

FINGERPRINTS - THE INFALLIBLE PHYSICAL EVIDENCE AND ITS IMPORTANCE

Abstract

Fingerprints serve as undeniable physical evidence discovered almost everywhere. These prints are utilized for the purpose of identifying unknown individuals viz. victims, suspects, witnesses, or for verifying records. They also play a crucial role in connecting suspects to crime scenes. These unique, unchanging, universally present, and categorizable pieces of evidence can be found on any object touched with bare hands. When identified and compared, these fingerprints are used as legal evidence in court cases. This practice is founded on the core principle that no two individuals can possess identical fingerprints; in other words, each person's fingerprints are distinctive and serve as a means of personal identification. Over time, numerous innovative techniques have been developed and tested to uncover latent fingerprints. While certain methods are remarkably sensitive and can reveal fingerprints that would have otherwise remained undetected, latent fingerprints are delicate traces that require careful preservation. A crime scene investigator must operate under the assumption that any item taken from the scene may carry fingerprints left by the perpetrator. It is crucial to take appropriate measures to safeguard and uncover such evidence. The quality of latent fingerprints can be influenced by the surrounding environment, often guiding examiners in determining the most suitable detection technique or sequence of techniques for a specific case. Various physical factors, such as heat, diffusion, dust settling, friction, as well as chemical elements like humidity, solvents, and air, can degrade the durability of latent fingerprints. The duration of exposure (or age of the prints) and the presence of bacteria can also contribute to

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their degradation. Consequently, preserving these prints is of utmost significance for purposes of comparison, classification, and analysis. Despite the existence of various scientific and forensic methodologies, fingerprints still stand out as the most effective means of personal identification within legal investigations. Furthermore, several studies have highlighted gender differences in fingerprints. Thus, utilizing fingerprints to determine gender can aid in streamlining investigations, saving time and resources. Additionally, utilizing the ridge density parameter to analyze sex and population differences can contribute to the field of forensic anthropology, allowing for the study of variability. Moreover, the ridge density parameter can be valuable in determining sex and/or population groups from partial or faint prints recovered from crime scenes, a task that would otherwise be unattainable.

Fingerprints also carry huge intriguing connections to various aspects of social sciences, particularly in the fields of criminology, psychology, and anthropology. In criminology, fingerprints play a crucial role, specifically in forensic science and criminal investigations. Each individual's fingerprints are unique, forming distinct patterns that aid in identification. This uniqueness has led to the development of fingerprint databases and automated recognition systems, which assist law enforcement agencies in solving crimes and identifying suspects. The study of fingerprint analysis falls under forensic science and is pivotal in linking individuals to crime scenes. In psychology, fingerprints are linked to studies of identity and individual differences. The concept of fingerprint uniqueness has sparked discussions about how our biological characteristics influence our sense of self and identity. Additionally, fingerprint analysis has been explored in relation to conditions like dermatoglyphics (the study of skin ridge patterns) and potential links to

psychological traits such as in the art of palmistry. However, these connections are often considered speculative due to limited empirical evidence. In anthropology, the cultural significance of fingerprints has been examined in various societies. Indigenous cultures and tribes, for instance, have integrated handprints and fingerprints into art, rituals, and symbolism. Anthropologists study how these unique identifiers are woven into cultural practices, offering insights into diverse societies' perceptions of individuality and identity. Overall, fingerprints bridge the gap between individuals' physical uniqueness and broader concepts such as identity, criminal justice, and cultural practices, rendering them a captivating subject of study in the realm of social sciences.

Keywords: Forensic Science, Fingerprints, Dermatoglyphics, Criminal Identification, Biometrics.

I. INTRODUCTION TO FORENSIC SCIENCE

The term "forensic" originates from the Latin word "forensis," signifying "in an open court or for the public" (Oxford English Dictionary, 2005). Forensic Science is the scientific field that links individuals, locations, and objects connected to a crime scene, whether indoors or outdoors. It encompasses various scientific branches that aid in investigating pertinent evidence tied to the crime scene, consequently establishing the perpetrator's identity in a legal setting, whether civil or criminal (Houck and Siegel, 2009). In essence, it involves applying diverse scientific disciplines to scrutinize physical evidence, establish connections between suspects, victims, and the crime scene, and ultimately identify the wrongdoer. It entails utilizing scientific knowledge within the context of legal proceedings. As per Prahlow (2010), the phrase "forensic science" alludes to a collection of scientific fields that utilize their specific expertise to address law enforcement, criminal and civil litigation, legal inquiries, and judicial matters. However, its first official record in the English language dates back to 1659 in the 'Merriam-Webster' dictionary. It is a well-known fact that; forensic science is an applied branch of science where the related expertise of various branches of knowledge is used scientifically for helping the criminal justice system in the delivery of justice.

Three Pivotal Concepts prevalent in all forensic sciences are as follows:

- 1. Chain of Custody:** All types of evidence must undergo meticulous documentation and assessment. Given the nature of certain evidence, perpetual collection and preservation are often unfeasible. Therefore, any transfer of evidence, whether between individuals or secure locales, must be meticulously recorded. Preserving this custody chain serves to ensure the integrity and uncontaminated state of the evidence. Failure to maintain an intact "chain of custody" may render the evidence inadmissible in a court of law due to potential compromise.
- 2. Admissibility of Tests, Evidence and Testimony:** Another overarching concern across all forensic domains is the existence of legal criteria for admitting forensic tests and expert testimonies as evidence.
- 3. Expert Witness:** The third universally applicable aspect in forensic sciences is the concept of the expert witness or expert testimony. To be acknowledged as such, the witness should possess specialized expertise within a specific discipline and be capable of delivering insights pertinent to that area. An expert witness must receive formal recognition or court-sanctioned qualification as an expert to testify. As per the understanding of *Section-45* of Indian Evidence Act, Opinions Rendered by Experts—In situations where the Court needs to develop an understanding about matters concerning foreign law, scientific or artistic domains, or matters of identifying handwriting or finger impressions, the viewpoints of individuals possessing specialized expertise in the particular foreign law, science, art, handwriting identification, or finger impressions are significant and applicable. These individuals are referred to as experts.

II. FORENSIC DERMATOGLYPHICS

The skin found on the palmar and plantar surfaces of the hands and feet displays intricate patterns of ridges and furrows, in contrast to the covering on other parts of the body.

Dermatoglyphic characteristics exhibit significant variability, not only among individuals within a population but also across different populations. These variations have a hereditary basis and contribute to making dermatoglyphics an invaluable tool for research in physical anthropology, forensic science, and medicine (Kapoor, 1991). In 1926, Cummins introduced the term "dermatoglyphics" to this scientific domain, which has since been internationally recognized and adopted. Etymologically, this term combines "Derma," meaning skin, and "Glyphe," implying carving, creating the image of imprints etched into the skin. These dermatoglyphic features develop during the 13th to 14th week of embryonic growth and remain unalterable throughout an individual's life, except for proportional adjustments linked to their growth. The paramount importance of personal identification in crime detection cannot be overstated. In this context, the attributes of dermatoglyphics assume a highly crucial role. The latent prints left behind at crime scenes are collected and compared with those of suspected individuals, ultimately leading to the identification of the perpetrator (Kumbhani, 2007). The historical trajectory of fingerprint systems has been documented, with Lauter (1912) outlining the fingerprint system's history, Herschel (1916) tracing the origins of fingerprinting, Cummins and Midlo (1926) discovering a thumbprint impression on clay, Heindl (1929) reporting the initial fingerprint identification in Germany, Cummins (1930) presenting the earliest fingerprint carving from the Stone Age, de Forest (1930) mapping dactyloscopy in the United States of America, Wilton (1938) penning the book "Finger Prints History, Law and Romance," Myers (1938) delving into the history of fingerprint identification, Penrose (1968) drafting the memorandum on dermatoglyphics nomenclature, and numerous investigators producing notable articles, including Wentworth and Wilder (1932), Hoover (1938), Mavalwala (1977), Hall (1979), and Meier (1980).

The skin encompassing the front surface of the human hand (palms and fingers) and the sole of the foot diverges in texture and appearance from the skin that blankets the body elsewhere. This specialized skin presents creases, minute ridges, and furrows. Known as friction ridges, these features enable a person to grasp objects securely and maintain footing. These ridges are devoid of hair but host sweat glands. While forensic scientists have primarily directed their research toward fingerprints for identification purposes, there is a contemporary shift towards exploring palm prints, sole prints, and toe prints for identification. This shift has expanded the scope of forensic dermatoglyphics, encompassing areas such as stature estimation through hand measurements and prints among different population groups. Examples include studies conducted on Himachal Pradesh population groups by Vijeta and Kapoor (2012), stature estimation through hand measurements and prints among the Ladhakis of Kashmir by Kapoor *et al.* (2013), and estimation of stature from palm prints within Indian populations by Choudhary and Kapoor (2014), among others.

- 1. Early Origins:** The historical exploration of fingerprints, also known as Dermatoglyphics – the scientific examination of the papillary ridges on hands and feet – traces its origins to approximately 1750 years BC. During this time, inhabitants of Babylon employed fingerprints to mark their identity on clay vessels they crafted. Around 220 BC, the Chinese pioneered the utilization of ink prints, temporarily relegating fingerprints to obscurity for several centuries.
- 2. Early Development of Dactyloscopy:** In the year 1684, Dr. Nehemiah Grew emerged as the first European to document observations on friction ridge skin, publishing his findings in a paper titled "Philosophical Transactions of the Royal Society of London." Further contributing to the understanding of friction ridge skin details, a Dutch anatomist

named GovardBidloo described these patterns in his 1685 book, "Anatomy of the Human Body." The year 1686 witnessed Marcello Malpighius, an anatomy professor at the University of Bologna, identifying fingerprint ridges, spirals, and loops in his treatise. His contributions were so significant that a layer of skin was named after him, known as the "Malpighi" layer, with a thickness of around 1.8mm. However, none of these early scholars discussed the uniqueness or permanence of friction ridge skin.

It was in 1823 when J. E. Purkinje, a Czech physiologist and biologist, unveiled the potential for classifying fingerprints, marking the inception of fingerprinting as a concept. Progressing into the mid-19th century, Sir William Herschel made a remarkable move in India around 1858 by requiring laborers to sign contracts using their fingerprints. This action brought the utility of fingerprints for personal identification to the forefront.

Notably, the year 1880 witnessed significant contributions from two papers published in Nature Word Journal. Authored by Henry Faulds and William James Herschel, these papers endorsed the application of fingerprints for individual identification (Faulds, 1880). Faulds' interest in fingerprints was sparked by encountering impressions of them on ancient Japanese pottery. He delved further by studying prints on contemporary pottery, creating inked "nature-prints" of both Japanese individuals and a selection of Europeans. Even the finger patterns of monkeys captured his attention. His observations revealed the remarkable diversity in designs and instances of strong resemblance between parents and offspring. Faulds recognized the potential of studying these patterns for purposes such as comparative primatology, ethological classification, archaeology, mummy analysis, and demonstrating blood relationships. Most significantly, he recognized their potential in personal identification.

3. **Uncovering the History of Fingerprints:** Sir William Herschel, who held the position of Chief Administrator of the Hooghly district in Bengal, responded promptly to Faulds letter by presenting his own extensive experience with "finger marks" spanning over two decades in India. He aimed to counteract false impersonation. Fingerprint identification had already been embraced in India, thanks to the efforts of Sir Edward Richard Henry, the Inspector General of Police. Collaborating with his two assistants, Rai Bahadur Hem Chandra Bose and Khan Bahadur Aziz-Ul-Haque, they formulated a practical fingerprint classification system, known as Henry's system of ten-digit fingerprints classification. Prior to this, anthropometry had been utilized in India. However, a committee appointed by the Government of India, reporting in March 1897, found fingerprint identification to be superior and endorsed its adoption. Just as Galton had participated in corresponding committee sessions in England in 1893-1894, Henry also engaged with the commission.

In 1892, Sir Francis Galton, whose lineage connected him to Erasmus Darwin and, in turn, made him a cousin of Charles Darwin (1809-1882), published his work on fingerprints (Galton, 1892). While Galton's early professional training lay in medicine, his focus largely shifted toward the utility of fingerprint identification (Durham and Plato, 1990). He ventured into studying the hereditary aspects of fingerprints, conducting comparisons among siblings, twins, and genetically unrelated individuals. He was the first to report concordance of papillary ridge patterns among relatives. This breakthrough conferred upon the field a valuable role in forensic science and personal identification, endowing it with substantial evidentiary value. Dermal palmar and plantar ridges emerged as significant subjects of study in biological research. Their distinctive

variations are non-replicable even among monozygotic twins or within the same individual. The details of these ridges remain unchanging. Although individual traits may vary, this diversity adheres to pattern limits conducive to systematic classification (Cummins and Midlo, 1943).

A parallel development of fingerprint identification occurred in Argentina, where Juan Vucetich independently formulated a practical fingerprint classification system and introduced its application as early as 1891. The world's very first Finger Print Bureau came into existence within the walls of Writer's Building in Calcutta (now Kolkata) in 1897. This monumental step followed a deep-seated conviction in the infallibility and dependability of finger impressions as a means of identification. Such faith led to their admissibility in the court of law under section 45 of the Indian Evidence Act (1872), a specific acknowledgment. Subsequently, fingerprint identification was officially embraced in England by 1905, and its global adoption followed suit by 1908. Among the key figures shaping the landscape of fingerprint science during the period of 1880-1904 are Faulds, Galton, Henry, Herschel, and Vucetich (listed alphabetically to emphasize shared contributions). Notably, Henry Jackson holds the distinction of being the first criminal captured solely based on fingerprints in 1902 (Kapoor, 1991). In the early 20th century, an American named Harris Hawthorne Wilder took the lead in conducting comprehensive studies on the methodology, inheritance, and racial variations of palmar, planter papillary ridge patterns, and fingerprints. Commencing his series of papers on these subjects in 1902, he continued his contributions until 1916 (Wilder, 1902; 1904; 1916). These studies marked the pioneering exploration of palmar and plantar dermatoglyphics (Wilder, 1916). His wife, Inez Whipple-Wilder, made her own impact with the first serious study of non-human epidermal ridges in 1904 (Inez and Wilder, 1904).

In 1924, the fingerprints records from the Federal Bureau of Investigation and Leavenworth prisons merged, forming the foundational identification records of the FBI. Today, this repository boasts over 300 million fingerprint records (Book by Gregory Russell A, 1957). During the mid-20th century, Harold Cummins, a prominent figure and a former professor of Microscopic Anatomy at Tulane University, significantly shaped the field. In 1926, he introduced the term "dermatoglyphics" at the annual meeting of the American Association of Anatomists (Durham and Plato, 1990). Collaborating with Charles Midlo, M.D., he further established the term's usage in a paper later that year (Cummins and Midlo, 1926). One of the most cited works on dermatoglyphic methodology, "Revised methods of interpreting and formulating palmar dermatoglyphics," was co-authored by Cummins, Midlo, and Wilders in 1929, appearing in the American Journal of Physical Anthropology (Cummins *et al.*, 1929). Cummins also left an enduring legacy through his seminal book "Finger Prints, Palms and Soles" (1943), which became a cornerstone in the realm of dermatoglyphics (Cummins and Midlo, 1943), dedicated to the visionary Harris Hawthorne Wilder.

Palmistry fortune tellers, also known as cheirologists, in 1973 by L. S. Penrose, a significant figure during the third quarter of the 20th century. He contended that these practitioners failed to harness the intricate dermal ridges that formed the foundation of dermatoglyphics science (Penrose, 1973). Mavalwala highlighted a noteworthy Japanese manuscript dating back to 1820, authored by Ashizuka-Sai Shofou. This manuscript enumerated 32 distinct whorl types along with their frequency of occurrence in various

combinations across the five fingers (Mavalwala, 1978). Such an approach often proves valuable in scientific investigations, seeking to uncover meaningful connections between fingerprints and genetic or chronic health indicators.

III. ADVANCES IN FINGERPRINT DETECTION TECHNIQUES

- 1. Early Beginnings:** Fingerprint identification remained a challenging endeavor for experts, propelling ongoing and unwavering research in this field. The primary goal of these experts and researchers revolved around uncovering latent fingerprints on surfaces and preserving them as records to aid in solving crimes. This pursuit led to the development of various fingerprint detection techniques, including the powder dusting method, silver nitrate method, ninhydrin method, cyanoacrylate ester fuming techniques, and others. These techniques predominantly fall under the category of physical methods, often relying on the adherence or deposition of particulate matter onto the latent finger mark residue. A classic and enduring example is the powder dusting method, which ranks among the oldest and most consistently used techniques (Lee, 2001). For more than a century, powders have been employed to enhance fingermarks. During this duration, numerous formulations have emerged, typically composed of a pigment component (e.g., metal oxides, sulphates, and carbonates) to provide contrast, and a resinous component (e.g., rosin, corn starch, and gum arabic) for adhering to moist and oily fingermark residues (Yamashita and French, 2011). This method entails the application of powder using a fine-bristle brush crafted from synthetic, natural, or glass fibers. While straightforward, this method can potentially harm delicate marks. Variations of this traditional approach encompass fluorescent powders, beneficial for enhancing contrast on challenging surfaces, and magnetic powders, which are applied using a magnetic wand to mitigate the risk of brush-induced damage. While effective on smooth, non-porous surfaces, the continued reliance on powder dusting has been curtailed, with preference given to more sensitive laboratory development for surfaces that cannot be extracted from crime scenes (Champod *et al.*, 2004).
- 2. Advancements in Latent Fingerprint Development:** Dalrymple *et al.* (1977) pioneered the use of lasers for latent fingerprint enhancement, marking a pivotal moment in forensic science. This innovation laid the foundation for fingerprint identification through laser techniques. Thornton (1978) outlined three distinct methods for detecting latent fingerprints: luminescent powder dusting, staining with fluorescent dyes, and chemical treatments that react with fingerprint material to generate fluorescent products. He specifically explored a modified fingerprint powder incorporating Coumarin 6 Laser Dye.

Menzel and Fox (1980) formulated fluorescent dusting powders for laser-based latent fingerprint detection. Almog and Gabay (1980) focused on chemical reagents to develop latent fingerprints, visualizing them through fluorescent reagents in the vapor phase. Herod and Menzel (1982) introduced a novel chemical composition involving ninhydrin and zinc chloride for laser-based latent fingerprint detection. Kendall (1982) pioneered glues containing cyanoacrylate esters to enhance latent fingerprint development. Menzel *et al.* (1983) highlighted the efficacy of glue treatment in conjunction with fluorescent powder, fluorescent stain, or a combination of ninhydrin and zinc chloride for laser-based latent fingerprint detection. Haque *et al.* (1983) advanced a

non-destructive method for latent fingerprint detection on documents using 7,8-benzoflavone dye.

Arndt (1985) standardized the Iodine-silver plate transfer method for latent fingerprint detection. Conversely, Hamilton (1985) devised a technique for detecting latent fingerprints on deceased bodies through Cyanoacrylate ester fuming followed by magna powdering. Hammer *et al.* (1986) employed an iodine-steam process for identifying latent fingerprints on challenging surfaces.

Mashiko *et al.* (1991) introduced a novel procedure involving ruthenium tetroxide fuming for latent fingerprint detection. In 1993, Misner and colleagues developed a fluorescent dye with a narrow emission band for detecting cyanoacrylate-developed fingerprints on non-porous substrates and cadavers. Wilkinson and Watkin (1993) utilized europium aryl- β -ketone complexes as fluorescent dyes to detect cyanoacrylate-developed fingerprints on human skin. Jones *et al.* (2001) explored factors impacting fingerprint quality, proposing that gathering donor information could prove beneficial for future comparative studies. These factors encompassed sex, age, racial origin, smoking habits, medication usage, health condition, and diet.

Lee and Gaensslen (2001) delved into fingerprint development using ninhydrin and its analogues, elaborating on the authenticated reaction mechanism of ninhydrin with amino acids. Cantu *et al.* (2002) unveiled a method to intensify fingerprints by converting silver to silver oxide through additional hypochlorite treatment. Broniek and Knaap (2002) utilized muriatic (hydrochloric) acid for latent fingerprint development on thermal paper. Wallace-Kunkel and coworkers (2004) and Beaudoin (2004) introduced a novel technique for detecting latent fingerprints on porous surfaces.

Yapping and Yue (2004) found that solid silver precipitates onto water-insoluble lipids, fats, oils, and waxes present in fingerprint residue, yielding gray images. This method proves effective for wet papers where amino acids are dissolved, making fats the primary target for development.

3. Fingerprints and Forensic Science-Goes Hand-In-Hand:

Layers of Friction Ridged Skin and Fingerprint Types

The skin's Friction Ridges Consist of Three Distinct Layers: The Epidermis, Dermis, and Hypodermis, as illustrated in Figure 1. The outermost layer is the epidermis, which serves as a protective barrier for underlying tissues, prevents water loss through evaporation, and acts as a sensory receptor. This layer is responsible for the formation of friction ridges and sweat pores, enhancing grip over objects. Beneath the epidermis lies the dermis, composed of connective tissues that provide structural support to the epidermis. It forms a network of cells, fibers, blood vessels, and gel-like substances that nourish and support the overlying epidermis. Additionally, the dermis functions as a blood reservoir, aids in temperature regulation, and contributes to sensory perception. The papillary layer within the dermis determines the distinct fingerprint code and contains sweat glands and nerve endings. The deepest layer, the hypodermis, consists of loose connective tissue housing a pad of adipose cells (fat). These adipose cells contribute to body contouring and serve as an energy reserve (Maceo, 2011).

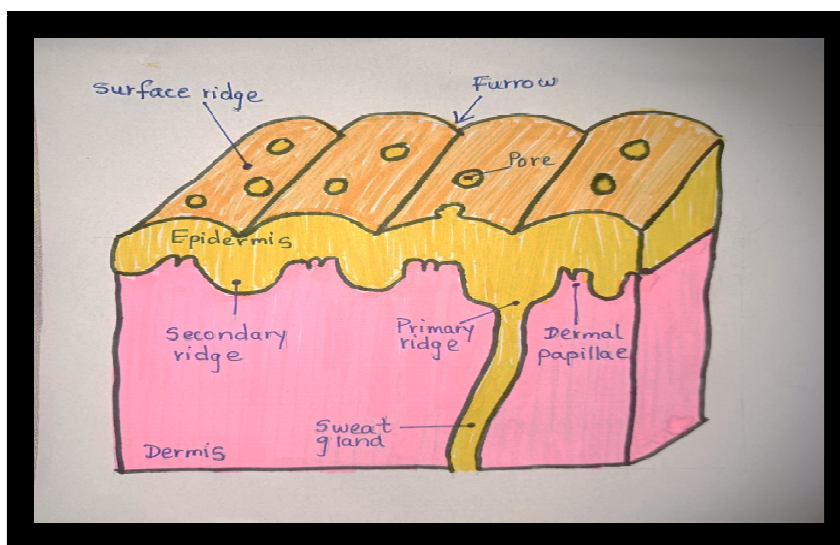


Figure 1: Anatomy of Primary and Secondary Friction Ridges

Ecceine sweat glands, the sole skin appendage in friction ridge skin, play a crucial role. While distributed across most of the skin's surface, these glands are most concentrated in friction ridge areas. They are particularly abundant on the soles of the feet and less so on the back. Ecceine sweat glands assist in temperature regulation by secreting sweat and aid in the elimination of metabolic waste. Sweat composition varies, containing mostly water but also a mix of organic and inorganic substances (Table 1). Excessive secretion of certain chloride salts by specific individuals can accelerate metal surface corrosion (Jensen *et al.*, 1979).

Table 1: Composition of Sweat

Inorganic (major)		Inorganic (trace)	
Sodium Potassium, Calcium, Iron, Chloride, Fluoride, Bromide, Iodide, Bicarbonate, Phosphate, Sulfate, and Ammonia.	34-266 mEq/L, 4.9-8.8 mEq/L, 3.4 mEq/L 1-70 mg/L, 0.52-7 mg/mL, 0.2-1.18 mg/L, 0.2--0.5 mg/L, 5-12 µg/L, 15-20 mM, 10-17 mg/L, 7-190 mg/L, and 0.5-8 mM.	Magnesium, Zinc, Copper, Cobalt, Lead, Manganese, Molybdenum, Tin, and Mercury.	
Organic (general)		Organic (lipids)	
Amino acids, Proteins, Glucose, Lactate, Urea, and Pyruvate.	0.3-2.59 mg/L, 15-25 mg/dL, 0.2--0.5 mg/dL, 30-40 mM, 10-15 mM, and 0.2-1.6 mM.	Fatty acids, Sterols	0.01-- 0.1 µg/mL, 0.01- 0.12 µg/mL

Creatine		Miscellaneous	
Creatinine		Enzymes	
Glycogen		Immunoglobulins	
Uric acid			
Vita mins			

(Source: Ramotowski, Robert S. "Composition of latent print residue." *Advances in Fingerprint Technology* (2001))

Fingerprints result from the papillary ridges depositing sweat on surfaces they touch, whether unintentionally or intentionally. Three types of fingerprint impressions exist: visible or patent, invisible or latent, and plastic.

Visible or patent fingerprints as the name itself makes it pretty clear are inked impressions easily observed by the naked eye. These prints are left by fingers stained with substances like blood, dirt, or ink, creating recognizable friction ridge impressions.

Latent fingerprints are left by unstained fingers on surfaces touched, remaining unseen until a developing agent is applied. Oily residues produced by sweat glands in the fingers form these prints, which are not apparent to the naked eye.

Plastic prints denote friction ridge impressions left on materials that preserve the intricate ridge details. These impressions are formed through indentation or pressing on soft, pliable surfaces like clay, wax, putty, wet paint, butter, or similar substances. Such surfaces retain a three-dimensional representation of the print. These prints are immediately visible and can be observed or photographed without any development process. To visualize fingerprints effectively, techniques such as color contrast, oblique lighting, or chemical treatments like fluorescent dyes are essential to enhance the ridge patterns on the impressed surface. Over the years, it has been observed that the most frequently encountered finger impressions are latent prints, which perpetrators may inadvertently leave behind in haste or 'by chance' at a crime scene.

The term "latent," derived from the *Latin* word meaning 'to lie hidden,' indicates something that is presently concealed but has the potential to become visible, obvious, or active. To bring these concealed or invisible prints to light, investigators may utilize various techniques that have been in use for many years. These techniques for developing latent fingerprints on different porous and non-porous surfaces include physical methods like powder developers and chemical treatments such as ninhydrin, silver nitrate, iodine fuming, and cyanoacrylate glue fuming. Optical illumination methods like UV light and infrared light are also employed to visualize and enhance latent prints. Latent fingerprints emerge as a result of the interaction of natural secretions and environmental contaminants. These prints stem from the replication of friction ridge patterns present on various parts of the fingers, palms, and feet. The prints consist of a mix of different chemicals originating from natural secretions, blood, and contaminants. The main sources of natural secretions are the eccrine and sebaceous glands, containing a variety of chemical components. Contaminants in prints result from contact with diverse materials in the environment. Latent prints can be found on surfaces of all types and are categorized as porous, non-porous, or semi-porous. However, latent prints can also be left

on objects or surfaces with distinctive characteristics, such as wet surfaces, backgrounds with multiple colors, surfaces tainted with blood or bodily fluids, objects with irregular shapes, waxed surfaces, fabrics, untreated wood, varnished surfaces, human skin, cardboard boxes, and various porous or non-porous surfaces. In these specific circumstances, conventional methods of latent print detection often prove ineffective and improper technique application might even lead to the unintentional destruction of potential latent print evidence (Lee & Gaensslen, 2001).

IV. CLASSIFYING FINGERPRINTS

The classification of fingerprints is determined by the arrangement of ridges found on the distal phalange of the finger. A fingerprint pattern consists of the shape, direction of ridges, type lines, as well as the presence of a delta and a core. Galton (1892) introduced a classification system based on the primary pattern types, which are loops, whorls, and arches. The distribution of these Galton-type fingerprint patterns has been noted to vary among different population groups. Additionally, there have been reports of associations between fingerprint patterns and genetically inherited diseases (Kulkarni *et al.*, 2006; Babu *et al.*, 2005). In general, it's observed that the most prevalent fingerprint pattern type is loops (approximately 60-65%), followed by whorls (30-35%), and finally arches (around 0-5%). According to Henry's classification (1900), there are four main types of fingerprint patterns: whorls, loops, arches, and composites. Refer to Table 2 and Figure 2 for a visual representation of these patterns.

Table 2: Sub-Division of Three Basic Fingerprint Pattern Types

Basic Patterns	Pattern type	Symbol	Number of Deltas Present
Arch	Plain arch	A	Zero
	Tented arch	T	Zero
Loop	Radial	R	One
	Ulnar	u	One
Whorl	Plain whorl	w	Two
	Central pocket	c	Two
Composites	Central pocket	c	Two
	Double loop Lateral pocket Twinned loop	s	
	Accidentals	x	Two or more

Loop patterns are characterized by starting from one side, curving towards the center, then curving backward and terminating on the same side. Loops can be further categorized into ulnar loops, where the curve opens toward the little finger or ulna bone, and radial loops, where the curve opens at the thumb or radial bone. Loops possess a single delta and a single core.

- Whorls consist of circular or spiral ridge arrangements in the center. They have two deltas and one core.
- Plain arches are marked by ridge lines starting from one side and ending on the opposite side, with a lower peak at the center. Tented arches exhibit a sharp spike at the center of the arch.

- Central pocket loop whorls involve ridges completing a circuit that can take on spiral, oval, circular, or other circle-like variations. This pattern is also known as the peacock-eye pattern type.
- Double loop whorls exhibit two separate loop formations, each with its own set of core and deltas. These formations can either intertwine as in the twinned loop or envelop one another as in the lateral pocket loop.
- Accidental whorls combine characteristics of two or more different pattern types.
- The ten-digit classification system is based on the presence of these patterns on the ten fingers. Henry's system of ten-digit classification includes primary, major, secondary, sub-secondary, second sub-secondary, final, and key classifications.

Ridge characteristics, also referred to as minutiae, are variations from the normal course of ridges. Each fingerprint contains numerous distinct minutiae in terms of their location, size, and shape relative to the delta and/or core. These minutiae combinations are unique to each individual's fingerprints and serve as the basis for comparison to determine if two prints belong to the same person. Different countries have varying requirements for matching ridge characteristics, as depicted in the Figure 3, frequently encountered ridge characteristics. In India, a range of 8-12 matching points is often used for potential conviction or acquittal.

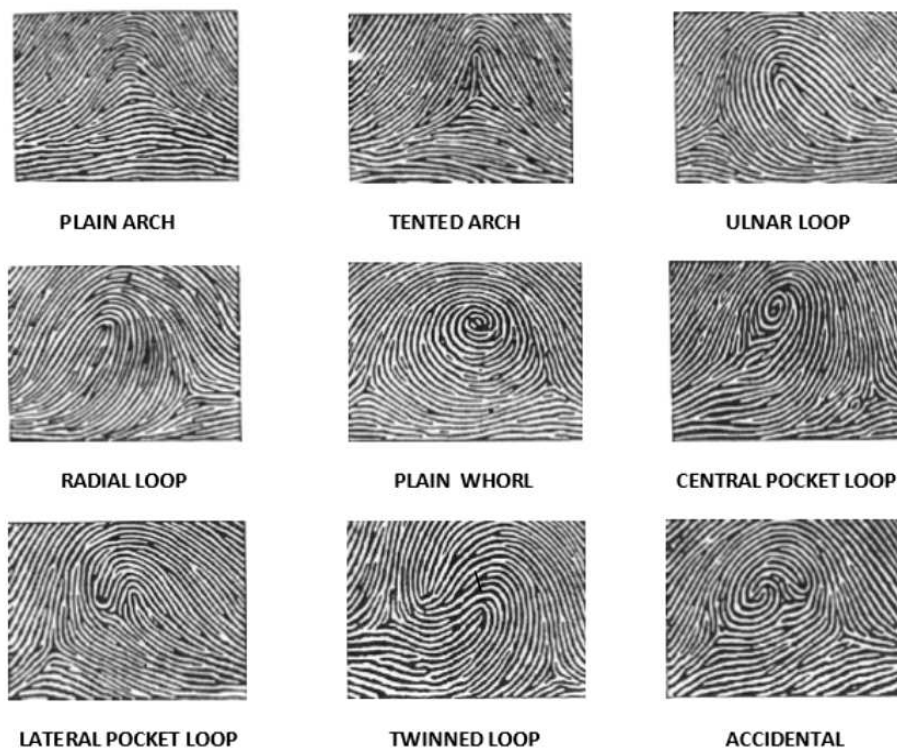


Figure 2: Fundamental insot-types of Fingerprint Patterns

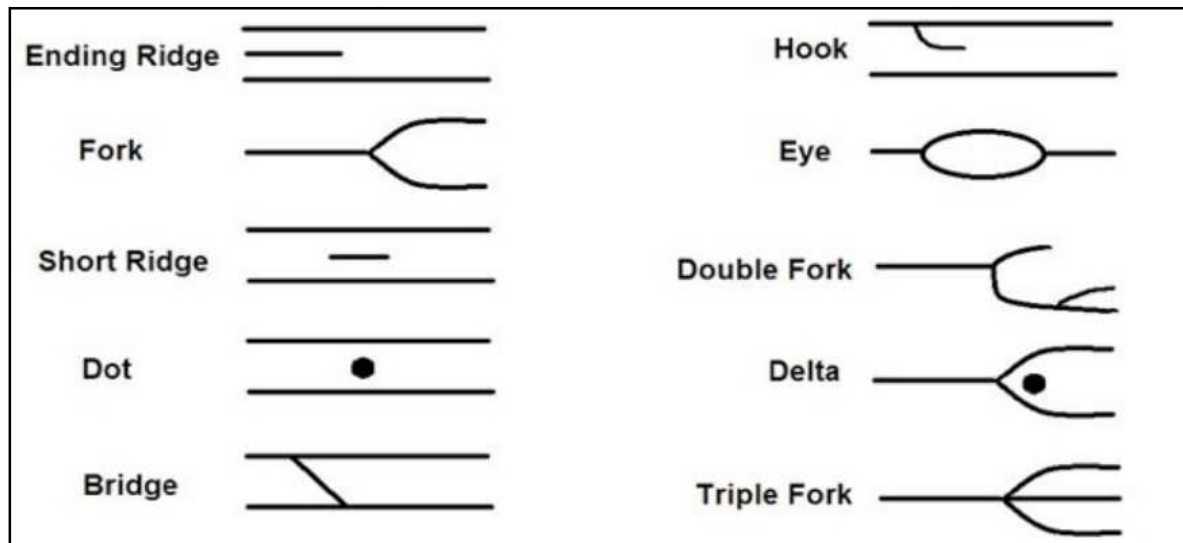


Figure 3: Fingerprint Ridge Characteristics

V. PRINCIPLES OF FINGERPRINT ANALYSIS

The ridge characteristics, once established, remain unaltered throughout an individual's lifetime, making them a reliable tool for personal identification. These principles can be summarized as follows:

- 1. Uniqueness of Fingerprints:** Fingerprints are distinctive traits of an individual's identity. No two people can possess identical minutiae positioning in their fingerprints unless the prints are produced by the same finger of the same person.
- 2. Permanent Nature of Fingerprints:** Once formed, fingerprints remain constant over an individual's entire life span. They do not undergo changes or alterations.
- 3. Systematic Classification:** Fingerprints exhibit ridge patterns that allow for systematic classification based on their unique characteristics.

VI. TECHNIQUES FOR DEVELOPING LATENT FINGERPRINTS

The understanding of fingerprint residue composition has led to the development of improved and innovative techniques. The effectiveness of a specific technique is influenced by various factors, categorized as follows:

- **Pre-deposition Factors:** These include donor-related factors such as age, sex, diet, and lifestyle.
- **Mid-deposition Factors:** Referring to substrate properties and contact dynamics during fingerprint deposition.
- **Post-deposition Factors:** Encompassing environmental conditions, surface chemistry, and porosity.

Considering these factors is essential for achieving optimal results using the most suitable development technique.

- 1. Powder Method:** The powder method relies on the mechanical adherence of powder composition to the moisture and oily residue of a fingerprint. Frictional charges generate electrostatic attraction between the residue and powder, facilitating adherence. The effectiveness of adherence is influenced by particle size and shape, ranging from 1-10 μm in diameter.

Regular, metallic, and luminescent powders are commonly used. Regular powders contain a resinous polymer like starch, kaolin, silica gel, or rosin for adhesion, along with a colorant. Metallic powders offer longer shelf lives but pose toxicity risks. Fine powders typically range from 1-50 μm and include materials like aluminum, zinc, copper, and iron.

Luminescent fingerprint powders have notable health hazards, leading to skin and vision disorders. Modern advancements include the use of sublimable powders, while organic dyes with fluorescence or laser activity, such as Rhodamine B and fluorescein, are also employed.

It is important to note that health hazards associated with certain powder compositions have led to the exploration of safer alternatives and techniques (Sodhi and Kaur, 2001).

- **Luminescent (Fluorescent and Phosphorescent) Fingerprint Powders:** Various fingerprint powders contain natural or synthetic compounds that exhibit fluorescence or phosphorescence upon exposure to ultraviolet (UV) light, laser light, and other light sources. These powders are valuable for visualizing latent prints on surfaces with multiple colors, where using regular fingerprint powder would pose a contrast challenge. While luminescent fingerprint powders have seen limited use in the field, the introduction of laser detection revealed their significant benefits. Applying fluorescent or phosphorescent powders to latent prints notably enhances their visibility during laser examination. Luminescent dyes and pigments, such as acridine yellow, acridine orange, coumarin 6, crystal violet, merocyanine 540, Nile Blue perchlorate, Rhodamine B, Rhodamine 6G, and phenothiazine, have demonstrated efficacy as dusting powders for laser examination. The choice of the most suitable powder depends on background colors and their luminescent properties.
- **Silver Nitrate Method:** The silver nitrate method for developing latent fingerprints dates back to 1891 and is based on the reaction between silver nitrate and the chloride present in fingerprint deposits. This reaction results in the rapid darkening of silver chloride upon light exposure. However, this technique's complexity and potential background staining have relegated it to historical interest. To mitigate these issues, Goode and Morris (1983) proposed using a methanolic solution instead of the conventional aqueous solution. This modification proved effective for latent prints on surfaces like newspaper and untreated wood. Nonetheless, silver nitrate's efficacy diminishes on evidence stored or exposed to high humidity, as humidity causes chloride migration by diffusion, leading to deterioration.

- **Ninhydrin Method:** Ninhydrin, synthesized by Siegfried Ruhemann in 1910, reacts with amino acids to form a non-fluorescent, purple compound called Ruhemann's purple. Though initially used in amino acid chromatography, ninhydrin found its application in latent fingerprint development in 1954 by Oden. Ninhydrin is a widely used method for porous surfaces. Early reagents were prepared using ethanol, petroleum ether, or acetone with ninhydrin concentrations ranging from 0.2% to 1.5%. However, these reagents were flammable and affected ink on printed paper. The introduction of non-flammable ninhydrin (NFN) addressed these drawbacks. NFN is prepared by dissolving ninhydrin in ethanol and acetic acid, followed by dilution with florosil. While all amino acids produce the same purple color with ninhydrin, the nitrogen of the amine group was identified as the reactive site. Enhancements to the method included post-treatment with zinc chloride, which forms a coordination complex and can be intensified using liquid nitrogen cooling. Lasers and alternative light sources further improved the technique's sensitivity. Heat application, though recommended for faster reactions, is limited to specific surfaces, with temperature, humidity, and pH control required for optimal results.

Ninhydrin analogues have been developed to offer enhanced quality and sensitivity. Notable analogues include 1,8-Diazanorene-9-one (DFO) and 1,2-Indanedione, which produce luminescence and intense color without additional treatment. Despite ninhydrin's popularity for developing latent prints on porous surfaces, these analogues offer operational advantages (Lennard *et al.*, 1987).

- **Cyanoacrylate Method:** The cyanoacrylate fuming technique has demonstrated efficacy in developing latent prints on a wide range of surfaces, including plastics, electrical tape, garbage bags, carbon paper, aluminum foil, wood (both finished and unfinished), rubber, metals like copper, cellophane, rubber bands, and even smooth rocks. In this method, the latent print specimen is placed within a fumigation chamber with 80% relative humidity, and the application of heat generates cyanoacrylate vapors. This technique produces effective results on both non-porous and semi-porous surfaces. However, the resulting deposition is often white, leading to inadequate contrast. To address this limitation, suggestions for post-treatments have emerged. Approaches such as powder dusting and dye staining have been proposed to enhance the quality of the developed prints (Prete *et al.*, 2013). Dyes like Basic Yellow 40 and Rhodamine 6G have been identified as effective options for post-staining (Mazella and Lennard, 1995). A study also explored the use of the Lumicyano™ technique, which employs a liquid mixture of 99% cyanoacrylate and 1% fluorophore. The resulting finger marks were further intensified using a solution of Basic Yellow 40 dye (Prete *et al.*, 2013).
- **Iodine Fuming Method:** The iodine fuming method involves exposing a latent fingerprint to iodine vapors, which causes the lipids within the print to absorb the vapors, resulting in a brown coloration. It's worth noting that prints developed using this method tend to fade quickly. As a result, immediate photography is essential to preserve the prints for legal proceedings. Despite its lack of long-term permanence, the iodine fuming method remains popular due to its ease of use, applicability across various surface types, and non-destructive nature. It's important to avoid using the iodine method on substrates exposed to water, as chlorides in the print can dissolve in

water (Pounds and Jones, 1981). Fixatives such as starch (Larsen, 1962) and benzoflavone (Savita, 2008) are frequently employed to stabilize iodine-developed prints. An alternative technique involves pressing a silver foil onto the iodine-developed prints. This process initially results in a yellow coloration due to silver iodide formation, which subsequently turns black upon light exposure (Savita, 2008).

- **Phase Transfer Catalyst (PTC):** Challenges in latent print development, such as weak or ineffective results, can often arise from disparities in the phases of the reagent (typically aqueous) and the fingerprint residue (often sebaceous). To address this issue, Phase Transfer Catalyst (PTC) is employed. PTC is a type of heterogeneous catalyst that facilitates the migration of a reactant from one phase to another. It consists of three main components: a hydrophilic phase, a hydrophobic phase, and an interphase. This setup enables the transfer of ions from the aqueous phase to the organic phase. In particular, tetrabutylammonium chloride has demonstrated efficient catalytic properties in phase transfer reactions (Kaur *et al.*, 1996). The method is applicable to both porous and non-porous surfaces. In one approach, tetrabutylammonium iodide is introduced as a precipitating agent, accelerating the reaction between the insoluble calcium ions in the fingerprint residue and an aqueous solution of disodium salt of eosin (Kaur *et al.*, 1996). Jasuja *et al.* (2007a) successfully applied the PTC method to develop latent prints on the adhesive side of tapes. Additionally, the PTC method was used on non-porous surfaces and adhesive tapes submerged in water for varying time intervals, yielding successful latent print development (Jasuja *et al.*, 2015).
- **Silica Particle Method:** The utilization of silica-based particles has emerged as an innovative approach to latent print development. With advancements in nanotechnology, cadmium sulphide and europium oxide-based powders have been explored for this purpose, although they tend to be more expensive than conventional powders. A notable recent development involves hydrophobically coated silica nanoparticles and micro-particles, equipped with macromolecules labeled with fluorescent dyes. The result is a latent print that exhibits fluorescence under appropriate illumination. Effective integration of dyes within these particles necessitates robust binding interactions between the dye molecules and the cross-linked matrix's backbone (Theaker *et al.*, 2008). This technique harnesses nanotechnology's capabilities to enhance latent print visualization, providing a novel solution to conventional challenges.
- **Vacuum Metal Deposition Method:** The vacuum metal deposition (VMD) technique is a well-established method for developing latent fingerprints on non-porous surfaces. VMD offers certain advantages over cyanoacrylate fuming, particularly when dealing with aged prints, prints exposed to adverse environmental conditions, or prints on semi-porous surfaces (Jones *et al.*, 2001). In 1989, Saunders introduced the multi-metal deposition (MMD) approach for visualizing latent prints on both porous and nonporous surfaces. Derived from a biochemical staining technique used for proteins, MMD involves treating latent prints with a colloidal gold solution (pH ~ 2.7) followed by a weak silver physical developer solution. The colloidal gold particles, carrying a strong negative charge, effectively bind with the print residue, creating catalytic nucleation sites for subsequent silver development (Lee and Gaensslen, 1994).

2. Chemical Imaging Method: A recent and groundbreaking approach relies on chemical imaging, which combines digital imaging with molecular spectroscopy. This method offers the ability to simultaneously view images and gather spectral information from the analyzed sample. Molecular chemical imaging employs various spectroscopic techniques such as UV-Vis absorption, fluorescent emission, photo-luminescent emission, Raman scattering, and infrared absorption (Payne *et al.*, 2005). Traditional spectroscopic techniques study how samples interact with electromagnetic radiation to deduce composition. In chemical imaging, intensity is recorded at each pixel, generating an electronic image. Payne *et al.* (2005) employed a macroscopic chemical imaging system encompassing an imaging spectrometer range of 400-720 nm. They applied this chemical imaging technique to three sets of samples: those without pre-treatment, treated with DFO, and treated with ninhydrin. Their study yielded promising results for both porous and non-porous surfaces. Another avenue involves using attenuated total reflection Fourier Transform Spectroscopic imaging to acquire chemical images of fingerprints. This novel method provides an advanced way to visualize latent prints and gather valuable chemical data.

- **Small Particle Reagent Method for Developing Latent Fingerprints:** The term "small particle reagent" (SPR) is often used as an umbrella term for various powder suspension techniques. However, there are notable distinctions between the standard molybdenum disulfide SPR and other wet powder suspensions. While both approaches incorporate a detergent, such as Kodak Photo-Flo, to maintain the suspension, SPR employs a significantly lower detergent concentration in the final solution. Moreover, the detergent-to-powder ratio in SPR is substantially higher compared to other wet powder suspensions (Kimble, 1996). For instance, a typical SPR working solution might consist of a concentration solution (500ml water, 7.5ml 10% surfactant, and 50g MoS₂) mixed with 4.5 liters of water. In contrast, a regular wet powder suspension working solution may comprise 20g iron oxide, 100ml water, and 20ml stock detergent solution (250ml surfactant, 350ml ethylene glycol, and 400ml water). Furthermore, SPR is typically applied through dipping or spraying, whereas wet powder suspensions are often prepared as a paste and brushed onto the surface (Hewlett *et al.*, 1998). In the realm of latent fingerprint development, the use of conventional powders in suspension emerged as an effective alternative to sticky-side powder for revealing prints on adhesive tape (Sneddon, 1999). The technique involves suspending powders of distinct colors, such as carbon (black) and titanium dioxide (white), to create contrast. This advantage is absent in standard SPR, which is limited to the dark gray color of molybdenum disulfide. Polimeni and colleagues (2004) introduced an innovative approach to detecting latent fingerprints on wet surfaces. Jasuja *et al.* (2008) developed a new SPR composition by combining zinc carbonate with various fluorescent dyes to enhance latent fingerprint visibility.

Recently, wet powder techniques have gained popularity for developing prints on non-porous surfaces (Daeid *et al.*, 2008a, 2008b; Jones *et al.*, 2010). These techniques involve suspending fine insoluble powders in aqueous surfactants. An advantage of this method is that pre-wetting the surface does not hinder development. Although the precise mechanisms governing the adherence of fine suspended powders to sebaceous residue are not fully understood, certain physical properties like

particle size, structure, and coating influence the effectiveness of development (Jones *et al.*, 2010).

The small particle reagent technique relies on fine particles suspended in a treating solution adhering to the oily components of latent fingerprint residue. This aligns it with powder dusting methods. Small particle reagent (SPR) involves suspending fine molybdenum disulfide particles in a detergent solution (Lee and Gaensslen, 1994). These particles bind to the fatty constituents of latent print residues, resulting in a gray molybdenum disulfide deposit. Goode and Morris (1983) provided detailed formulations and procedures for SPR. Pounds and Jones (1981) suggested substituting choline chloride with molybdenum disulfide dispersed in Manoxol OT in the SPR formulation. SPR is particularly effective for detecting latent fingerprints on non-porous, wet surfaces (Kabklang *et al.*, 2009). The formulation's success spans various surfaces, including paper, cardboard, metal (both rusted and non-rusted), rocks, concrete, plastic, vinyl, wood, galvanized metal, and glass (Sukkasem *et al.*, 2008). The method relies on the interaction between fatty components in traces and the hydrophobic tails of the reagent. These tails attach to metal salts, forming a precipitate (Cuce *et al.*, 2004). SPR is often applied through immersion or spraying. This technique, also known as the wet powdering method, is particularly useful for moist surfaces that may challenge other reagents sensitive to eccrine secretions. While the traditional molybdenum disulfide-based SPR adheres to fatty components to form a gray deposit, variations in structure can impact print quality. Larger particle sizes (1-10 micrometers) are more effective than finer particles due to reduced sedimentation time, leading to lighter gray, more densely suspended particles that produce poor-quality prints (Mock, 1984).

Efforts to optimize SPR formulas have resulted in variations such as zinc carbonate-based fluorescent SPR compositions, which incorporate different dyes to improve contrast and visibility (Jasuja *et al.*, 2008; Dhall *et al.*, 2014). These developments have expanded the applicability of SPR, enabling successful latent print development on a range of surfaces, even those exposed to water. The utilization of cost-effective and non-hazardous materials adds to the technique's appeal (Sodhi and Kaur, 2012; Rohatgi *et al.*, 2015). Overall, the advancement of SPR formulations enhances its potential in forensic investigations, offering the ability to detect faint and chance prints, thereby augmenting its utility in real-world case work investigations.

- **Latent Prints Immersed in Drainage Water:** Disposing of incriminating evidence in waterways remains one of the most common methods for criminals to eliminate traces. While successful recovery of latent prints from water bodies has been reported (Vandiver, 1976), establishing a reliable and standardized technique holds paramount importance. Contrary to assumptions, water might not be as destructive to latent prints as previously believed (Devlin, 2012). Various studies have demonstrated successful recovery of latent prints from diverse surfaces exposed to aquatic environments (Vandiver, 1976).

In the late 1960s, researchers explored the impact of water on latent prints by immersing glass slides with prints in water-filled beakers. Remarkably clear and sharp prints were obtained even after a week of water exposure, using "brilliant red"

fingerprint powder. The quality of prints remained consistent regardless of exposure time, and even rotational agitation at 150 rpm for half an hour did not compromise print quality. These findings extended to simulated real-world scenarios involving exposure to heat, rain, snow, and sub-zero conditions, where clear and identifiable prints were recovered (Hanggi and Alfulit, 1969). More recent investigations have delved into latent print recovery in underwater crime scenarios. This has particular significance for crimes involving scuba divers, hit-and-run incidents at sea, submerged vehicles, or explosive devices left at the bottom of ships or boats. Researchers submerged glass and transparent plastic substrates in water and standard soap, followed by hot water and immersion in a diethyl ether and alcohol mixture. After drying, the substrates were submerged in tap water for varying durations (1 to 15 days) and developed using techniques like UV light, metallic powders, lysochrome dyes, and the SPR method. This study revealed a successful development rate of 80%, with black powder being the most efficient technique followed by Sudan black powder and SPR (Castelló *et al.*, 2013). However, latent prints might not always be discarded in clean aquatic environments. More commonly, they end up in drainage water, where factors like sedimentation, pH, composition, temperature, microflora, and microfauna differ from pristine aquatic environments. Surprisingly, no studies have explored latent prints immersed in drainage water. Thus, the present study aims to address the development of latent fingerprints immersed in drainage water.

- **Latent Prints Buried under Snow and Soil:** The survivability and subsequent development of latent prints are influenced by air, temperature, and water. Criminals often bury weapons of offense in soil or snow to evade detection. However, soil significantly deteriorates fingerprints due to its moisture, humidity, and temperature, alongside the presence of flora and fauna that accelerate damage. Surface temperature plays a pivotal role in print development. High surface temperatures lead to rapid evaporation, while low temperatures cause sweat residue condensation. High humidity can also lead to residue condensation, potentially washing it away. Conversely, low humidity causes residue water content evaporation. Rain, dew, and snow, similar to rain, negatively impact latent prints. They dilute sweat residue, potentially creating a barrier between the surface and the friction ridge skin, hindering sufficient residue for detection (Johnson, 1973; Cowger, 1983).

3. Factors Affecting Latent Print Quality: The quality of latent fingerprints can be influenced by various factors (Comber *et al.*, 2011):

- The composition of sweat deposits affects print durability, with higher sebaceous content improving resilience. Foreign contaminants like ink or paint can diminish print lifespan.
- The amount of residue deposited impacts print quality, with excessive deposit potentially obliterating detail and insufficient deposit resulting in weak prints.
- The pressure and duration of contact between the fingertip and surface influence print clarity. Excessive pressure leads to smudges, while minimal pressure produces uneven prints.
- The time between deposition and development is critical. Fresher prints have better chances of detection, while aged prints experience dehydration, loss of adhesion, bacterial attack, and natural deterioration.

- Environmental conditions determine dehydration rates. High temperatures, low humidity, sun exposure, and wind accelerate dehydration, leading to component loss due to moisture (e.g., loss of eccrine material due to rain).

4. Surface Types:

The type of surface where prints were deposited also plays a role in latent print quality. Surface phenomena play a pivotal role, as observed by Bobev (1995), who noted various interactions occurring on different surfaces under distinct environmental conditions. Generally, surfaces bearing latent fingerprints can be categorized into three groups:

- **Porous Surfaces:** These surfaces swiftly absorb water-soluble deposits shortly after deposition (within seconds). The non-water-soluble residue remains on the surface for an extended period. Examples of porous surfaces include paper, cardboard, fabric, and untreated wood.
- **Semi-Porous Surfaces:** Semi-porous surfaces absorb water-soluble deposits at a slower rate after deposition. Non-water-soluble components persist on the surface for an extended duration, ranging from hours to several days. Examples encompass certain plastics, waxed surfaces, fruit peels, plywood, and wall paints.
- **Non-Porous Surfaces:** Non-porous surfaces are particularly suitable for latent fingerprint development. They do not absorb either water-soluble or non-soluble fingerprint components. Instead, these mixtures remain on the non-porous surface as an emulsion for an extended time until degradation or smudging occurs. Illustrative non-porous surfaces include glass, ceramic tiles, metal handles or door knobs, mirrors, bakelite, and CD surfaces.

Table 3: Fingerprint Detection and Enhancement Techniques

Dye & Methods	Preparation	Reacting Surface	Substrate
Crystal Violet	Gentian Violet-0.1 gm + Distilled water- 100 ml	Non-Porous	Protein
Iodine	Iodine crystal	Porous/ non - porous	Fatty lipids
Sudan IV	Sudan IV – 1.875, Ethanol – 125ml, Distilled water- 62.5ml	Non-porous	Lipids, oils, sebaceous glands
Superglue	Relative Humidity – 80% Temperature – 120 ⁰ c		
Rhodamine	REG – 3ml, Acetone – 15ml Acetonitrile – 10ml, Methanol- 15ml, Isopropanol – 32ml, Petroleum ether – 925ml		

Coomassie Brilliant Blue	CBB – 0.44 g, Glacial Acetic acid – 40 ml Methanol – 200 ml Distilled water – 200 ml	Porous surface/ non-porous	Blood, raw – wood, paper, tape glass
Ninhydrin	Ninhydrin-0.5 – 0.20g 25ml acetone 0.5% ethanol Zinc salt 50ml ethanol, 10ml propanol, 10ml acetic acid, 6 g zinc chloride	Non – porous	Amino Acids
Silver nitrite	0.75 g Agno3 25ml of water	Dry porous surface	Lipids and Oils
Amido Black	0.1g Amido Black 40 ml Methanol	Porous/non- porous dark blue colour	Blood
LMG	S-sulfosalicylic acid 2.2 g 100mg distil water LMG – 0.16 g 30% hydrogen peroxide 10ml	Porous	Blood
Phenolphathalin	Phe- 2 g Potassium hydro – 20g Distilled Water – 100ml Zinc powder – 20g	Porous	
LCV	s- sulfo 10 g 3% hydrogen per – 500 Sodium acetate – 3.7 g LCV - 19	Porous/ non- porous	

VII. APPLICATIONS

- 1. Forensic Dermatoglyphics and Sex Determination:** Variation in Fingerprints across Ethnicities in Forensic Dermatoglyphics Extensive anthropological studies have been undertaken on distinct populations to identify patterns in the formation of fingerprint patterns. One notable comprehensive review of this extensive body of research was conducted by Jamshed Mavalwala, resulting in a bibliography of dermatoglyphic references spanning 300 pages (Mavalwala, 1977). A significant finding from this body of work was the recognition that variations in friction ridge pattern frequencies within a tribe were more significant than variations between different tribes. Moreover, within-species variations in primates were found to be greater than inter-species differences. The research on ethnic variation strongly suggests that multiple genes influence pattern formation, and these genes interact to produce the final pattern characteristics. Over the years, ridge density analysis has been utilized to distinguish between male and female donors of fingerprints found at crime scenes. In the past, there was an assumption that women tend to exhibit "fine" epidermal ridge detail, whereas men display "coarse" ridge detail. While this hypothesis has been investigated, the statistical significance of the

observed differences has not always been clearly established. The objective of this study is to determine if women indeed possess significantly higher ridge density, and consequently finer epidermal ridge detail, compared to men, by counting the ridges within a well-defined area. Recent studies have explored the forensic application of dermatoglyphic traits, such as epidermal ridge breadth or ridge density, for inferring gender and population origins from unknown fingerprints. These studies have highlighted the differences in fingerprints between genders and among various populations. However, discrepancies in findings could be attributed to methodological variations, such as inconsistent positioning of the counting area and differences in fingerprint acquisition methods. Therefore, investigating the impact of counting area placement and fingerprint acquisition methods on ridge density differences is crucial. Jantz (1977) examined correlations between ridge counts on ten fingers in 11 samples representing Caucasians and Negroes of various origins, including sub-Saharan Africa, America, Europe, and India. The study revealed that while samples of European ancestry showed no consistent sex differences in mean correlation, there were differences observed in other groups. These findings suggested the involvement of sex chromosomes, particularly the Y chromosome, in the development of dermal ridges. Acree (1999) highlighted significant gender differences between males and females and explored the potential for inferring gender from ridge densities. He studied a sample of 400 subjects, analyzing ridge densities on ten-print cards. The results indicated that women tend to have higher ridge densities than men, irrespective of their racial background. Gungadin (2007) aimed to establish a link between sex and fingerprint ridge density. The study involved 500 subjects (250 males and 250 females) in the age range of 18-60 years. The findings indicated that fingerprints with ridge densities below 13 ridges/25 mm² are more likely to be of male origin, while fingerprints with ridge densities above 14 ridges/25 mm² are more likely to be of female origin. Krishan *et al.* (2010) suggested that differences in finger ridge density between males and females within a given area could be attributed to variations in body proportions. They noted that males generally have larger body proportions than females, which could account for the differences in ridge density. Gutiérrez-Redomero *et al.* (2008, 2013) conducted studies on Spanish Caucasians to examine fingerprint ridge density variability and its application in sex determination. Regardless of the counting area or fingerprinting technique, the results consistently indicated that females tend to have higher ridge densities than males. Krishan *et al.* (2014) analyzed palm print ridge density in North Indian population but concluded that it cannot effectively infer gender. Taduran *et al.* (2015) studied ridge density in different areas of fingerprints among Filipinos. They found that ridge densities in specific areas varied between genders. Another study focused on medical college students and revealed that females tend to have higher ridge densities compared to males. The ridge density counts below 14 ridges/25 mm² was more likely to be male, while a count above 14 ridges/25 mm² was more likely to be female (Shah *et al.*, 2016). Overall, research on the ethnic variability in fingerprints suggests that while gender and population differences do exist, standardization of methodologies is essential for accurate comparisons between studies, especially in forensic applications.

- 2. Uses of Fingerprints:** Fingerprints serve as a recognized method of personal identification, providing invaluable support to law enforcement agencies and various fields. Their applications encompass:

- **Document Authentication:** Fingerprints are used to authenticate documents in favor of a party.
- **Unidentified Body Identification:** Fingerprints aid in identifying unidentified deceased individuals.
- **Crime Scene Identification:** Fingerprints help identify criminals through chance prints left at crime scenes.
- **Mass Disaster Victim Identification:** Fingerprints assist in identifying individuals in mass disaster situations.
- **Personal Identification Documents:** Fingerprints establish personal identification on documents like passports and Aadhaar cards (biometric Unique Identification Authority of India).
- **Missing Persons Identification:** Fingerprints aid in identifying missing persons and refuting impostor claims.
- **Legal Proceedings:** Fingerprints support state prosecutors by demonstrating prior convictions for habitual offenders through fingerprint comparisons.
- **International Identification:** Fingerprints provide identification assistance to other countries and help identify illegal immigrants and missing nationals.
- **Identity Records Maintenance:** Fingerprints are used to maintain identity records of service holders and pensioners.
- **Licensing Procedures:** Fingerprints play a role in identifying procedures for licenses related to automobiles, firearms, and more.
- **Probation and Parole:** Fingerprints assist probation and parole officers by providing information for decision-making.
- **Forgery Detection:** Fingerprints are instrumental in detecting bank forgeries and similar crimes.

VIII. LEGAL SIGNIFICANCE

1. Statutory Recognition of Fingerprints in Indian Law

- **The Identification of Prisoners Act, 1920:** The Identification of Prisoners Act, enacted in 1920, holds the primary purpose of providing legal authorization for the collection of measurements relating to finger impressions, footprints, and photographs of individuals accused or suspected of criminal offenses. This legislation legitimized the practice of obtaining finger impressions and measurements, as outlined in Section-3 of the Act.

Section-3 establishes that individuals convicted of offenses punishable by rigorous imprisonment for a year or more are required to provide their measurements, which includes finger impressions, to a police officer. This Act further mandates the destruction of these measurements upon an individual's discharge or acquittal by a court.

Section-4 of the Act addresses the measurement-taking of non-convicted individuals, stipulating that anyone arrested for an offense carrying a sentence of rigorous imprisonment for a year or more must allow their measurements to be taken.

Under Section-5, magistrates are empowered to direct individuals to allow their measurements for investigative purposes.

- **Code of Criminal Procedure, 1973:** Section-293 of the Code of Criminal Procedure, 1973, permits the acceptance of reports submitted by the Director of Forensic Bureau as evidence. This provision aims to streamline legal proceedings by avoiding unnecessary examinations. However, should suspicions arise from the report, the court can summon the report submitted for clarification.
- **Indian Evidence Act, 1872:** Fingerprints, distinguished by their uniqueness, permanence, universality, inimitability, and classifiability, have been given statutory recognition in the Indian Evidence Act of 1872. Section-45 of the Act allows for the opinions of experts skilled in various fields, including finger impressions, to be accepted by the court when forming an opinion on points of law or science. Originally, the term "finger impression" was not included, but an Amendment Act in 1899 incorporated it. Section-73 authorizes courts to direct individuals present in court to provide their fingerprints when required for comparison with questioned fingerprints.
- **Fingerprints and the Right against Self-Incrimination:** A pivotal concern in fingerprinting is the policy of self-incrimination, as its implications in obtaining finger impressions from accused individuals have been subject to debate.

The right against self-incrimination is a vital safeguard in criminal proceedings, ensuring the accuracy of statements made by accused individuals and the voluntary nature of these statements. The potential for coercion or threats during investigations may lead to false testimonies, jeopardizing justice.

The right serves as a protection against torture and places the onus on prosecution to prove charges against the defendant. In *Re Sheik Muhammad Hussain*, the Madras High Court held that acquiring fingerprints during investigation did not amount to testimonial compulsion under Article 20(3) and is admissible as evidence.

In *Selvi and others vs. State of Karnataka*, it was established that involuntary administration of certain tests doesn't fall under "testimonial compulsion" since the test subject need not provide verbal answers.

In *State of Kerala vs. Sankaran Nair*, the Kerala High Court concluded that obtaining handwritings by non-voluntary means does not violate the privilege against self-incrimination.

Similarly, in various cases such as *Gulzhar Khan v. State, Delhi Administration v. Pali Ram*, and *Kumaran Nair v. Bhargavi*, courts upheld the direction to provide fingerprints or specimen handwritings, indicating no infringement of Article 20(3). However, conflicting decisions arise in cases like *State of Bombay vs. Kathikalu Oughad*, which raised questions about whether obtaining handwritings for comparison, directions by the court to provide handwriting specimens, and obtaining palm and finger impressions violate Article 20(3). In

summary, the provision of impressions, writings, or signatures by accused individuals, while constituting evidence, doesn't qualify as "to be a witness." These materials belong to the category of material evidence and fall beyond the realm of testimony.

2. Key Case Laws: In *Ammini v. State of Kerala*, fingerprints found on glasses in the deceased's home were challenged for clarity, but the Supreme Court relied on fingerprint evidence to establish guilt.

- In *Balakrishna Das Agarwal v. Radha Devi*, the court emphasized that a forensic scientist is a witness of the court, expressing opinions based on experience, knowledge, and training.
- *BhalukaBehra v. State* highlighted the weight given to expert opinions, with fingerprints deemed unforgeable signatures.
- In *Pathumma v. Veerasha*, Kerala High Court held that no two persons have the same fingerprints, and even an individuals finger impressions vary.
- *James v. State of Kerala* recognized that even blurred and dirty fingerprints can be reliable evidence.
- In *State v. Karugope*, Patna High Court accepted fingerprint expert opinions as sufficient evidence for convictions.
- **Section-73 in the Indian Evidence Act, 1872:** Comparison of signature, writing or seal with others admitted or proved.—In order to ascertain whether a signature, writing or seal is that of the person by whom it purports to have been written or made, any signature, writing, or seal admitted or proved to the satisfaction of the Court to have been written or made by that person may be compared with the one which is to be proved, although that signature, writing, or seal has not been produced or proved for any other purpose. The Court may direct any person present in Court to write any words or figures for the purpose of enabling the Court to compare the words or figures so written with any words or figures alleged to have been written by such person.

According to this section, Court may order any individual to provide fingerprint sample for the purpose of comparison with questioned fingerprint.

According to NCRB (National Crime Research Bureau) data 2021, around 2961 cases have been solved through chance prints found on crime scenes. Also, NCRB is implementing the National Automated Fingerprint Identification System (NAFIS), which is collecting criminal fingerprint data in India.

- **Section-3: Taking Measurements of Convicted Persons:** This section pertains to individuals who have been either convicted of an offense carrying a sentence of rigorous imprisonment for one year or more, or who have been ordered to provide security for their good behavior under section 118 of the Code of Criminal Procedure, 1898. If required, these individuals must allow a police officer to take their measurements, including fingerprints, footprints, and photographs, in the prescribed manner. This legal provision grants police the authority to record such measurements for the purpose of criminal identification.

- **Section-4: Taking Measurements of Non-Convicted Persons:** This section applies to individuals arrested in connection with an offense carrying a sentence of rigorous imprisonment for one year or more. If so required by a police officer, these individuals must allow their measurements to be taken in the prescribed manner.
- **Section-5: Magistrate's Power to Order Measurements or Photographs:** When a Magistrate determines that, for the purpose of any investigation or proceeding under the Code of Criminal Procedure, 1898, it is necessary to direct an individual to permit their measurements or photograph to be taken, they may issue an order to that effect. The individual named in the order must then appear at the specified time and place and allow a police officer to take their measurements or photograph, as specified. Notably, an order for photography can only be issued by a first-class magistrate, and the order may be made only if the person has been arrested in connection with the relevant investigation or proceeding.
- **Section-293: Reports of Government Scientific Experts:** This section pertains to documents presented as reports by Government scientific experts. Such documents, relating to matters examined or analyzed by these experts in the course of legal proceedings under the Code, may be admitted as evidence in inquiries, trials, or other proceedings under the Code. The court has the discretion to summon and examine the expert as well. If the expert cannot attend in person, a responsible officer working with the expert may attend the court on their behalf. This section applies to various Government scientific experts, including the Director of the Finger Print Bureau.
- **Section-45: Opinions of Experts:** When the court needs to form an opinion on foreign law, science, art, identity of handwriting, or finger impressions, opinions from individuals especially skilled in the relevant field are considered relevant facts. These individuals, referred to as experts, provide insights based on their expertise. Therefore, when the court must establish the identity of fingerprints, opinions from fingerprint experts are deemed significant and admissible.

IX. SOCIETAL BENEFITS OF FINGERPRINTS

The significance of fingerprints extends far beyond their role as primary tools for criminal identification. While we have extensively explored their use in this context, fingerprints have broader applications that impact society in various ways.

In India, fingerprints have been leveraged for national-level personal identification through the implementation of the 'AADHAR CARD,' which constitutes the world's largest biometric identification system. Creating an Aadhar card involves fingerprint and iris scans that link to an individual's 12-digit unique identification number (UID). The core purpose of AADHAAR is to eliminate fraudulent or duplicate identities through a highly digitized approach.

In the 21st century, fingerprints play a critical role in our security systems. They are employed to unlock our smartphones and facilitate bank transactions. Fingerprint authentication is favored due to its individualistic nature and perceived security. Among

various biometric options, fingerprints stand out for being non-invasive and cost-effective. A remarkable example of sophisticated biometric technology is fingerprint door locks. These locks rely entirely on the uniqueness of fingerprints to authenticate individuals for access. These keyless locks replace the need for physical keys, eliminating concerns about key loss. Moreover, they offer heightened reliability and accuracy compared to traditional locks. Fingerprint door locks find application not only in personal residences but also in offices and shops. With the proliferation of personal mobile phones, security has become a concern. Fingerprint sensors are widely adopted to unlock phones and secure essential applications. Fingerprint authentication offers speed and convenience, eliminating the need to remember pins, passwords, or patterns. Unlike other security methods susceptible to unauthorized access, fingerprint locks are unique to the individual, enhancing overall security.

Banks, being pivotal to the financial sector, face numerous threats. The rise of digital banking has escalated cybercrimes, prompting banks to adopt robust security measures. Fingerprint authentication is used to ensure secure access for banking transactions. Transactions proceed only if biometric data matches, countering unauthorized use and enhancing security. Fingerprint technology is also integrated into ATM cards, rendering banking activities safer. In the context of education, fake impersonation during examinations is a recurring issue in India. Implementing fingerprint identification at examination halls can address this problem. By comparing standard fingerprints with those collected from the AADHAR database, security measures become nearly impenetrable.

In essence, fingerprints hold multifaceted significance beyond their role in criminal identification. Their utilization spans from national identification systems to smartphone security, door locks, banking, and education, contributing to a more secure and efficient society.

X. CONCLUSION

Fingerprints serve as undeniable physical evidence discovered at crime scenes. They play a pivotal role in identifying unknown victims, suspects, witnesses, and verifying records. Furthermore, fingerprints are instrumental in linking suspects to crime scenes. These unique, unchangeable, universally present, and classifiable pieces of evidence can be found impressed on various objects handled with bare hands. Once detected and compared, these fingerprints are employed as evidence in legal proceedings. This is founded on the fundamental principle that no two individuals possess identical fingerprints, thus making fingerprints a distinct means of personal identification.

Over time, numerous novel methods have been developed and tested for revealing latent fingerprints. Despite the existence of highly sensitive techniques that can uncover previously undetectable fingerprints, latent prints are delicate traces that require safeguarding. When investigators arrive at a crime scene, it's crucial to assume that any object taken from the scene could potentially carry fingerprints left by the perpetrator.

Thus, proper measures must be taken to preserve and enhance such evidence. Factors such as the environmental conditions surrounding latent fingerprints can impact their quality. These conditions often guide examiners in determining the most appropriate detection technique (or sequence of techniques) for a specific case. Physical elements like heat, diffusion, dust settling, friction, and chemical factors such as humidity, solvents, and air can

all affect the durability of a latent fingerprint. The duration of exposure (or the age of the prints) and the presence of bacteria can also compromise the longevity of these prints. Hence, ensuring the preservation of these prints is of paramount importance for their subsequent comparison, classification, and analysis. Despite the array of scientific and forensic methods available, fingerprints remain unrivaled as the optimal form of personal identification for legal investigations.

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