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The Inheritance of Fingerprint Patterns

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Although there have been a few reports on the inheritance of normal fingerprint patterns, and the dominant inheritance of rare features [1, 2], there has been no comprehensive analysis of pattern genetics. This paper proposes the mode of inheritance of a number of aspects of fingerprint patterns analyzed in a population isolate.

The fingerprint patterns of 571 individuals of an Israeli community, who formerly lived in the town of Habban in South Yemen and in Beida in Yemen, 150 km to the west of Habban, were studied. These "Habbanites" form an isolate, since there were no Jewish communities nearby and no known interbreeding with the local Moslems. The isolate migrated en masse to Israel in 1950 and settled in its own village. The demography, blood and serum groups, anthropometry, and data on fingerprints have been reported by Bonné et al. [3, 4].

Of the 571 Habbanites whose fingerprints were studied, nine were incomplete for one or more fingers. Blood groups were determined for each individual. When blood typing inconsistencies were found, the affected relationship was not utilized.

Family sizes are large, and most individuals have many close relatives within the sample; 62% of marriages are consanguineous. A few men have two wives in polygamous marriages contracted when they lived in Yemen, and some women have children by a second husband after the death of their first. Pedigrees are usually traceable to the grandparents of the oldest living family members, but the interrelationships are not known for that generation.

To develop additional evidence on the inheritance of fingerprint patterns, fingerprints of both parents and one or more children from a non-Habbanite sample of 86 families were used as controls.

THUMB PATTERNS

*Arches on the Thumb**

Arches occur on the thumbs of about 5% of 1,480 white Americans (H. M. Slatis and T. Hassold, in preparation) and 2% of 571 Habbanites (10), bilater-

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* Fingerprints are classified into four possible patterns: ulnar loops (U), radial loops (R), whorls (W), and arches (A).

ally in six of them. Of the 10 Habbanites with this trait, seven are among the 25 descendants of one deceased woman (I-2 in fig. 1). Although some individuals with this trait have as many as seven digits with an arch, the postulated gene may be identified by only an arch on one thumb. One unaffected carrier of the gene (II-5) has a large disorganized field of dots filling all but the center of the whorl pattern core on one thumb. This unusual pattern may be a manifestation of the gene for arches on the thumb. Two additional family members without thumb arches (III-12 and IV-4) show arches on other fingers, which may also be a manifestation of this genotype.

The fingers of the two unaffected carriers (II-2 and II-5) have mostly whorls with some ulnar loops. Whorls do not occur on any fingers of those who have the trait except in the rare sequence AWUUU (arch on thumb, whorl on index, and ulnar loops on the other fingers), which is bilateral in IV-6 and unilateral in III-11. Pedigree 1 supports the interpretation that this is an incompletely penetrant dominant gene that tends to produce arches, particularly on the thumbs, and ulnar loops on the remaining fingers, and that genotypes producing whorls can be epistatic to the arch phenotype.

In a family with a dominant gene for arches on the fingers (fig. 1, pedigree 2), the action of this gene appears to include the thumbs in two individuals (III-18 and IV-65). The tenth person with an arch on the thumbs is, on the basis of blood group data, of uncertain paternity.

Radial Loops on the Thumb

Although radial loops are rarely observed on thumbs, four Habbanites had a radial loop on one thumb. There is no evidence that this trait is in inherited; radial loops were not found on the thumbs of parents (5), sibs (18), half-sibs (2), or children (9) of these four individuals.

Ulnar Loops and Whorls on the Thumb

When both parents have ulnar loops on both thumbs, most of their children exhibit the same patterns. As the proportion of whorls among the parents increases, the proportion of children with whorls also increases (table 1).

TABLE 1

INHERITANCE OF ULNAR LOOPS AND WHORLS ON THE THUMB

Parental Phenotypes	Phenotypes of Habbanite Children						Phenotypes of Non-Habbanite Children			
	UU	UW	WW	Other	(%) UU	(%) WW	UU	UW	WW	Other
UU × UU	58	7	6	...	82	8	30	3	1	2
UU × UW	50	29	15	2	52	16	17	2	7	1
UU × WW	27	23	39	...	30	44	19	8	8	2
UW × UW	15	6	8	2	48	26	3	1	4	...
UW × WW	6	7	9	1	26	39	3	2	6	...
WW × WW	1	...	7	...	12	87	7	3	20	...

NOTE.—UU = both thumbs of an individual carry ulnar loops; UW = one thumb carries an ulnar loop, the other a whorl; WW = both thumbs carry whorls.

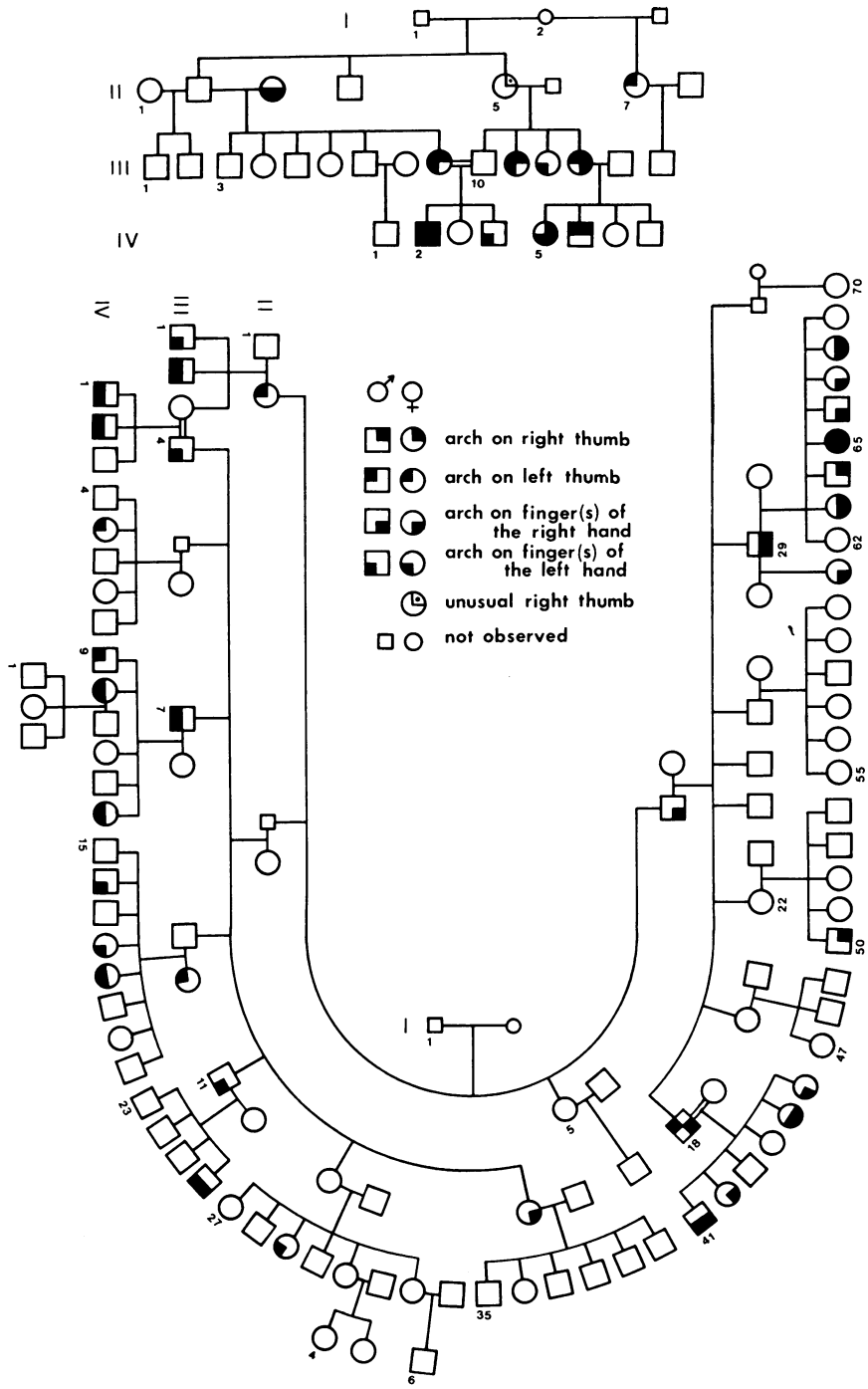

FIG. 1.—The inheritance of arch patterns. Pedigree 1 (*top*) is a family that includes seven of the 10 Habbanites with arches on the thumbs. Pedigree 2 (*bottom*) is a family with an incompletely dominant gene for arches on the fingers, with two members (III-18 and IV-65) with arches also on the thumbs.

Among the Habbanites, the distribution of thumb patterns is 279 UU:131 UW: 143 WW. Some dominant genes may produce tendencies for both thumbs to have whorls (see the sections on WWUWW and WUUWW), but the data are compatible with the hypothesis that persons of genotype *UU* have ulnar loops on both thumbs, *uu* have whorls on both thumbs, and *Uu* may have an ulnar loop on one thumb and a whorl on the other, or may have two ulnar loops, or, less frequently, two whorls. If almost all WW individuals are *uu* and a quarter of all Habbanites are WW, then the gene frequencies are about .5 *U*:.5*u*. Since UW individuals are about half the expected frequency, then *Uu* individuals may be either UU or UW in phenotype, with a few WW. UU individuals are, therefore, either *UU* or *Uu* in genotype. The children of UU $\times$ UU crosses should have genotype frequencies of .5625 *UU*:.3750 *Uu*:.0625 *uu* and phenotype frequencies of about .75 UU:.1875 UW:.0625 WW. The observed phenotypes were .82 UU:.10 UW:.08 WW, which is in good agreement with the expected (with an average family size of 4.5 in this cross, the major source of error will be nonrandom sampling of parents, rather than of children, and a test of these deviations of the children would not be appropriate). The genotypic frequencies would predict that the UU $\times$ WW crosses should be about half *UU* $\times$ *uu* and half *Uu* $\times$ *uu*. The children should be about .75 *Uu*:.25 *uu*, with phenotype frequencies of .375 UU:.375 UW:.25 WW. The observed frequencies of .30 UU:.26 UW:.44 WW could arise from an excess of *Uu* $\times$ *uu* marriages and/or of children from these marriages.

The non-Habbanite sample shows a similar distribution of children of the various crosses, except for a larger frequency of UU and UW children from the WW $\times$ WW cross. Perhaps most human populations have a similar polymorphism that can be explained by this hypothesis.

WHOLE-HAND PATTERN SEQUENCES

Arches on the Fingers

If pedigree 1 is excluded, 92 Habbanites have an arch on one or more fingers (A) and 455 have no arch patterns (non-A). The distribution of children from crosses with both, one, or neither parent A is given in table 2.

Pedigree 2 demonstrates the inheritance of arches in one family. Individuals with the family's A phenotype have 21 A and 25 non-A children while the non-A members married to non-A's have 2 A and 22 non-A children. The data are consistent with the hypothesis that in this family, the presence of a particular dominant gene produces a tendency toward arches on the fingers which rarely extends to the thumbs. If pedigrees 1 and 2 are excluded from the Habbanite sample, the remaining individuals, like the non-Habbanite sample and a group studied by Trube-Becker [5], show fewer than half of the children of A $\times$ non-A marriages with an A phenotype, and many A children from non-A $\times$ non-A marriages (table 2). The data are not compatible with any simple mode of inheritance, but we postulate that various genes for arches on the fingers exist, and while most of these genes are dominant, they have incomplete penetrance. The Habbanites (excluding pedigrees 1 and 2), the non-Habbanites, and the Trube-Becker sample include 114 A children among 370, or about 62% of those expected if all crosses

TABLE 2

INHERITANCE OF ARCHES

POPULATION	PARENTAL PHENOTYPES		
	A × A	A × Non-A	Non-A × Non-A
		(excluding pedigree 1)	
Habbanites:			
Families	1	27	53
Children:			
A	4	39	12
Non-A	2	76	203
		(excluding pedigrees 1 and 2)	
Families	1	17	46
Children:			
A	4	18	10
Non-A	2	51	181
Non-Habbanites:			
Families	2	33	50
Children:			
A	3	21	16
Non-A	0	56	75
Trube-Becker Sample:			
Families	21	83	131
Children:			
A	51	75	50
Non-A	29	149	271

are $Aa \times aa$. Because other genes occasionally produce arches on fingers (see Radial Loops on Index Fingers) the penetrance of average genes for arches is probably about two-thirds; incomplete penetrance may be due to epistasis, particularly by genes for whorls. Most arch genes have only a slight effect on the thumbs, which often have whorls but only rarely have arches; fingers that do not carry arches usually have ulnar loops and rarely have whorls.

The Sequence WWUWW

There were 47 Habbanites who had the pattern sequence WWUWW (ulnar loop on the middle finger, whorls on all others) on one or both hands. This sequence occurred on the right hand in 33 persons, on the left in eight, and bilaterally in six additional individuals. When the trait is unilateral, the other hand has only once been seen with a radial loop and never with an arch; it often has five whorls.

It is probable that the sequence WWUWW arises because of a variety of genotypes, but 34 of the 47 WWUWW individuals are concentrated in three families, of which pedigree 3 (fig. 2) is typical. All three families can be interpreted as carrying a dominant gene with a high degree of penetrance. An alternative hypothesis, that this pattern sequence is due to the simultaneous transmission of two or more unlinked genes for whorls, has a low probability.

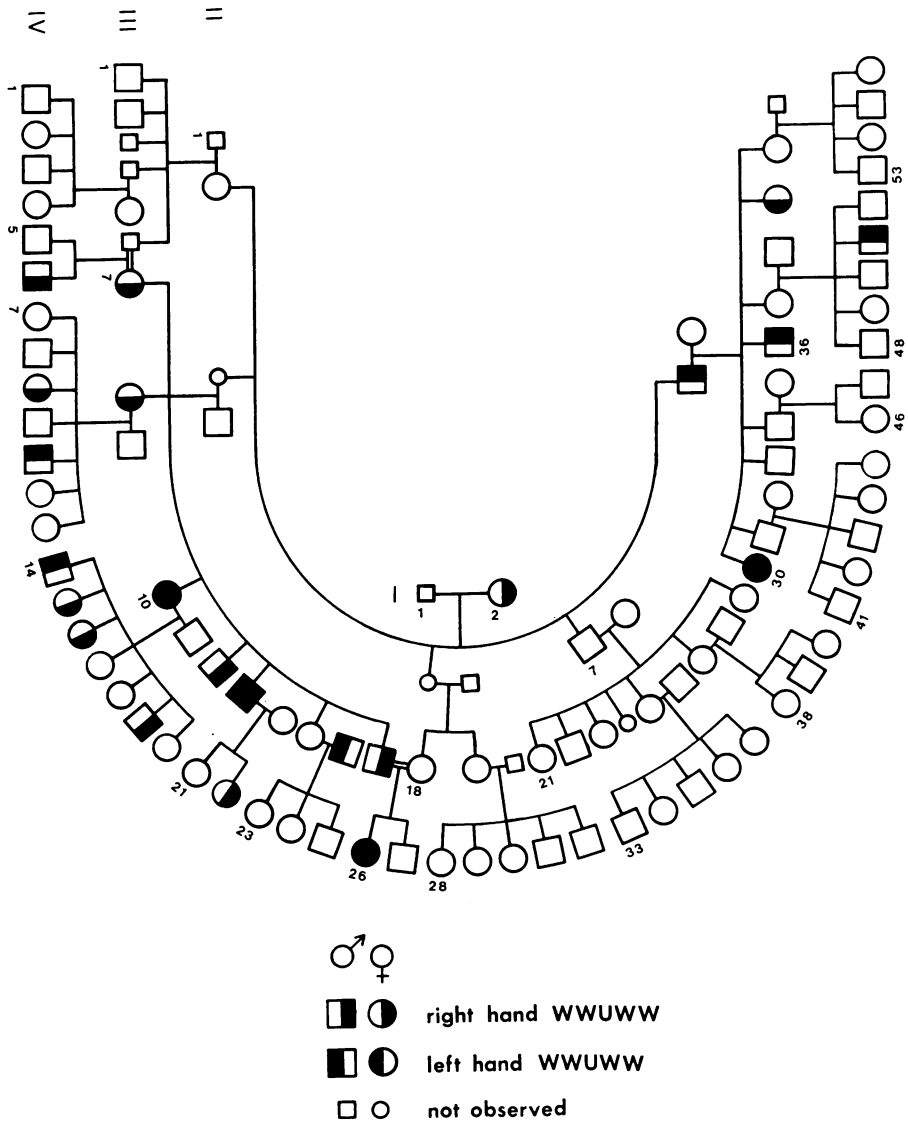

FIG. 2.—Inheritance of the pattern sequence WWUWW in pedigree 3 (ulnar loop on the middle finger, whorls on all other fingers).

The Sequence WUUWW

The sequence of WUUWW is interesting because it is more frequent bilaterally in Down syndrome than in a normal population (5/538 in Down syndrome, 1/1,480 among normals; H. M. Slatis and T. Hassold, in preparation). Among the Habbanites, this sequence is found bilaterally in three individuals (a man, his daughter, and her daughter). These three individuals have a total of 10 sibs,

none of whom has even one hand WUUWW. Perhaps a single gene strongly predisposes the hands toward this sequence, but in this family, other genes (a gene for arches on the fingers is present) are epistatic in some family members.

INDEX AND MIDDLE FINGER PATTERNS

In most families, the heritability of index finger patterns is poor. When both parents have ulnar loops on each index finger, only 11 of 32 children have that phenotype; when both parents have whorls on each index finger, only 12 of 23 children are like their parents.

Radial Loops on the Index Fingers

A radial loop is present on at least one index finger of 119 of the 571 Habbanites. Contrary to the claim of Walker [6], there is no evidence for sex-linked determination of this phenotype. In most instances, individuals with radial loops only show a slight clustering into family groups, and the common sequence URUUU may represent a variation from a sequence of all ulnar loops (UUUUU). However, a few families show highly non-random distributions of radial loops on the index fingers. One woman with this trait apparently transmitted it to five of her six children and 17 of her 28 grandchildren. In this family, the middle finger never carries a radial loop, and 8 of 23 with the trait have an arch on the middle finger. Others have arches on both index fingers, as if that is also a manifestation of this genotype. No other arches appear in this family, indicating the absence of a gene for arches; this family accounts for three of the 12 A Habbanite children with both parents non-A. One presumed carrier of this radial loop gene has a radial loop on one thumb and whorls on both index fingers. In summary, this family appears to have a highly penetrant gene for radial loops on the index fingers with the frequent occurrence of an arch on the middle finger, and occasionally on the index finger. Another family shows a weaker pattern of radial loops and arches on the index and middle fingers; 21 of 42 family members show this pattern.

Middle Fingers

This population exhibits ulnar loops on about 75% of middle fingers with little indication of a simple pattern of inheritance.

RING AND LITTLE FINGER PATTERNS

Radial Loops on the Ring and Little Fingers

Radial loops are present on the ring and/or little fingers of about 2% of a normal U.S. white population (25/1,480) and 5.6% (32) of Habbanites. Individuals with this trait had 10 children with and 39 without the trait. All four families with a parent and one or more children with the trait are closely related both by ancestry and marriage (fig. 3, pedigree 4). Their pedigree suggests the influence of a dominant gene with a high degree of penetrance. However, recessive inheritance is possible because the spouse without the trait is always a cousin closely related to parents with the trait. All but one ancestral line trace to two couples

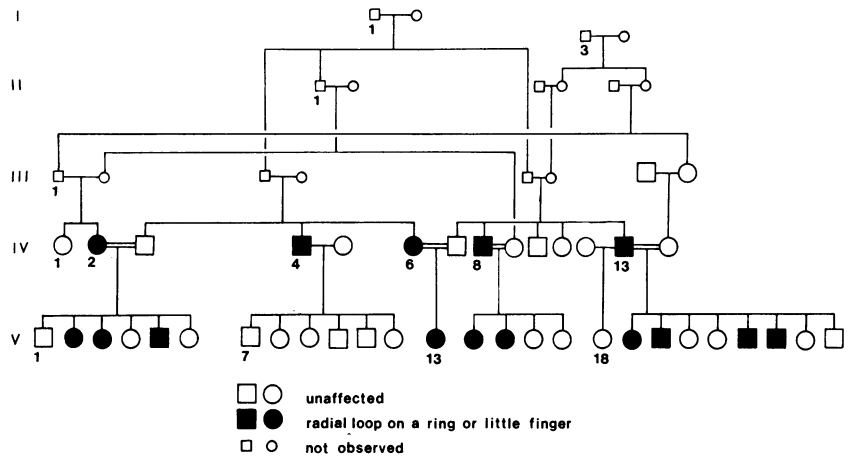

FIG. 3.—The inheritance of radial loops on a ring and/or little finger in pedigree 4. The only four instances of apparent parent-offspring transmission involve a curious pattern of inbreeding and intermarriage, suggestive of recessive inheritance.

who carried the presumed recessive gene. Sporadic instances of radial loops on the ring or little finger may also occur, and genotypes that produce a radial loop on the index finger may cause radial loops to appear on the ring finger.

Ulnar Loops and Whorls on the Ring Finger

The frequency of ulnar loops or whorls on the ring fingers of Habbanite parents is similar to that of their children. The data are not as striking as for the thumbs but are consistent with semidominance (table 3). A gene *W*, when homozygous, may be responsible for the development of whorls on both ring fingers; its allele *w*, when homozygous, may cause ulnar loops on both ring fingers. The heterozygote, *Ww*, may have one whorl and one ulnar loop, but more frequently has either two whorls or two ulnar loops. The frequent similarity between thumb and ring finger patterns is probably affected by genes for whole-hand patterns.

TABLE 3

INHERITANCE OF ULNAR LOOPS AND WHORLS ON THE RING FINGER AMONG HABBANITES

PARENTAL PHENOTYPE	PHENOTYPES OF CHILDREN					
	UU	UW	WW	Other	(%) UU	(%) WW
UU × UU	37	6	2	6	72	4
UU × UW	5	4	7	...	31	44
UU × WW	31	17	31	3	38	38
UW × UW	6	1	8	1	38	50
UW × WW	6	10	25	...	15	61
WW × WW	3	11	18	1	9	55

NOTE.—UU = both ring fingers carry ulnar loops; UW = one ring finger carries an ulnar loop, the other a whorl; WW = both carry whorls.

DISCUSSION

This analysis of the inheritance of fingerprint pattern sequence leads to a general description of the factors governing the determination of the individual fingerprint patterns. The simple relationships between gene and phenotype that occur for biochemical factors cannot be observed here, but fingerprints may be the most complex example available of the genetic determination of a normal morphological characteristic in people.

The most common fingerprint pattern sequence is all ulnar loops. Deviations from this basic pattern may be in three directions: toward whorls, arches, or radial loops. Individual genes may affect the whole hand or only one or more of the fingers. Most of the genes identified among the Habbanites showed dominant or semidominant inheritance; one instance of recessive inheritance has been suggested. If recessive traits are common, they would probably have been observed in this highly inbred population. Phenotypic variability of genotypes (observed in studies of identical twins) introduces some uncertainty in the genetic interpretation of studies such as those presented here.

The gene for arches on the thumb has been identified with confidence as the determinant of a common morphological trait in a human population. The gene for radial loops on the ring and little fingers has been reasonably well defined, although it may be either dominant or recessive. Comparing the frequency of these radial loops between parent-offspring pairs and sib pairs should distinguish between dominance and recessivity in populations with this trait. The proposal that whorls on the thumbs and ring fingers are determined by semidominant genes relative to ulnar loops on these digits should be verified by family studies in other populations.

Non-Habbanite data suggest that the highly penetrant gene for arches on the fingers is not common in other populations. The family with the gene for radial loops on the index fingers with arches on the middle fingers included five members with the pattern sequence URAUU on at least one hand. This uncommon combination (present in 19/1,480 Americans; H. M. Slatis and T. Hassold, in preparation) may identify families with this gene. Large pedigrees in other populations may also indicate dominant inheritance of the WWUWW phenotype, and perhaps of WUUWW.

The genes mentioned in the above paragraph were identified because particular carriers happened to transmit them in high frequency to their offspring. Other populations may lack these genes and have factors for other fingerprint characteristics.

SUMMARY

Analysis of the fingerprints of 571 members of the Habbanite isolate suggest inherited patterns and pattern sequences. A genetic theory has been developed; it assumes that the basic fingerprint pattern sequence is all ulnar loops and that a variety of genes cause deviations from this pattern sequence. Genes that have been proposed include: (1) a semidominant gene for whorls on the thumbs (one homozygote has whorls on both thumbs, the other has ulnar loops on both thumbs and

the heterozygote usually has two ulnar loops or one ulnar loop and one whorl); (2) a semidominant gene for whorls on the ring fingers which acts like the gene for whorls on the thumbs; (3) a dominant gene for arches on the thumbs and often on other fingers; (4) one or more dominant genes for arches on the fingers; (5) a dominant gene for whorls on all fingers except for an ulnar loop on the middle finger; (6) a dominant gene for radial loops on the index fingers, frequently associated with an arch on the middle fingers; and (7) a recessive gene for radial loops on the ring and little fingers. These genes may act independently or may show epistasis.

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