FINGERPRINT PATTERN DISTRIBUTION ACROSS DIVERSE INDIAN POPULATIONS: REVIEW OF LITERATURE

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ABSTRACT

Background: Fingerprints are one of the most important tools in forensic science because of their uniqueness and immutability, making it possible to use the prints for the identification of individuals. Their importance, however, goes beyond criminal investigations; fingerprints provide meaningful information about genetic diversity, population structure, and demographic character, thus making them an extremely important tool in biological anthropology. **Objectives:** This review article closely examines fingerprint pattern distributions across different regions of India, based on data from 49 cross-sectional studies. **Methodology:** A search was conducted in Scopus, PubMed, and Google Scholar using the keywords 'fingerprint pattern' and 'dermatoglyphics,' resulting in the inclusion of 49 articles for this review. **Results:** The study explores the fingerprint patterns of tribes, rural and urban populations across parts of the country- north, east, northeast, west, central, and south. From the analysis of the current studies, we find a vast diversity in the fingerprint pattern distributions across the regions. While loops were the commonest, followed by whorls and arches, regional characteristics were quite evident. Intra-community variations and differences between sexes were also detected, suggesting that fingerprint patterns vary across communities and between sexes, highlighting the rich demographic and genetic diversity of India. **Conclusion:** It seems such studies can contribute to improved approaches in forensic science and provide insights into India's rich reservoir of phenotypic diversity. The study further emphasizes the necessity of conducting more region-specific studies in order to progress forensic identification and further anthropological studies.

Keywords: Fingerprint patterns, Indian population, Diversity, Literature review

INTRODUCTION

Forensic science facilitates precise identification through distinctive physical characteristics of both existing individuals and the deceased, including victims and offenders. Fingerprints are essential characteristics required for conclusive identification, as they are frequently discovered at crime scenes, and their highly individualistic in nature **(Mandrah & Kanwal, 2015; Rastogi et al., 2023; Shrestha & Malla, 2019**). In addition to their forensic significance, fingerprints are a specialized focus in biological anthropology, human biology, and morphology, examining patterns and variations among different population groups **(Banik et al., 2009; Karmakar et al., 2008; Siváková et al., 2007)**, allowing researchers to understand genetic diversity and demographic characteristics **(Gutiérrez-Redomero et al., 2013)**. This provides valuable insights into human evolution, population diversity, and the demographic characteristics of various regions and ethnic groups.

Fingerprint patterns are basically the configurations of epidermal ridges (elevated portion) and the depressions between them, known as furrows **(Acree, 1999; Gutiérrez-Redomero et al., 2008)**. Epidermal ridges hold small openings known as pores, holding part of the opening of the ducts of the sweat glands, which is unique in shape, size and varies in location. These, when sweat secretion spread upon a touch surface by contact, appear as prints known as fingerprints **(Sharma et al., 2019)**. Moreover, oils are often transferred from the tips of the fingers, thereby obtained by touching the face can also increase the visibility on various materials of these fingerprint impressions **(Das et al., 2024)**. Volar Pads on which epidermal ridges appear begin to form within the palmar aspect of the fingertips, inter-digital spaces, as well as the thenar and ulnar hypothenar areas during the 6th and 7th week of gestation **(Glover et al., 2023; Hall et al., 1989)**. The epidermal ridge structure begins to develop around approximately the 10th week of gestation and completes by the 16th week **(Gutiérrez-Redomero et al., 2013; Okajima,**

1975). During embryonic development, the total number of ridges is determined to a large extent by genetics **(Soanboon et al., 2016)**, but other environmental elements of the womb, such as the amniotic fluid composition, determine the final outcome **(Ali & Ahmed, 2020)**. These epidermal ridge patterns remain consistent throughout an individual's life and persist even posthumously, making them a dependable means of identification **(Rivaldería et al., 2016; Seidenberg-Kajabova et al., 2010)**.

The configuration of epidermal ridges varies according to the size and symmetry of the volar pads, resulting in the formation of distinct fingerprint patterns. On the fingertip, if the pads are large, they form a whorl pattern, if the pads are intermediate, they show loop patterns and if the pads are small, they tend to show arch patterns **(Hall et al., 1989)**.

OVERVIEW OF FINGERPRINT PATTERNS

Based on widely used Henry's Classification System **(Henry, 1900)**, fingerprint patterns are categorized based on the arrangement of the epidermal ridges. In Arches, ridges run side to side without turn backward and no delta present. However, in Tented Arches, central ridges may have upward thrust and arrange themselves from both sides of an axis where neighbouring ridges merge. Loops are ridges that take a backward turn without any twist, usually with one delta. Loops are further categorized into two types depending upon the direction of the downward slope. An Ulnar Loop slopes down from the thumb to the little finger and a Radial Loop slopes down from the little finger to the thumb. In Whorls, some ridges complete the circuit forming two deltas. The Central Pocket Loop feature has a core of ridges forming a loop middle of a central area known as a "pocket" that diverges with the general ridge flow; it has two deltas as well as at least one recurving ridge within that pocket that does not communicate with the surrounding ridge pattern. A Lateral Pocket Loop is a term describing when the loop ridges curve sharply downwards on one side before recuring and, in this case, make an interspace or "pocket" on that side, which is commonly filled by ridges from another loop. There are two interlocking loops found in a single fingerprint pattern known as the Twin Loop. Accidentals refer to the uncommon patterns characterized by combining features of more than one type of fingerprints such as loops and whorls and that yield a rather ill-structured result due to lack of classification **(Henry, 1900)**.

The Indian population is heterogenous in nature; thus, fingerprint patterns too vary considerably across sub-populations **(Anand et al., 2023; Bansal et al., 2014; Khadri et al., 2013; Nagesh et al., 2012; Nithin et al., 2009; Shukla et al., 2016; Singh & Garg, 2004)**. Analysing this variation is crucial for understanding genetic as well as phenotypic diversity within the Indian subcontinent. Understanding these trends will help in exploring population and area-specific fingerprint features. To date, no research has classified the distribution of fingerprint patterns in the Indian population by distinct zones of the country. Thus, the present literature review would seek to thoroughly examine the two-dimensional fingerprint patterns across various tribal, rural and urban communities within India, thereby highlighting its diversity and addressing critical gap in existing studies.

METHODOLOGY

A literature search was conducted using Scopus, PubMed, and Google Scholar with keywords like 'fingerprint pattern' and 'dermatoglyphics'. Additional manual searches included forward citation tracking and backward reference screening. Observational studies on fingerprint pattern distribution in the Indian context were included. Since only published data were used, ethical approval was not required.

RESULTS

The present review comprises of 49 cross-sectional studies **(Ali & Haroon, 2023; Anand et al., 2023; Balgir & Sharma, 1986; Bandyopadhya & Sharma, 1995; Banik et al., 2009; Bansal et al., 2013; Bansal et al., 2014; Basu, 1976; Bharadwaja et al., 2004; Binorkar & Kulkarni, 2017; Biswas, 2011; Borah et al., 2021; Choudhury, 2005; Das et al., 2018; Dorjee et al., 2015; Ghosh et al., 2011; Gogoi & Hazarika, 2024; Gupta & Singh, 2024; Gupta & Singh, 2020; Joshi et al., 2016; Khadri et al., 2013; Koneru et al., 2014; Maity & Dolai, 2021; Marak, 2024; Marigoudar et al., 2020; Mehta & Mehta, 2015; Nagaraj et al., 2015; Nagesh et al., 2012; Nagrale et al., 2021; Nandan et al., 2015; Nithin et al., 2009; Pandey & Vyas, 2014; Pathan & Mondal, 2021; Patil et al., 2017; Rastogi et al., 2023; Rastogi & Pillai, 2010; Ray et al., 2015; Sharma & Sahu, 1973;**

Shukla et al., 2016; Singh, 2016; Singh & Garg, 2004; Srivastava, 1963; Tripathi et al., 2020; Varma et al., 2023; Verma et al., 2015; Vishwakarma et al., 2021; Kapoor & Badiye 2015; Baryah & Krishan, 2020, Raloti et al., 2013) that investigate fingerprint patterns across diverse sub-populations within India. Inclusion of these studies in this review ensures a comprehensive and unbiased representation of fingerprint pattern diversity across India's diverse sub-populations, covering multiple regions and communities.

The review included 13 studies conducted in the Northern zone of India **(Ali & Haroon, 2023; Anand et al., 2023; Balgir & Sharma, 1986; Bansal et al., 2013; Gupta & Singh, 2024; Gupta & Singh, 2020; Joshi et al., 2016; Shukla et al., 2016; Singh, 2016; Singh & Garg, 2004; Srivastava, 1963; Verma et al., 2015, Baryah & Krishan, 2020)**. Studies from Moradabad and Aligarh of Uttar Pradesh state consistently identified Loops as the most common fingerprint pattern, followed by Whorls and Arches. Loops remained the most prevalent pattern for both males and females, followed by Whorls and Arches **(Ali & Haroon, 2023; Shukla et al., 2016)**. In a study conducted in Lucknow, Uttar Pradesh among medical students, Loops (39.7%) were the most frequent pattern, followed by Whorls (33.7%), Arches (25.2%), and Composite (1.5%) **(Gupta & Singh, 2024)**. Investigations done in Varanasi, Uttar Pradesh found out Ulnar loops to be the most common patterns in males (41.2%) and females (46.1%), followed by Plain whorls (male 24.5%, female 25%) **(Anand et al., 2023)**. In the Gorakhpur region of Uttar Pradesh, Whorls were the most common fingerprint pattern among males (54.4%), while Loops were predominant among females (63.6%). Arches, on the other hand, were the least common pattern observed in both sexes **(Singh, 2016)**. Among the Lodhis and Yadav communities of Lucknow, Uttar Pradesh Loops were observed at a higher frequency, while Arches were the least common **(Gupta & Singh, 2020)**. Among the Danguria Tharu community of Uttar Pradesh, Loops (55%) were the most prevalent, followed by Whorls (40.8%) and Arches (4%) **(Srivastava, 1963)**. Similarly, a study in Rohtak, Haryana state identified Loops (56.3%) to be the predominant pattern **(Verma et al., 2015)**. A study conducted in Mullana, Haryana also found loops to be the most common fingerprint pattern, followed by Whorls, with Arches being the least common **(Bansal et al., 2013)**. Among dental students in Baddi, Himachal Pradesh state, Loops (53.4%) were the most prevalent fingerprint pattern, followed by Whorls (31.2%), Arches (15.1%). Females (53.3%) exhibited a higher frequency of loops compared to males (46.4%) (Joshi et al., 2016). Similar findings were reported among Hindu and Muslim Gujjar tribal community of Punjab and Himachal Pradesh **(Balgir & Sharma, 1986)**. Among the male Rajputs of Himachal Pradesh, Whorl (49%) and Loop (49%) were the most common, whereas among the females Whorls (53.3%) were the most prevalent **(Singh & Garg, 2004)**. Another study conducted among the Rajput and Brahmin ethnic groups from Shimla and Solan in Himachal Pradesh analyzed fingerprint pattern distribution among males and females. In the Rajput group, loops were the most prevalent pattern, observed in 51.41% of males and 55.64% of females, followed by whorls (34.95% in males and 28.76% in females), composites (8.85% in males and 10.57% in females), and arches (4.78% in males and 5.01% in females). Similarly, in the Brahmin group, loops were the most common, accounting for 56.35% in males and 54% in females, followed by whorls (32.25% in males and 29.92% in females), composites (9% in males and 10.15% in females), and arches (2.38% in males and 5.92% in females) **(Baryah & Krishan, 2020)**.

8 studies have been retrieved from the Eastern zone of India **(Bandyopadhya & Sharma, 1995; Biswas, 2011; Choudhury, 2005; Ghosh et al., 2011; Maity & Dolai, 2021; Rastogi et al., 2023; Ray et al., 2015; Sharma & Sahu, 1973)**. Among Asur males of Palamau, Bihar state, Whorls were the most common fingerprint pattern, observed in 50.3% of cases, followed by Ulnar Loops (44.62%), Radial Loops (3.3%), Arches (1.1%), and Tented Arches (0.5%) **(Bandyopadhya & Sharma, 1995)**. A study among healthcare students and workers in Patna, Bihar revealed that Loops were predominant (55.9%), followed by Whorls (34.9%), Arches (6%), and Composites (3.1%). The distribution pattern was consistent among both males and females (Rastogi et al., 2023). Representatives of the Oraon tribe of Ranchi, Jharkhand state exhibited a maximum frequency of Whorls (60.5%) and Loops (36.9%) **(Sharma & Sahu, 1973)**. In Orissa state, Loops were found to be

the predominant pattern across three Kondh groups—Kutia, Dongoria, and Kuvi males and females **(Choudhury, 2005)**. Among students in Bhubaneswar, Odisha, Loops dominated (33.2%), followed by Whorls (28.7%), Plain Arches (20.5%), and Tented Arches (3.2%) (Ray et al., 2015). Among the Dhimals of West Bengal state, the distribution included 52.6% Whorls, 45.2% Loops, and 2.16% Arches, with males (55.1%) and females (50.2%) both showing a predominance of Whorls (Biswas, 2011). Research conducted on Sunni Muslim population of West Bengal showed a higher overall frequency of Whorls, followed by Loops and Arches **(Ghosh et al., 2011)**. In a population of Purba Medinipur district of West Bengal, Loops were more common (46.1%), with Whorls (36.2%), Arches (10.8%), and Composites (6.7%) occurring less frequently **(Maity & Dolai, 2021)**.

Across 7 studies from the North-Eastern zone of India **(Banik et al., 2009; Borah et al., 2021; Das et al., 2018; Dorjee et al., 2015; Gogoi & Hazarika, 2024; Koneru et al., 2014; Marak, 2024)**, different fingerprint pattern distributions were observed. Among the Rengma Nagas of Nagaland state, Whorls were the dominant pattern in both males (52.1%) and females (55.6%), followed by Loops (47.7% in males and 42.8% in females) **(Banik et al., 2009)**. In a study of the Mishing tribal community in Assam state, Ulnar Loops were predominant among both sexes (53% in males and 59.2% in females), followed by Whorls (39.8% in males and 29.8% in females). Other observed patterns included Plain Arches (3.5% in males, 5.9% in females), Radial Loops (2.5% in males, 2.9% in females), and Tented Arches (1% in males, 2% in females) **(Borah et al., 2021)**. An investigation among medical students in Tezpur of Assam and Manipur state indicated Loops as the predominant pattern, followed by Whorls and Arches with similar trends observed in both male and female participants **(Das et al., 2018; Koneru et al., 2014)**. Among the Ahom population of Assam, Loops were more common in both males (50.4%) and females (54.6%), followed by Whorls (46.4% in males, 40.2% in females) and Arches (3.2% in males, 5.2% in females) **(Gogoi & Hazarika, 2024)**. The Limboo population of Sikkim state showed a prevalence of Loops (64.3% in males, 75% in females), with Whorls (31% in males, 21.3% in females) and Arches (4.6% in males, 3.6% in females) being less common **(Dorjee et al., 2015)**. Two localities in Tura, Meghalaya state, revealed Loops as the most prevalent fingerprint pattern across both sexes, while Arches were the least common **(Marak, 2024)**.

10 studies were retrieved from the Western zone of India **(Bansal et al., 2014; Bharadwaja et al., 2004; Binorkar & Kulkarni, 2017; Mehta & Mehta, 2015; Nagrale et al., 2021; Pandey & Vyas, 2014; Pathan & Mondal, 2021; Patil et al., 2017; Kapoor & Badiye, 2015; Raloti et al., 2013)**. Research at a medical college in Ahmedabad, Gujarat state, found Loops to be the most common fingerprint pattern (57%), followed by Whorls (26%), Composites (9%), and Arches (8%) **(Raloti et al., 2013)**. In a study conducted at Sabarmati Jail, Gujarat, convicted males had a higher prevalence of Loops (54.5%), followed by Whorls (41.5%) and Arches (3.9%). Among control males, Loops (55.2%) were also the most common, followed by Whorls (36.9%) and Arches (3.6%) **(Pandey & Vyas, 2014)**. Among the Bhil population in Udaipur, Rajasthan, Loops were observed as the dominant pattern (60.2%), followed by Whorls (32.3%) and Arches (7.4%) **(Pathan & Mondal, 2021)**. Studies conducted at the Medical College of Ajmer in Rajasthan state, Vidarbha region of Nagpur, Navi Mumbai, and Wanadongri region in Nagpur in Maharashtra state similarly identified Loops as the predominant pattern, with Whorls as the intermediate, and Arches being the least frequent **(Bharadwaja et al., 2004; Nagrale et al., 2021; Patil et al., 2017, Mehta & Mehta, 2015)**. Study conducted on the Marathi speaking population of Nagpur, Maharashtra inflicted, Ulnar Loops (51.3%) to be prevalent, followed by Whorls (26.5%), with less common patterns including Twinned Loops (7.1%), Central Pockets (5.7%), Radial Loops (2.8%), Accidentals (2.1%), Tented Arches (1.4%), Plain Arches (1.4%), and Lateral Pocket Loops (1.3%) **(Bansal et al., 2014)**. Research conducted in Nanded district, Maharashtra reported Loops as the most frequent pattern (65.4%), followed by Whorls (24.3%), Arches (7.1%), and Composites (3%) **(Binorkar & Kulkarni, 2017)**. Among the Muslim population in Nagpur, Maharashtra, a study found that the most common pattern was loops (50.25%), followed by whorls (28%), composites (17.33%), and arches (4.42%). The ulnar loop was the most common pattern both

in males and females, and the prevalence was 50.83% among males and 46% among females **(Kapoor & Badiye, 2015)**.

This review included only 1 study from the Central zone of India. Study conducted at a medical college in Indore, Madhya Pradesh state revealed that Loops (56.6%) were the predominant fingerprint pattern, followed by Whorls (35.2%) and Arches (8.2%). Among male participants, Loops accounted for 59.6%, followed by Whorls (32.4%) and Arches (8%). For females, the most common patterns were Loops (52.9%), followed by Whorls (38.7%) and Arches (8.4%) **(Vishwakarma et al., 2021)**.

11 studies were retrieved from Southern zone of India **(Basu, 1976; Khadri et al., 2013; Koneru et al., 2014; Marigoudar et al., 2020; Nagaraj et al., 2015; Nagesh et al., 2012; Nandan et al., 2015; Nithin et al., 2009; Rastogi & Pillai, 2010; Tripathi et al., 2020; Varma et al., 2023)**. One study on an urban population of Mysore, Karnataka state observed that Ulnar Loops were the most commonly found pattern, followed by Whorls, Simple Arches, Tented Arches, Radial Loops, Twinned Loops, and Accidental types **(Nithin et al., 2009)**. In research conducted in Bijapur, Karnataka, Ulnar Loops were the most prevalent fingerprint pattern in both males (38.4%) and females (44.5%), followed by Plain Whorls (24% in males and 18.2% in females) and Central Pocket Loop Whorls (14.8% in males and 14.6% in females) **(Khadri et al., 2013)**. A study carried out at a medical college in Mysore, Karnataka indicated that Loops were prevalent (55.3%), followed by Whorls (34.7%) and Arches (10%), with both sexes showing a similar distribution **(Marigoudar et al., 2020)**. In a study conducted by Nagaraj et al. (2015) among school teachers of a school at Mysore, Karnataka, Loops (64%) were predominant, followed by Whorls (14%), Arches (14%) and Mixed (composed of 2/3 basic types) patterns (8%) **(Nagaraj et al., 2015)**. Among Lingayat and Vokkaliga caste groups in Mysore, Karnataka, the most prevalent patterns were Ulnar Loops, Whorls, Arches, and Radial Loops. Among Adi Karnataka females, the distribution was similar, while males showed Ulnar Loops as most common (60.3%), followed by Whorls (35.6%), Radial Loops (2.5%), and Arches (1.5%) **(Basu, 1976)**. Another study carried out at a medical college of Mangalore, Karnataka, revealed Loops (60.9%) were commonly found, followed by Whorls (32.5%) and Arches (6.5%) **(Rastogi & Pillai, 2010)**. Research involving male and female students at a medical college in Visakhapatnam, Andhra Pradesh state inferred Loops to be occurring more frequently (65.6% in males and 58.1% in females), followed by Whorls (27.4% in males and 34% in females) and Arches (6.9% in males and 7.8% in females) **(Varma et al., 2023)**. An investigation from Andhra Pradesh found out Loops as the most common pattern both in males (44%) and females (42%) and in pooled data as well (Nandan et al., 2015). In a study on the Telugu speaking population in Andhra Pradesh, Ulnar Loops were the most common pattern (50.3%), followed by Whorls (22.1%), Central Pocket Loops (6.8%), and Plain Arches (5.3%) **(Tripathi et al., 2020)**. At a medical college in Kerala, researchers found that Loops were predominant (55%), followed by Whorls (37%) and Arches (8%) **(Koneru et al., 2014)**. **(Nagesh et al., 2012)** in their study from a South Indian population found that Ulnar Loops were predominant pattern followed by Whorls.

CRITICAL ANALYSIS OF FINGERPRINT PATTERN VARIATIONS IN INDIAN SUB-POPULATIONS

The reviewed literature on fingerprint pattern distribution across different sub-populations of India sheds light upon the varied as well as complex nature of dermatoglyphic traits prevalent in the country. Fingerprint patterns, comprising Loops, Whorls, Arches, and Composites display similarity in addition to differences in various groups and populations. Such a fact assumes significant importance in the context of forensic, anthropological, and genetic investigations. Regional diversity represented through the present review makes apparent how regional differences itself explain the differences in fingerprint patterns.

The selected studies highlight a significant trend- loop patterns are the most common in Indian sub-populations, followed by whorls, and arches. This dominance correlates well with the global trends detected in the fingerprint distribution **(Nandy, 2001)**. However, the extent and rank order may vary depending on sub-populations from different geographic regions, ethnic groups, or social classes in India. For instance, whorl patterns were found predominant in tribes rather than in the urban population, highlighting a possible link to

genetic inheritance or environmental influences within isolated communities. Such differences therefore make it important to account for individual population dynamics in interpreting fingerprint profiles.

Despite these significant findings, the existing literature presents several notable shortcomings. Many studies have relied on small and non-representative samples, often drawn from populations of a few educational institutions or localized areas. This results in significant biases, limiting the generalizability of the conclusions to larger sub-populations. Furthermore, there is a noticeable disparity in the distribution of fingerprint research across different regions of India, with the Central and the North-Eastern zone of India being particularly underrepresented. Additionally, the variations in methods of classification and definitions of fingerprint patterns across studies hinder comparative and synthesizing approaches. The other side of the problem is that infrequently appearing fingerprints patterns, such as composites and accidentals, which might be more specific or unique features to distinguish one sub-population from another are not extensively explored.

CONCLUSION

The present literature review provides important insights into the fingerprint patterns of Indian sub-populations. The review underlines the need for more intensive and methodologically robust studies. It further concludes for greater standardization, broader sampling, and rigorous statistical evaluation for greater generalizability, to could pave way towards a deeper understanding of dermatoglyphic traits and their practical applications.

RECOMMENDATIONS

1. To enhance the reliability and generalizability of fingerprint research, future studies should address critical areas including the inclusion of representative samples from diverse age groups, sexes, geographic regions, and ethnic subgroups, adopting rigorous random sampling techniques to eliminate bias, and establishing standardized protocols for classifying and analyzing fingerprint patterns to improve data reliability and enable meaningful comparisons across studies.

2. Robust statistical methods such as chi-square tests, t-tests, ANOVA, and regression analysis can be utilized to assess pattern distributions and relationships with continuous variables.

3. Additionally, exploring rare fingerprint patterns like composites and accidentals can offer unique insights into sub-population differentiation.

4. A multidisciplinary approach integrating genetic and environmental factors is necessary to comprehend their interplay in shaping fingerprint variability.

5. Methodologically rigorous studies with broader sampling will strengthen generalizability and provide deeper insights into dermatoglyphic traits, facilitating applications in forensic sciences, biological anthropology, population genetics and related fields.

CONFLICT OF INTEREST

The author(s) declare that they have no competing interests.

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