

Dermatoglyphics – A Concise Review on Basic Embryogenesis, Classification and Theories of Formation of Fingerprints

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Abstract

The study of fingerprints known as Dermatoglyphics, has been utilized for individual identification in forensics for greater than 2000 years. They have been fully analyzed from various points of views such as embryogenesis, patterns of fingerprints and empirical mechanisms on how they are formed. Several studies have also linked them to certain human features such as gender, etc. This review paper is a systematic compilation on basic embryogenesis, classification of fingerprints and several canonical mechanisms involved in fingerprint formation. The knowledge about this is essential and can open new innovative areas for researchers working in forensics that can help solve the criminal disputes and cases.

Keywords: Buckling Hypothesis, Dermatoglyphics, Finger Print/Classification, Theories, Gender

Introduction

“The womb defines what the black smudge in our passport look like”

Dermatoglyphics, the study of fingerprints, is used as one of the parameters for individual identification for more than 2000 years. This branch has gained significant attention in forensic sciences, due to the fact that everybody's fingerprints are unique and remain constant throughout life¹. Apart from forensic application, this notoriously complicated biological phenomenon has been the subject of curiosity in various diverse fields of biological sciences i.e., embryology, genetics, anthropology and forensics i.e., forensic pathology,

forensic toxicology, forensic optometry, forensic podiatry, digital forensics^{2,3}.

Detailed investigation and study of fingerprints from different points of view such as embryogenesis, statistical patterns of fingerprints and empirical mechanisms on how these are formed have already been carried out. Many studies on fingerprint patterns have also been conducted and published in Pub Med literatures. They have also proved that these patterns are linked to certain common human features such as gender, etc. Hence, this paper is the systematic compilation and concise review on basic embryogenesis, classification of fingerprints and several canonical mechanisms involved in fingerprint formation. Evidence procurement: Pub med search using MeSH

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terms was conducted in English and retrieved articles were reviewed.

Basic Embryogenesis

The timeline for fingerprint formation varies from 7th week to 24th week of intra uterine life and the sequence of events that occurs are hereby briefed.

During the 10th – 16th week of gestation, the formation of fingerprint begins^{4,5}. Antecedent to this event (approx. 7 weeks), a pristine biological structure named “Volar Pads” form. They are temporary elevations of volar skin resting on fingertips, distal part of palms, thenar and hypothenar surfaces. Based on this location, they are named as Apical volar pads, Interdigital volar pads, thenar volar pads and Hypothenar volar pads respectively⁶.

Volar pads are ephemeral structures that grow until the 9th week of pregnancy. They are present both, in upper and lower limbs of humans and appear as round, raised hillocks with well-defined base. However, differences do

occur in their development and existence in both the limbs. In upper limb (hands), they are not well developed and are temporary transient structures that disappear early in human life. In the lower limb (foot), formation of hallucal pad (below the big toe) occurs by merging of thenar pad with the first interdigital volar pads. It has been noted that, the areas covered by volar pads are the sites for fingerprint pattern formation (whorl, loops and arches) and the areas devoid of volar pads form parallel ridges surrounding the patterns. This signifies that volar pads are obligatory and important for formation of fingerprints during embryogenesis. However, these structures disappear at about 10th week of intra uterine life.

Histologically, the basal layer of the dermis shows numerous foldings that quickly become more prominent with an amorphous appearance. This constitutes the PRIMARY RIDGE formation. The appearance of this does not occur at the same time and later establishes, the different fingerprint patterns. Subcutaneous tissue, fibroblast, collagen and fat are also evident as shown in figure 1^{1,3}.

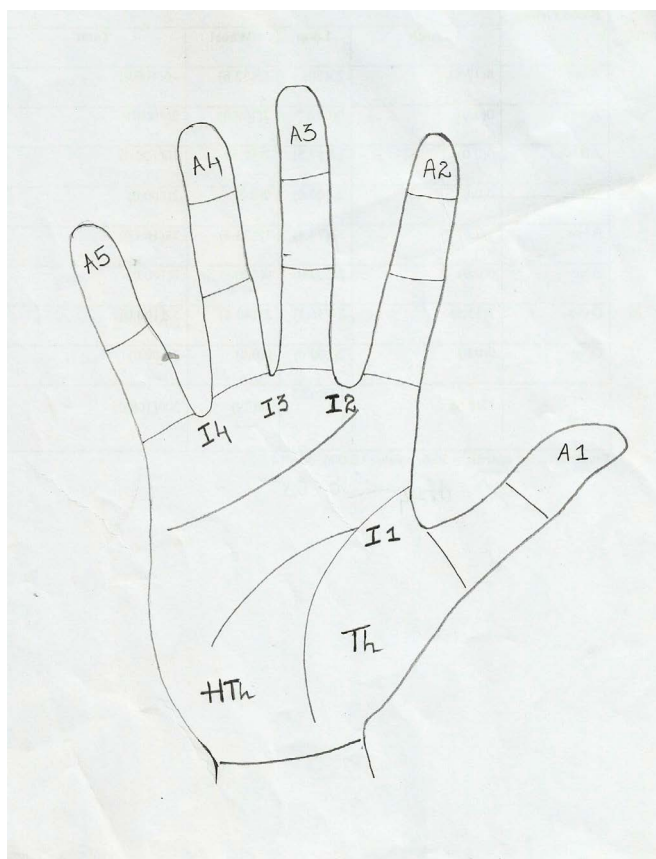


Figure 1. Hand drawn illustration demonstrating the Apical Volar Pads (A1, A2, A3, A4, A5), Interdigital Volar Pads (I1, I2, I3, I4), Thenar Volar Pads (Th) and Hypothenar Volar Pads (HTh).

Traced back, in 1948, Bonnevie & Scharuble examined and studied the pattern of ridge formation on both the limbs. Their study interpreted that, the ridge formation of hands and palms antedate ridge formation on toes and soles. In addition, they also observed that the ridges first occur in the middle of the volar pads and then along the nail furrows. They named as Ridge Anlage or Papilla anlage⁷⁻¹⁰. Further, they defined Ridge anlage as “a small patch of volar skin characterized by intense cell proliferation at the time of ridge initiation and an overall increased thickness of epidermis”. Later the interphalangeal flexion creases occur. In this way, the three converging ridge systems form. More detailed study revealed that there are three different types of ridge anlagen- pattern ridges (middle of volar pads), mantle ridges (nail furrow) & basal ridges (distally to the flexion). When these three ridge systems converge and meet, triradii and minutiae forms. Moreover, studies on ridge multiplication were carried out which documented that, the number of ridges increases as the fetus size increases¹¹.

At about 14th week, sweat gland ducts appear at the bottom of primary ridges. Finally, the ridge patterns appear on the skin surface and configuration of ridge systems is established for life that remains unchangeable¹². At about 19 weeks, the primary ridge formation ceases and secondary ridge formation commences. The only difference between primary and secondary ridges is that secondary ones are shallower and lack sweat glands. This empirical event occurs at about 24th week of pregnancy. Finally, the dermal papillae shows peg like extensions in between primary and secondary ridges, leading to double row formation¹³.

Classification of Fingerprints

In 1892, Sir Francis Galton⁴ proposed a basic classification for fingerprints as Whorls, Loops and Arches. In 1900, Edward Henry further sub-classified Galton's classification as arch, tented arch, right loop, left loop and whorl. The same person also introduced the anatomical landmarks such as core and delta points. He described core as the central area of fingerprint and delta (triradii) as triangular pattern where different ridge systems meet¹⁴.

Loops (60-65%) – This is the most common pattern seen. The loop configuration occurs initially on either sides of fingerprints and then recurve in the same direction and finally terminate. There is one delta and

one core in each loop pattern. Loops have been classified as ulnar loops and radial loops. Ulnar loops are seen on little finger and named after the ulnar bone whereas radial loops are seen on thumb and named after the radius i.e., the lateral bone of finger.

Whorls (30-35%) – are more complex, complicated type of finger prints. Being roughly circular in shape, they have two deltas and type lines^{15,16}. Consisting of one or more free recurving ridge lines, they are of four major types: plain whorl, central pocket whorl, double loop whorl and accidental whorl. The type of whorl that has one ridge and touches from one delta point to other is a *Plain whorl*.

The type of whorl that has one ridge and does not touch from one delta point to other is a *Central pocket whorls (also called as Balloon)*. The type of whorl that has two separate loops with two separate, two delta points and core is *Double loop whorls (S type)*. The type of whorl that doesn't fall in the above-mentioned categories is *Eddy* or *Accidentals whorl*.

Arches (5%) – Being devoid of type line, delta or core, these ridges run from one side to other with no backward turn and are basically of two types: *Plain arch* & *Tented arch*. Plain arch has even and easy flow of ridges with no significant up thrusts whereas tented arch possess an angle, a significant up thrust without an easy flow as that of plain arch¹⁷. These enigmatic configurations are further associated with triradii. A triradius is formed when three ridge systems converge and meet at an angle of 120 degree. Furthermore, these patterns exhibit, Minutiae that are minute defects such as ridge endings, ridge bifurcations, fork formations, islands and enclosures (figure 2). They are also known as Galton points/details or Points of identity. All these structures have created tremendous curiosity among researchers to further study on how actually these processes are formed and what is the enigmatic mechanism behind them^{1,3}. These are not just benchmarks for identification but also reveal other features. E.g., Reinaut *et al.* conducted a study to determine sex differences using Minute Ridge Length Ratio (MRLR). His study showed that these minute structures could help to reveal the race of an individual. MRLR is one such criterion which shows significant variation in sex, race as well as fingerprint determination. Ohler *et al.* studies conducted in 1942 showed variation in MRLR across all five fingers except ring and little finger¹⁸.

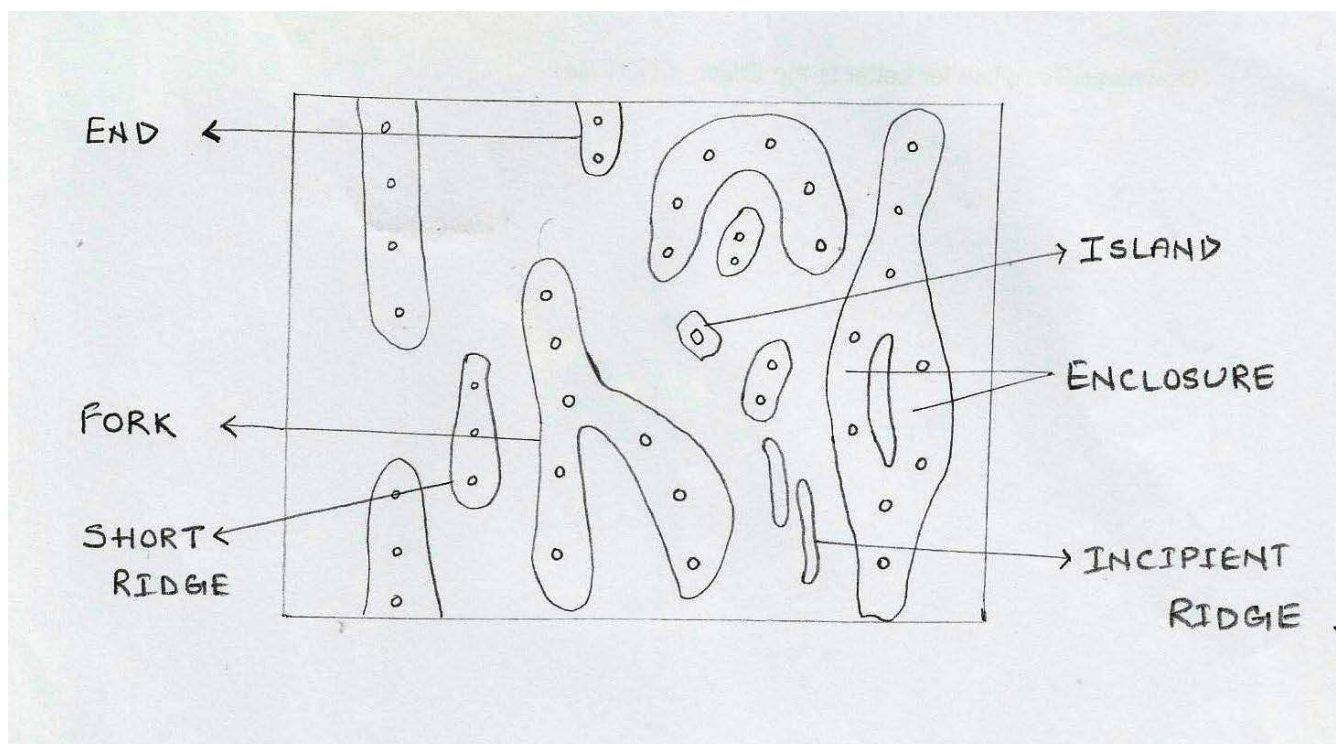


Figure 2. Hand drawn illustration demonstrating anatomical landmarks of finger prints and ridge patterns.

Theories of Ridge Formation

Folding (BUCKLING) Hypothesis

Kollman in 1883 and Bonnevie in 1933 proposed and published series of papers on this theory¹⁹. In 1927, Bonnevie²⁰ observed that basal layers of cells rapidly proliferate and get compressed, thus penetrating the softer dermis leading to primary ridge formation. This enigmatic empirical phenomenon is termed as “BUCKLING PROCESS”. She hypothesized that “epidermal ridge patterns are established as a result of buckling process acting on the basal layer of epidermis”. She further explained that basal cells are connected to other basal cells by desmosomes and to basal layer by hemidesmosomes forming an elastic sheet. This can combat any kind of forces that can resist bending. Moreover, due to faster rapid differential growth of basal cells, compressive stress builds up. Once this stress crosses a particular limit, buckling occurs. The fold grows towards dermis rather than epidermis due to its softer consistency. Although this theory, did not gain universal acceptance, German researchers Abel & Steffens^{21,22} accepted this theory. Later Harold Cummins, a highly influential researchers

in the field of dermatoglyphics suggested that certain mechanical growth forces are responsible to determine the ridge patterns. However, he could not specify from where the forces arise and how the fingerprint patterns were formed. Whipple²³ rejected this theory by claiming that no theories have proved to be the sole contributor of basal cell proliferation to form fingerprint patterns. To substantiate and make this theory more authentic, the source of growth forces acting on basal layer and the implied stress distribution on corresponding patterns should be explored. This was tackled by Gould²⁴ who correlated this situation into mathematical equation based on Von Karman equation of elasticity, which in turn determined the pattern type, ridge spacing and ridge direction.

Nerve Hypothesis

In 1973, two eminent researchers Hirsch & Schweichel contemplated the role of nervous system for the formation of fingerprints²⁵. Numerous vessel nerve nexus is present below the primary ridges in areas where ridge formation took place. This phenomenon was further ratified in case of neurahypotrophies, a condition wherein, either

abnormal fingerprint patterns or complete absence of the same were noted. Furthermore, the unusual fingerprint patterns seen in spina bifida by Schaumann²⁶ and role of ridge- nerve capillary network to form them as inspected by Blechschmidt²⁷ could support the above said theory. However, the formation of patterns was confined only to the proximal and distal parts, sparing the central area, led to non-acceptance of this theory. Traced back to historiography in 1927, Bonnevie also showed a correlation between nervous system and ridge anlage formation that was further studied by Dell & Munger (1986) and Moore & Munger (1989). These authors hypothesized the role of grid arrangement and hexagonal growth cones of nerve fibers in fingerprint formation^{28,29}. These hexagonally organized cones that protrude in epidermis could revamp the amount of space seen in between the ridges which was approximately about 40 micrometers. However, Morohunfolo *et al.* 1992, observed the failure of the same in case of affected leg of Monodelphis domestica that disapproved the hypothesis^{30,31}.

Fibroblast Hypothesis

This theory was proposed by Bentil & Murray based on the phenomenon of Haptotaxis that emphasized on the ability and interaction of fibroblasts and Extra Cellular Matrix (ECM) that formed the main monad for formation of fingerprints³²⁻³⁴. Fibroblast, the principal active cell of connective tissue, with its dynamic potentiality of producing tensile stresses and its affinity towards glutinous areas could contribute for fingerprint formation. However, the lack of substantial evidence could not authenticate this theory.

Applied Aspect of Fingerprint Patterns

Since fingerprints are unique, permanent, individualistic features that remain constant throughout life, few evidence based studies have been conducted to correlate fingerprints with blood groups wherein the study results inferred that the loop patterns were more common in B+ blood group individuals³⁵⁻³⁷. Thus, fingerprint patterns are considered as one of the life-long markers that cannot be easily altered. Therefore, more emphasis should be given on basic understanding of their embryogenesis and formation.

Conclusion

To conclude, this treatise is a short review on basic embryogenesis, classification and theories on fingerprint formation and patterns can help the reader to understand the enigmatic mechanism involved behind various fingerprint patterns. The knowledge about this is essential and can open new innovative areas for researchers working in forensics that can help solve the criminal disputes and cases.


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