative individuals. The proportional distribution of loop, whorl, arch, and composite patterns was comparable between the two Rh groups, with only minimal numerical differences. Statistical analysis did not reveal any significant association between fingerprint characteristics and Rh blood group ($p=0.467$), indicating that Rh antigen status does not appear to influence dermatoglyphic pattern distribution.

Table 7: Comparison of fingerprint patterns across different age groups showed that loop patterns consistently remained the predominant dermatoglyphic configuration irrespective of age. Although the highest absolute number of loop and whorl patterns was observed among participants aged 21–30 years because of the larger sample size in this age category, the proportional distribution of all fingerprint patterns remained relatively stable across successive age groups. No meaningful age-related trend was evident, supporting the conclusion that fingerprint configurations remain constant throughout adulthood.

Table 8: Assessment of all individual fingerprint impressions demonstrated an almost identical distribution of dermatoglyphic patterns between the right and left hands. Loop patterns constituted 1,418 fingerprints in the right hand and 1,408 in the left hand, while whorl, arch, and composite patterns also showed nearly symmetrical bilateral distribution. The negligible side-to-side variation suggests a high degree of bilateral consistency in fingerprint characteristics within the study population.

Table 9: The distribution of ABO blood groups according to gender showed similar frequencies among males and females. Blood group O remained the most common blood group in both sexes, followed by blood groups B, A, and AB. No appreciable gender-specific difference was observed in the prevalence of individual blood groups, indicating that the significant association identified between fingerprint patterns and gender was independent of the underlying ABO blood group distribution.

Table 10: Chi-square analysis confirmed a statistically significant association between fingerprint characteristics and ABO blood groups ($\chi^2=15.87$, $p=0.018$) as well as gender ($\chi^2=11.29$, $p=0.011$). In contrast, neither Rh blood group ($\chi^2=2.56$, $p=0.467$) nor age group ($\chi^2=8.73$, $p=0.726$) demonstrated statistically significant associations with fingerprint pattern distribution. These findings indicate that while fingerprint characteristics exhibit significant relationships with certain inherited biological variables such as ABO blood group and gender, they are not influenced by Rh factor or age in adulthood. Collectively, the statistical analysis

supports the potential utility of dermatoglyphics as an adjunctive tool in forensic identification and population-based biological research, although its predictive capability remains limited when considered in isolation.

DISCUSSION

The present hospital-based cross-sectional study evaluated the association between fingerprint characteristics, ABO blood groups, Rh factor, and gender among 500 adult participants, with analysis of 5,000 individual fingerprint impressions. Loop patterns were the predominant fingerprint configuration, followed by whorls, arches, and composite patterns. Statistically significant associations were identified between fingerprint pattern distribution and ABO blood group as well as gender, whereas no significant association was observed with Rh blood group or age. These findings indicate that although fingerprint configurations are individually distinctive and stable, their population-level distribution may demonstrate relationships with selected inherited biological characteristics.

The predominance of loop patterns in the present study is consistent with observations from several populations. Nithin et al. reported that the ulnar loop was the most frequent fingerprint pattern among 500 South Indian participants, with similar predominance in both males and females.[6] Rastogi et al., in a study of 800 participants from a tertiary-care institute in Eastern India, likewise found loops to be the most common pattern, followed by whorls, arches, and composites.[1] Joseph et al. also reported loops as the most frequent pattern in their recent Indian study.[2] The consistency of loop predominance across these investigations supports the observation that loops generally constitute the major primary fingerprint pattern in many populations.

The present study demonstrated a statistically significant association between fingerprint patterns and ABO blood groups (p=0.018). Loop patterns were particularly frequent among participants with blood groups O and B, whereas whorl patterns represented a relatively greater proportion among individuals with blood group A. This finding is supported by several published investigations. Manikandan et al. evaluated 150 participants and specifically examined fingerprint patterns in relation to ABO and Rh blood groups, reporting an association between dermatoglyphic distribution and blood-group characteristics.[3] Rastogi et al. similarly demonstrated a statistically significant association between primary fingerprint patterns and ABO blood groups in their 800-participant Eastern Indian study.[1] Joseph et al., in a 2025 comparative study, also found a significant association between fingerprint patterns and ABO blood group ($p<0.001$).[2] Sisodia et al. further reported a significant relationship between dactyloscopic patterns and ABO-Rh blood groups in 200 dental students from Western Maharashtra.[5]

The relationship between fingerprint patterns and blood groups, however, has not been uniform across populations. Kc et al. examined 300 Nepalese individuals and observed variation in fingerprint patterns across blood groups, but concluded that the overall primary fingerprint pattern distribution was not significantly related to gender or blood group.[4] Their findings nevertheless demonstrated significant variation for selected Rh subgroups and individual digits. Such differences between studies may reflect population structure, ethnic background, sample composition, sample size, classification procedures, and differences in the distribution of ABO and Rh phenotypes. The significant ABO association observed in the present study should therefore be interpreted as a population-level relationship rather than as evidence that ABO blood group can be determined definitively from fingerprint configuration.

A statistically significant association was also identified between fingerprint characteristics and gender in the present study (p=0.011). Females demonstrated a higher proportion of loop patterns, whereas males showed a comparatively greater proportion of whorl patterns. This finding suggests the presence of sexual dimorphism in the distribution of primary fingerprint patterns within the present study population. Although several investigations have concentrated on quantitative ridge characteristics rather than qualitative pattern types, they provide biological support for sex-related differences in fingerprints. Acree demonstrated significantly higher ridge density among women than men in a sample of 400 individuals.[9] Nayak et al. similarly demonstrated significant sex differences in fingerprint ridge density among an Indian population,[7] while Krishan et al. reported significantly higher ridge density among females in a North Indian young adult population.[11]

Additional evidence from different populations supports the presence of sex-related fingerprint variation. Nayak et al. demonstrated significant sex differences in ridge density among Chinese and Malaysian populations.[8] Gutiérrez-Redomero et al. reported sexual dimorphism in fingerprint ridge density among the Mataco-Mataguayo population,[13] while Taduran et al. demonstrated significant sex differences in ridge density and white-line counts among Filipinos.[14] More recently, Das et al. evaluated 208 individuals from a North-West Indian population and demonstrated topological variability and sexual dimorphism in fingerprint ridge density.[16] These findings support the broader observation that sex-related differences can occur in fingerprint characteristics, although the precise pattern and magnitude of the difference may vary among populations.

The qualitative gender association identified in the present study should nevertheless be distinguished from quantitative ridge-density analysis. Several studies have demonstrated that females generally possess greater ridge density than males, whereas the distribution of qualitative patterns such as loops and whorls may vary less consistently. Nithin et al. demonstrated significantly higher finger ridge counts among females in 550 South Indian participants,[12] and Gutiérrez-Redomero et al. similarly reported population-specific differences in ridge density.[10,13] Therefore, the significant qualitative pattern association observed in the present study represents an additional population-specific observation rather than a universal rule applicable to all populations.

The influence of age on fingerprint characteristics requires careful interpretation. In the present study, age did not show a statistically significant association with the qualitative primary fingerprint pattern. This finding is compatible with the fundamental stability of the primary ridge configuration after its establishment. However, quantitative ridge density can change with age. Sánchez-Andrés et al. demonstrated that ridge density decreases with ageing in selected regions of the distal phalanx, particularly as hand dimensions change during adulthood.[15] Gutiérrez-Redomero et al. similarly demonstrated age-related variation in ridge density in the Mataco-Mataguayo population.[13] Thus, the absence of an age association in the present qualitative pattern analysis does not imply that every measurable fingerprint characteristic remains quantitatively unchanged throughout life.

The biological basis for the observed relationships is supported by the genetic and developmental characteristics of dermatoglyphics. Fingerprint patterns have a substantial genetic component, but their final configuration also reflects the intrauterine developmental environment. Arrieta et al. demonstrated heritability of the major digital dermatoglyphic patterns in monozygotic and dizygotic twins.[17] Karmakar et al. identified significant additive genetic components for multiple quantitative dermatoglyphic traits in twin populations,[18,19] while Temaj et al. reported highly heritable qualitative dermatoglyphic traits involving the digits in Albanian twins.[20] These observations support the concept that genetic influences contribute substantially to fingerprint phenotype while allowing individual variation to develop.

Fingerprint development is also strongly influenced by prenatal developmental processes. Kahn et al. reported that fingerprint characteristics have a significant genetic component while also reflecting aspects of the early prenatal environment, with fingerprints becoming permanently configured before approximately the twentieth week of gestation.[21] Modern developmental work by Glover et al. has further demonstrated that fingerprint ridge formation involves complex molecular and cellular patterning mechanisms involving EDAR, WNT, and BMP signalling pathways.[22] These findings provide a biological basis for understanding why fingerprints show both strong heritable characteristics and substantial individual variation.

The absence of a significant association between fingerprint patterns and Rh blood group in the present study ($p=0.467$) is also noteworthy. The pattern distribution remained broadly comparable between Rh-positive and Rh-negative participants. Rastogi et al. reported a non-significant association between primary fingerprint patterns and Rh blood group,[1] while Kc et al. found that most Rh-related pattern comparisons were statistically insignificant except for selected subgroup analyses.[4] These findings suggest that any relationship between fingerprint configuration and Rh status is weaker and less reproducible than the relationship observed with ABO blood groups.

The bilateral distribution of fingerprint patterns in the present study was broadly symmetrical, with loops remaining the predominant configuration on both hands. Bilateral variation is expected because dermatoglyphic development involves both genetic determination and local developmental influences. Studies involving twins have demonstrated that concordance differs according to the particular digit and dermatoglyphic characteristic examined, indicating that bilateral similarity does not imply complete identity between corresponding digits.[17,20] This developmental variability is also consistent with the individualistic nature of fingerprints and explains why examination of all ten digits remains important in forensic assessment.

From a forensic perspective, the principal value of fingerprints remains personal identification rather than prediction of blood group or gender. The persistence and stability of friction-ridge characteristics form the basis for their widespread forensic application. A comprehensive review of friction-ridge persistence confirmed the stability of key ridge characteristics and supported the continued use of fingerprint comparison and identification.[23] Fingerprint analysis may therefore provide supplementary population-level information regarding sex or blood group when statistically demonstrated associations are present, but such characteristics cannot substitute for direct blood-group testing, DNA profiling, or individual fingerprint comparison.

The present study has several strengths. A relatively large sample of 500 participants was examined, and all ten digits were evaluated, resulting in analysis of 5,000 fingerprint impressions. ABO and Rh blood groups were assessed together with gender and age, allowing simultaneous evaluation of several potentially associated variables. The use of standardized qualitative fingerprint categories also permitted comparison with previous dermatoglyphic studies conducted in Indian and other populations.

The study also has limitations. It was conducted at a single tertiary care institution and therefore may not

represent the entire Indian population. The analysis was based primarily on qualitative fingerprint patterns and did not incorporate quantitative parameters such as total ridge count, ridge density, a-b ridge count, atd angle, or palmar dermatoglyphic characteristics. The study also did not incorporate molecular genetic analysis that could clarify the biological mechanisms underlying the observed associations. In addition, the significant association between qualitative fingerprint pattern and gender observed in the present population requires validation in larger multicentric populations because published studies have demonstrated variability in the strength and direction of gender-related associations.[1,4,16]

Overall, the present study demonstrates that loop patterns constitute the predominant fingerprint configuration and that primary fingerprint pattern distribution shows significant associations with ABO blood group and gender within the studied population. No significant association was identified with Rh blood group or age. The findings are consistent with the broader evidence that dermatoglyphic characteristics have substantial genetic and developmental determinants, while also demonstrating population-specific variation. Accordingly, fingerprint characteristics may provide useful supplementary information in forensic and anthropological investigations, but their associations with blood group and gender should be interpreted probabilistically and should not replace established identification and laboratory methods.

CONCLUSION

The present study demonstrated that loop patterns were the predominant fingerprint configuration among the 500 participants, followed by whorls, arches, and composite patterns. A statistically significant association was observed between fingerprint pattern distribution and ABO blood groups, with loop patterns predominating particularly among individuals with blood groups O and B, while whorl patterns were relatively more frequent among those with blood group A. A significant association was also observed between fingerprint characteristics and gender, with females showing a greater proportion of loop patterns and males demonstrating comparatively more whorl patterns. In contrast, no statistically significant association was identified between fingerprint patterns and Rh blood group or age.

The findings support the possibility that dermatoglyphic characteristics may demonstrate population-level associations with selected genetically determined biological variables. However, the inconsistent findings reported by studies from different geographical and ethnic populations indicate that these relationships are not universal and should not be used to predict an individual's blood group or gender with certainty. Fingerprint examination therefore remains primarily a method of personal identification, while associations with blood groups and gender should be regarded as supplementary observations. Larger multicentric studies incorporating diverse populations, quantitative dermatoglyphic parameters, standardized digital fingerprint analysis, and genetic approaches are warranted to further clarify these relationships and determine their forensic and anthropological significance.

Declarations

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Conflict of interest

The authors declare that there is no conflict of interest related to this study.

Ethical approval

The study was approved by the Institutional Ethics Committee of the tertiary care teaching hospital before commencement of the study. All procedures were performed in accordance with the ethical principles of the Declaration of Helsinki and institutional ethical guidelines.

Informed consent

Written informed consent was obtained from all participants prior to their enrolment in the study.

Author contributions

All authors contributed substantially to the conception and design of the study, data collection, data analysis, interpretation of results, manuscript preparation, critical revision of the manuscript, and approval of the final version for publication.

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