Friction Ridge Skin: Morphogenesis and Overview

Anatomy

Outer Morphology of the Skin

The friction ridge skin occurs on the palmar sides of the hands and the plantar sides of the feet of all primates, including humans. As the name implies, the skin is ridged to produce friction. The friction aids in grasping and walking. The friction ridge skin also contains numerous sweat glands, and the pore openings are located along the tops of the ridges. The friction ridge skin does not contain sebaceous (oil) glands or hair follicles. In addition to the ridges, creases are found cress crossing through the friction ridge skin. These creases, in addition to the furrows between the ridges, permit flexibility of the skin. Figure 1 shows the friction ridge skin on a foot, palm, and finger; arrows point to ridges (R) and creases (C).

Regions of the Hands and Feet

Areas of the hands and feet are described in relation to their orientation to the body. Proximal describes an area located toward the core of body while distal describes an area located away from the center of the body. For instance, when describing the hand, the wrist is located proximally (closer to the core of the body) and the tips of the fingers are located distally (further from the core of the body). The sides of the hands and feet are described relative to the bones of the forearm and lower leg, respectively. The thumb side of the hand is referred to as the *radial side* and the little finger side (blade of the palm) is referred to as the *ulnar side*. The great toe side (instep) of the foot is called the *tibial side* and the little toe side (outer edge) is called the *fibular side*.

The palmar side of the hand and soles of the feet are divided into different regions and contain prominent ridge flows delineated by deltas. A delta is the triradius formed where three ridge fields meet (Figure 2).

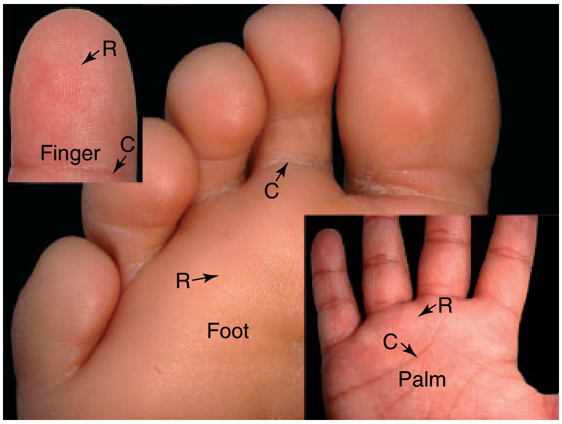

Figure 1 Friction ridge skin of the foot, palm, and finger showing the ridges (R) and creases (C)

Regions of the Hand. The hand is divided into three main regions: interdigital, thenar, and hypothenar. As shown in Figure 3, the radial side of the palm is called the *thenar* (includes area labeled I) and the ulnar side of the palm is called the *hypothenar*. At the base of the palm, between the thenar and hypothenar, is the carpal (proximal) delta [1]. The interdigital region of the palm lies proximal to the fingers and contains the areas labeled II, III, and IV in Figure 3. The interdigital region also contains the digital deltas; there are typically four digital deltas (a, b, c, and d in Figure 3). The fingers are composed of three phalanges: distal, medial, and proximal. The thumb lacks a medial phalange. The phalanges are delineated by creases, which correspond to the underlying joints of the fingers.

Regions of the Foot. The foot is divided into five primary regions: interdigital, hallucal, thenar,

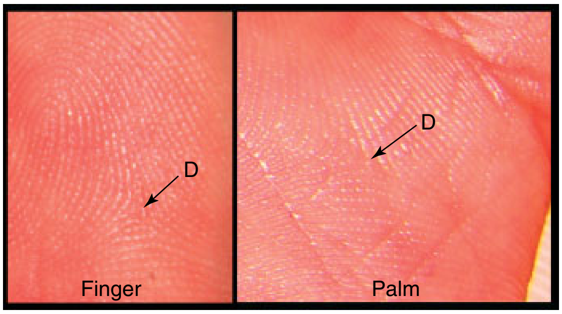

Figure 2 Deltas (D) on a finger and a palm

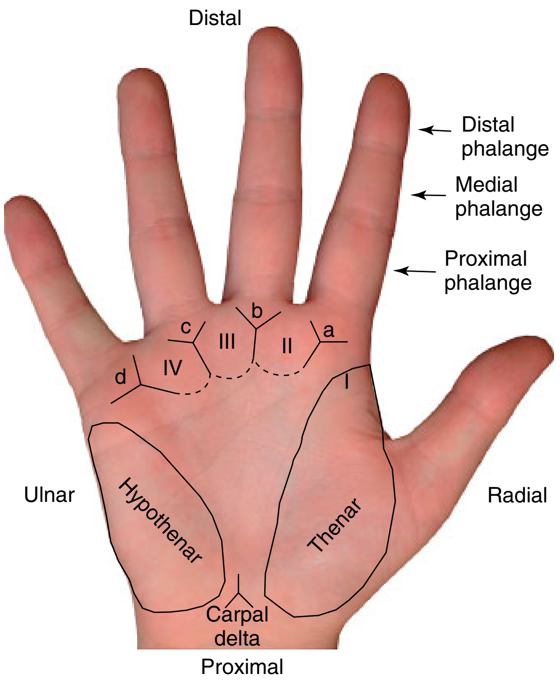

Figure 3 Areas of the palm showing the primary digital deltas (a, b, c, and d) and the carpal (proximal) delta. The thenar area is on the radial side of the palm and includes the region marked I; the hypothenar is on the ulnar side of the palm. The interdigital region contains areas II, III, and IV and the digital deltas. The phalanges of the fingers are marked as the distal, medial, and proximal

hypothenar, and calcar. The foot typically contains five digital deltas and a proximal delta. As shown in Figure 4, the interdigital area includes the areas marked II, III, and IV and digital deltas a, b, c, and d. The hallucal area corresponds to the ball of the foot and contains digital delta e. The interdigital and hallucal areas are demarcated from the rest of the foot by the ridge flows established by the proximal delta. The tibial side of the foot is called the *thenar* and the fibular side of the foot is called the *hypothenar*. The heel of the foot is called the *calcar area* [1]. Like the thumb, the great toe has a proximal and distal phalange. The remaining toes have proximal, medial, and distal phalanges.

Creases of the Hands and Feet

The general position of major creases is very robust between individuals due to their purpose – affording the hands and feet mobility. The major creases occur on all individuals with normal hand and foot morphology [2]. Figure 5 shows the normal configuration of the major creases of the hand. The only major creases of the foot are the creases associated with the toes. Additional creases on the hands and feet exist; however, these may not be present in all individuals.

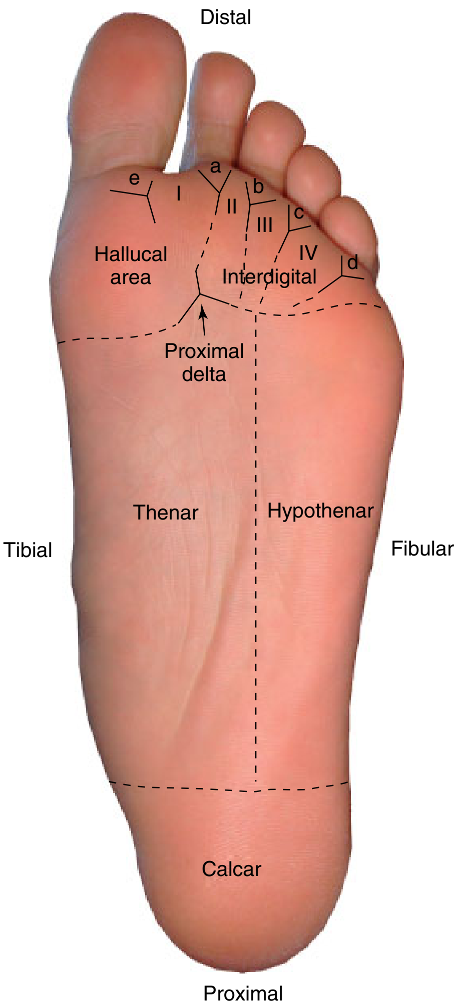

Figure 4 Areas of the foot showing the primary digital deltas (a, b, c, d, and e) and the proximal delta at the base of the ball of the foot. The hallucal region is the area under the great toe (including digital delta e); the interdigital region includes areas II, III, and IV and digital deltas a, b, c, and d; the fibular side of the foot is called the *hypothenar*; the tibial side of the foot is called the *thenar*; and the heel is called the *calcar area*

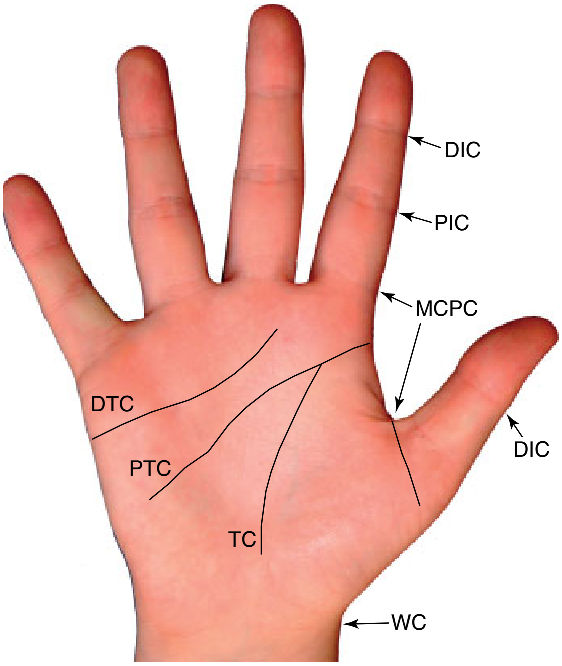

Figure 5 Major creases of the hands. Digital creases include the digital interphalangeal crease (DIC), the proximal interphalangeal crease (PIC), and the metacarpophalangeal crease (MCPC). The palmar creases include the distal transverse crease (DTC), the proximal transverse crease (PTC), thenar crease (TC), and the wrist crease (WC)

Anatomy of Friction Ridge Skin

The skin is composed of three principle layers: epidermis, dermis, and hypodermis. The superficial epidermis is a rapidly regenerating layer composed of stacked cells. The dermis is a supportive layer of connective tissue providing flexibility to the skin. The inner hypodermis is an insulating layer that cushions the skin.

The ridges and furrows seen on the outer surface of the epidermis reflect the complex structure beneath the surface of the skin (Figure 6). While the surface of the epidermis has alternating ridges and furrows, the bottom of the epidermis (where it is attached to the dermis), has alternating primary and secondary ridges. The primary ridges of the epidermis correspond to the surface ridges. The secondary ridges of the epidermis correspond to the surface furrows. The areas of dermis between adjacent primary and secondary ridges are called *dermal papillae*.

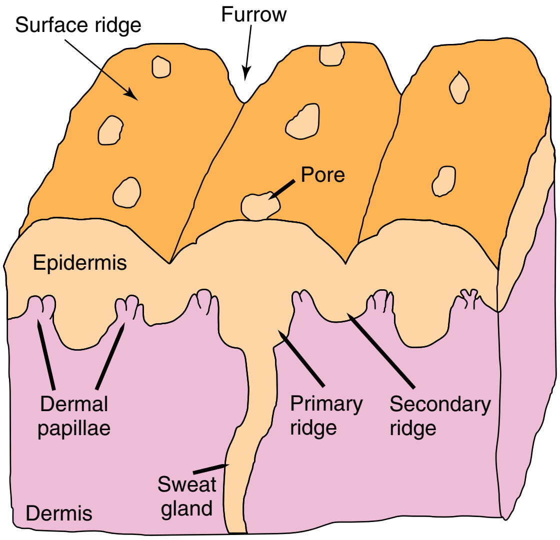

Figure 6 Cross section of the friction ridge skin

The sweat glands are appendages of the epidermis. As shown in Figure 6, the sweat glands are located in the primary ridges of the friction ridge skin. The coiled, secretory portions of the sweat glands are buried in the dermis. Sweat passes from the coiled portion, through the ducts in the primary ridges, and onto the surface of the ridge via a pore (Figure 7).

A fibrous sheet called the *basement membrane* tightly binds the primary and secondary ridges of

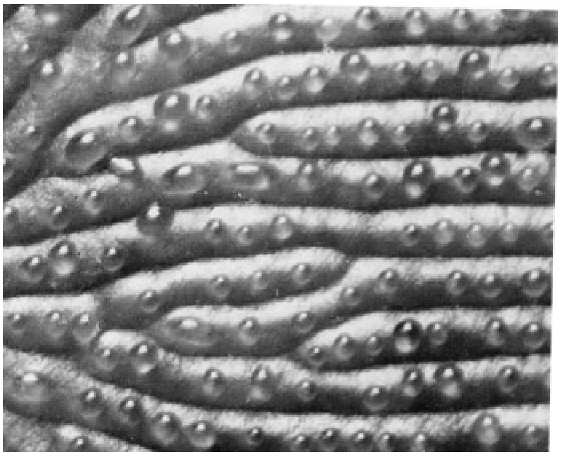

Figure 7 Pores of the friction ridge skin emitting sweat. [Reprinted from Montagna, p. 381) [3]

the epidermis to the underlying dermis. This tight bond ensures that the ridges and furrows are locked into their configuration over the life of an individual, barring injury or disease.

Epidermis. The epidermis is a layered tissue composed primarily of skin cells called *keratinocytes*. The layers of the epidermis represent the biochemical changes that keratinocytes undergo as they are pushed from the bottom of the epidermis to the surface. As shown in Figure 8, the primary layers of the epidermis include the following: stratum basale (generating layer), stratum spinosum, stratum granulosum, stratum lucidum, and stratum corneum. There is also a specialized population of rapidly dividing cells in a suprabasal layer in the primary ridges. The keratinocytes of the stratum basale are responsible for generating all the new cells that are pushed toward the surface to maintain the protective outer stratum corneum.

The keratinocytes of the epidermis are tightly bound to one another via intercellular junctions called *desmosomes*. This network of intercellular attachments prevents the cells from migrating laterally; the cells can only be pushed toward the surface of the skin. Movement toward the surface without lateral migration ensures that the configuration of ridges and furrows persists.

Other cells of the epidermis include melanocytes, Langerhans cells, and Merkel cells. The melanocytes provide pigmentation to the skin. The Langerhans cells are an extension of the immune system and Merkel cells are an extension of the nervous system [4].

Dermis. The dermis is the connective tissue layer that supports the epidermis. The dermis is composed primarily of fibers (collagen and elastin) and a gelatinous ground substance. The primary cell of the dermis is the fibroblast; it is responsible for maintaining both the fibrous and gelatinous structure of the dermis. Several immune response cells also populate the dermis: monocytes, macrophages, dermal dendrocytes, and mast cells [4]. The dermis contains capillary loops to provide nourishment to the epidermis and neural networks to provide sensitive touch discrimination.

Hypodermis. The hypodermis is the innermost layer of the skin. The hypodermis is composed primarily of subcutaneous fat. This fat cushions the skin, insulates the body, and serves as an energy reserve.

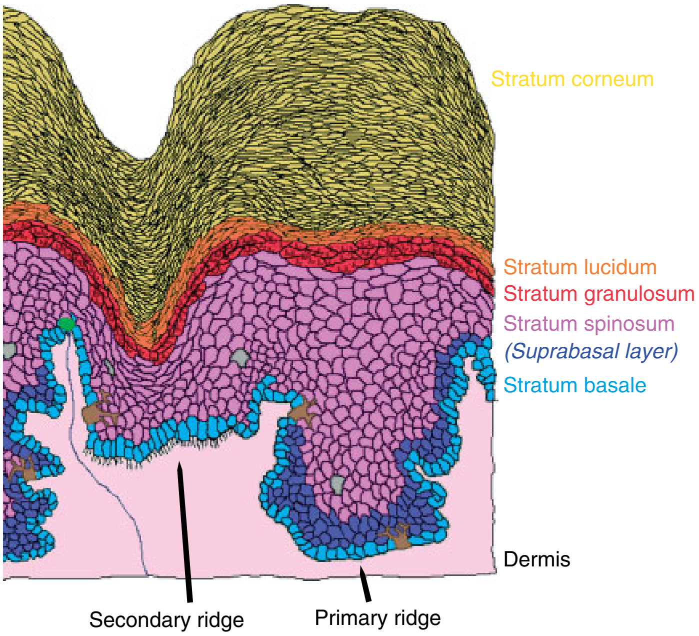

Figure 8 Layers of the epidermis

It also permits mobility of the skin over underlying muscle and bone [4].

Physiology

Keratinization

The sheet of keratinocytes forming the stratum basale is responsible for dividing and pushing cells toward the surface of the epidermis. As the newly generated cells are pushed from the basal layer toward the surface, they undergo a process called *keratinization*. Keratinization prepares the cells for their ultimate purpose: providing a protective layer of dead, cornified cells on the exterior of the body. Figure 9 shows the cornified keratinocytes on the outer surface of the skin. The layers of the epidermis previously described represent the various stages of keratinization as the cells progress toward the surface of the skin.

Keratinocyte Proliferation

The keratinocytes of the stratum basale (basal cells) are responsible for continually dividing; pushing previously generated cells toward the surface to replace those lost at the surface during exfoliation. The rate at which the basal cells divide must be equal to the rate at which cells are sloughing at the surface to maintain the appropriate skin thickness. The basal cells rely on chemical signals from the upper layers of the epidermis and from the dermis below. These signals either induce or inhibit cell division, enabling the skin to maintain the outer protective barrier [4]. If there is too much abrasion at the surface (resulting in a thinning of the stratum corneum), the basal cells will divide faster to provide additional replacement cells. If the skin is too thick, the cells will slow down the rate of division until enough cells at the surface slough off and the proper thickness is achieved. The skin's inherent drive to maintain the epidermis (ridges and furrows) contributes to the persistency of the friction ridge skin.

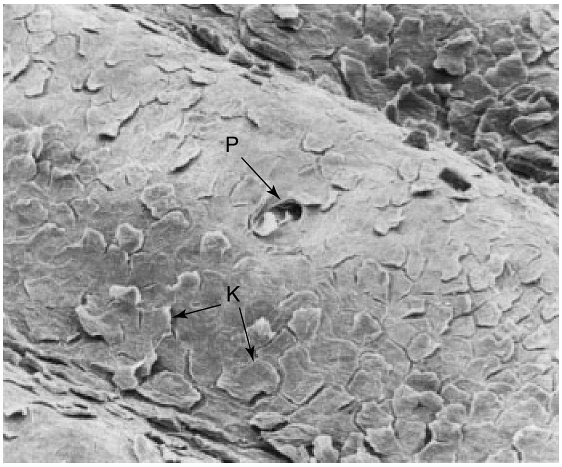

Figure 9 Surface of the friction ridge skin showing cornifed keratinocytes (K) and a sweat pore (P). [Reprinted from Montagna, p. 25]

Persistence

The configuration of the friction ridge skin persists due to a combination of physical attachments and constant regulation of basal cell division in the epidermis. The basal keratinocytes proliferate in unison and are a template for the surface ridges and furrows. The intercellular attachments of the keratinocytes ensure that the cells migrate to the surface in concert, faithfully reproducing the surface features. The structure of the primary and secondary ridges of the epidermis and the protective dermis and hypodermis also provide durability to the skin.

Embryology

The friction ridges and major creases of the hands and feet develop on the growing fetus from approximately 8–18 weeks estimated gestational age (EGA). The shape and growth stresses of the fetal hand at the time of formation of creases and ridges have a direct impact on the position of creases and the general ridge flows (patterns) in the different regions of the hands and feet. While the shape and growth stresses of the fetal hand certainly guide the ridges and creases across the volar surface, the actual paths and shapes of the ridges and creases are left up to random events. This randomness imparts the friction ridge skin with its unique features. Figure 10 shows several ridge paths and a crease path.

Hand and Foot Development

The hands and feet undergo a similar developmental sequence; however, the development of the feet

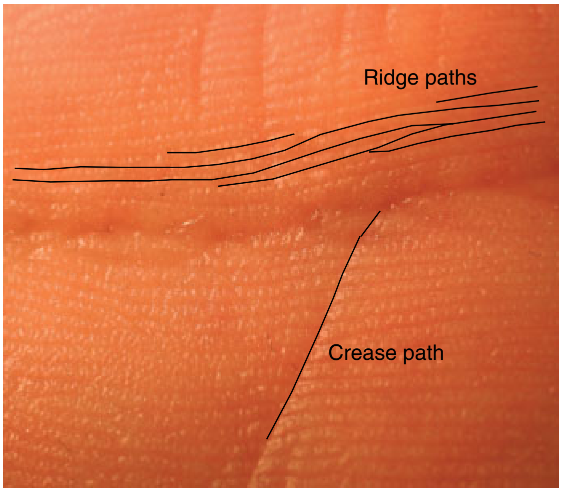

Figure 10 Ridge paths and a crease path on the palm of a hand

typically lags 0.5 week behind the development of the hands [5]. Between 6 and 13 weeks EGA, the hands and feet transform from flat paddles to recognizable hands and feet [2]. From 8 to 12 weeks EGA, however, there are special transient structures on the hands and feet that have a significant impact on the ridge flows and major creases seen on the hands and feet; these structures are called *volar pads*. The volar pads are localized swellings that occur on the hands and feet. As shown in Figure 11, there are prominent volar pads associated with distal phalanges, the interdigital regions, the hypothenar regions, and thenar regions of both the hands and feet [6].

Crease Formation. The major creases of the hand form concurrent with the volar pads, beginning at approximately 8 weeks EGA [2]. The thenar crease encircles the thenar pad (Th.) and the proximal portion of digital pad I. The proximal transverse cuts through the center of the palm and typically ends at the hypothenar pad (Hp). The distal transverse crease follows along the proximal edge of the interdigital volar pads III and IV and typically ends at interdigital pad II. The digital creases form at the joint locations of the fingers and thumbs. The digital creases of the feet start forming at approximately 9 weeks EGA [2].

Volar Pad Formation. The volar pads reach their maximum size at different times across the hands and feet. The volar pads of the palm peak in size at approximately 10 weeks EGA; the volar pads on the fingers (distal phalanges) peak at approximately 11 weeks EGA; and the volar pads of the feet peak at approximately 12 weeks EGA [5]. After the maximum size is attained, the volar pads discontinue growth and begin to disappear into the rapidly growing hand or foot. The size and shape of any volar pads present at the time of formation of the friction ridges have a direct impact on the general ridge flows in the hands and feet [5].

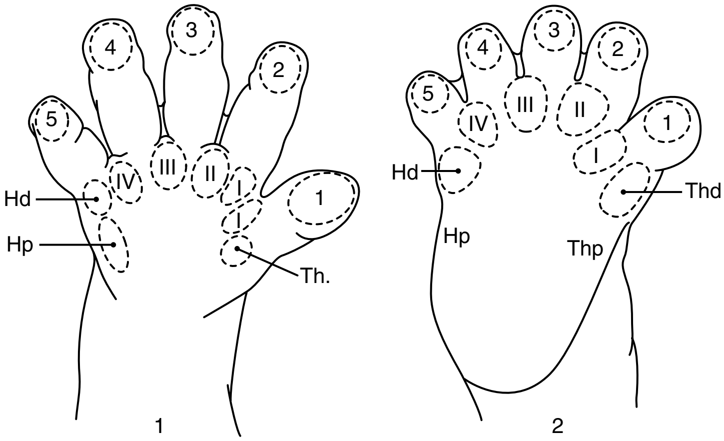

Figure 11 The volar pads of the hands and feet. The digital pads are marked as 1, 2, 3, 4, and 5. The interdigital pads are marked as I, II, III, and IV. The hypothenar pads are Hd (hypothenar distal) and Hp (hypothenar proximal). The thenar pads are marked as Th. (thenar), Thd (thenar distal), and Thp (thenar proximal) [Reprinted from Cummins 1929, p. 114.] [6]

Friction Ridge Formation

The friction ridges typically form on the hands of the fetus at approximately 10 weeks gestation, and on the feet shortly thereafter. The general flow of ridges across the hands and feet is established by the growth stresses present on the hand or foot at the time of formation of the friction ridges. The predominant growth stress of the hands and feet is longitudinal (wrist to fingertip and heal to toe, respectively), causing the main ridge flows to cross the hand and foot laterally (side to side). If the developing ridges encounter a volar pad, the ridges are redirected based on the growth stresses established by the volar pad [7].

The fingers and toes tend to have intense patterns, as the volar pads are often quite prominent when the ridges are forming. Figure 12 shows the three primary pattern types that develop on the fingers: whorls, loops, and arches. These patterns reflect the size and shape of the volar pads at the time of formation of the friction ridges. Whorls tend to form on very high, rounded volar pads. Loops tend to form on asymmetrical volar pads that lean to one side. Arches tend to form on very low volar pads [5].

The palms and the feet may also have prominent volar pads when the friction ridges form. The palms and feet tend to have looping patterns in the interdigital region, including the hallucal area of the foot, that correspond to the interdigital pads. Occasionally, the thenar and hypothenar areas of the hands and feet have patterns; these patterns occur if the hypothenar or thenar pads are still prominent at the time of formation of friction ridge. Figure 13 shows the common ridge flows on the hands and feet.

Uniqueness

Although there is certainly variation to the general flows (patterns) of ridges on the palms and feet, this variation is limited by the general growth stresses on the hands and feet. For instance, one would not find a hexagonal pattern of ridges since there is no fetal hand structure that would permit such a pattern. Within these general ridge flows, however, the specific paths and shapes of the ridges show infinite variability. This variability exists because the final path of each ridge and final three-dimensional shape of each ridge is not dictated during development.

During the development of any organism, the genetic code is responsible for ensuring that the organism has the proper body plan; genes are turned on and off in a regimented sequence to ensure that the limbs and organs have the appropriate form and functionality. There are many fine details of an organism; however, that are not programmed in the genetic code. For instance, the human body is programmed by the genetic code to develop hands and feet containing friction ridge skin on the volar surfaces. The overall ridge and crease patterns vary in a limited manner because the shape and function of the hand or foot is consistent between normal individuals.

The exact placement of each ridge and crease, however, is left up to the chance events that take place during development. These chance events are referred to as "developmental noise" [9] or "noise in gene expression" [10]. Essentially, during the developmental process of an organism, there are features that are not hardwired into the genetic code. Consequently, these features are at the mercy of random formation. The ridges and creases of the friction ridge skin are such features. The classic

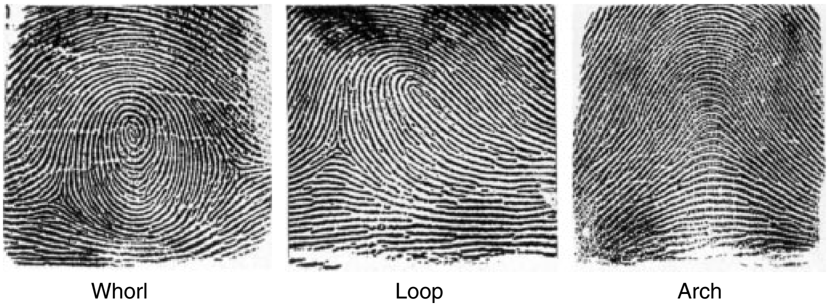

Figure 12 Three primary finger pattern types [Reprinted from Cummins 1943, p. 32 [8].]

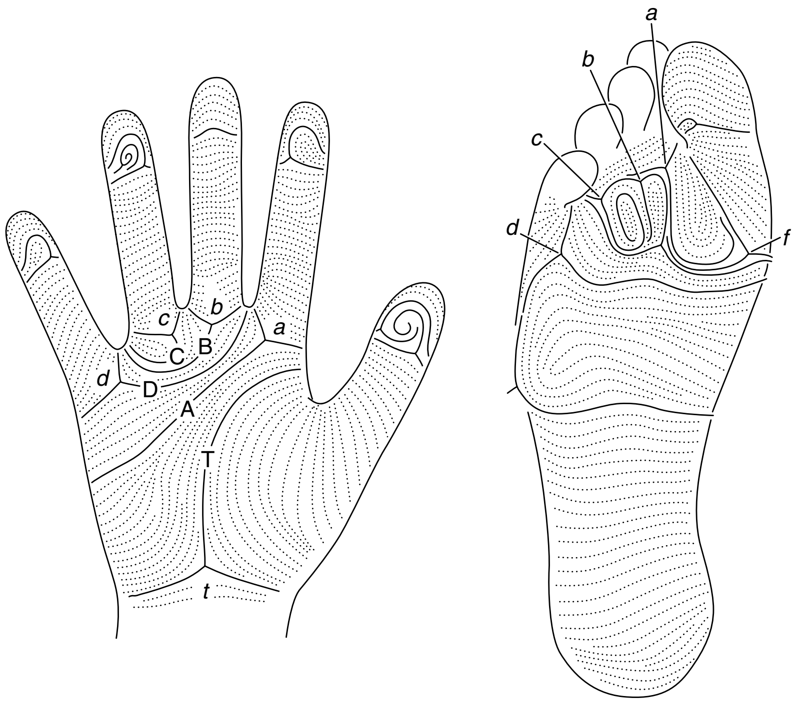

Figure 13 Predominant ridge flows on the hands and the feet. Digital deltas of the hands and feet are marked a, b, c, and d. The proximal delta of the hand is t and the proximal delta of the foot is f. On the hand, A, B, C, D, and T are the main ridge flows [Reprinted from Holt pp. 16, 24, respectively [1].]

example is identical (monozygotic) twins who share the same genetic code but have different finger, palm, and footprints. Figure 14 is the left middle and index fingers from monozygotic twins.

As the ridges are formed on the fetal hands and feet, the hands and feet continue to grow, pulling existing ridges apart. As the ridges reach a critical separation distance, new ridges form in between to ensure the skin is continually ridged [11]. The process is dependent upon the growth of the fetus and the stresses on the epidermis during the development of the friction ridge skin. As a result, the length and path of each ridge is not determined by the genetic code of an individual, but instead by the unique forces at play on any particular area of the hand or foot during development.

The ridges continue to form until the fetus is approximately 18 weeks EGA. At this time, the friction ridge system stops adding new ridges. The ridges are locked into their configuration. The hands of an adult are obviously much larger than the hands of a fetus, but the relationship of the ridges

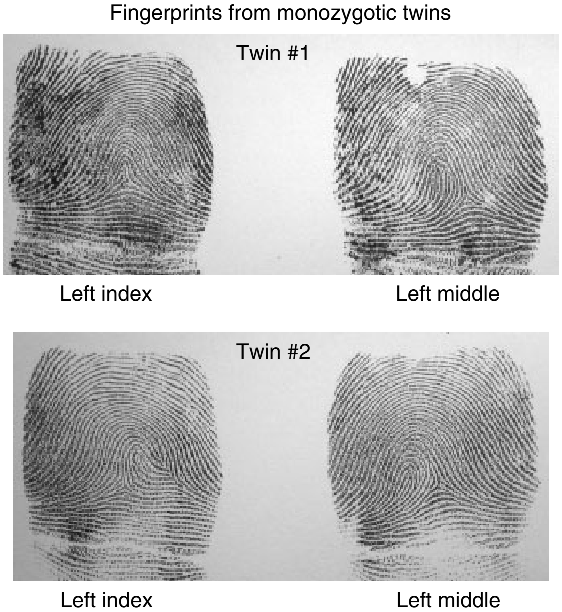

Figure 14 Left index and left middle fingerprints from monozygotic twins

to each other is conserved during growth to adulthood.

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