

Prenatal Selection and Dermatoglyphic Patterns

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ABSTRACT Although human dermatoglyphics have been extensively studied, little is known of the prenatal origins of dermatoglyphic patterns. Digital patterns, i.e., loops, whorls, and arches, were obtained from 81 human abortuses, ranging in age from 11 to 25 weeks post-fertilization. Patterns were discernible with the earliest indications of epidermal ridge development. Findings indicate that pattern frequencies during early prenatal development differ from those of later fetal and postnatal periods. Furthermore, a high frequency of arches is seen associated with spontaneous abortion, suggesting evidence for prenatal selection in human abortuses.

Development of epidermal ridges is first seen in the form of localized cell proliferations in the basal layer of the epidermis around the tenth to eleventh week of human prenatal development. These cell proliferations form epidermal ridges that project into the dermis. The number of primary ridges, as they are termed, continues to increase by the formation of new ridges between existing ridges or from existing ridges on the periphery of the pattern. This increase in the number of primary ridges accompanies a general increase in the size of the digit and continues until approximately the seventeenth week (150-mm Crown-Rump Length). At this time the ridges become discernible on the volar surface as fingerprints. However, ridge patterns are recognizable with the initial formation of epidermal ridges in the basal layer of the epidermis as early as 60-mm Crown-Rump Length. During the period of ridge formation, ridge patterns become more elaborate, increasing the number of ridges that comprise the pattern. During this period also, the fetus is susceptible to developmental insult from various environmental factors as well as important genetic actions, e.g., cell differentiation and control of growth rates.

Prenatal origins of dermatoglyphic patterns have interested human biologists for the last century and a half. Purkinje (1823), first to systematically classify pattern types, believed that the ridge patterns and directional hair patterning in various body regions were the

result of similar developmental processes. What these processes were, however, is unclear. In 1892, Galton demonstrated the permanence of ridge patterns throughout postnatal life. In the fetus, Hale ('49, '52) was first to measure ridge growth quantitatively and establish that ridge development terminates at 17 weeks post-fertilization. Recently, Penrose and O'Hara ('73) used electron microscopy to study epidermal ridge development. Okijima ('75) and Miller ('73) reported on techniques to study surface ridges of the fetus. While Muhvihill and Smith ('69) offered a hypothesis to explain ridge pattern configuration, nothing is known of the frequencies of dermatoglyphic patterns during the period of ridge formation or even during the fetal period as a whole. The present study examines differences in the frequencies of arches, loops and whorls both within the fetal period and between the fetal and postnatal periods.

MATERIALS AND METHODS

Sample

Right hands free from epidermal sloughing and showing minimal shrinkage were obtained from 81 American Caucasian fetuses, 41 male and 40 female specimens, ranging from 60- to 250-mm Crown-Rump Length (CRL) (approximately 11-25 weeks post-fertilization age). Sex was determined by development of external genitalia and gonads.

Of these 81 fetuses, 51 were derived from spontaneous abortions and 30 from elective

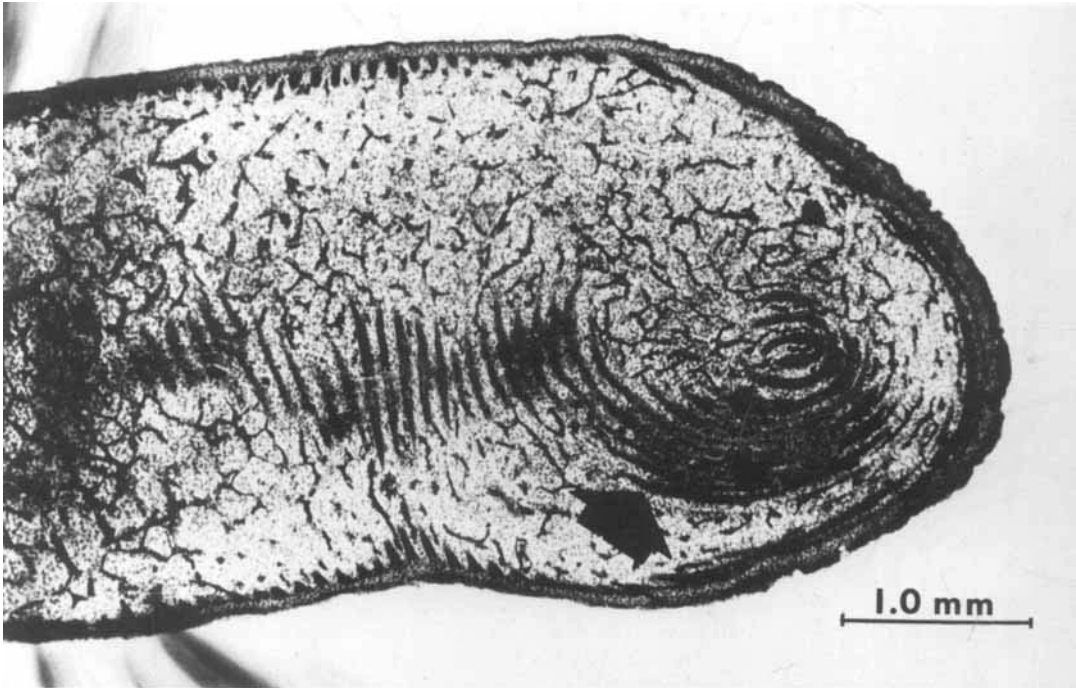


Fig. 1 A histologic section through the volar surface of the second digit of a 13-week (88-mm CRL) fetus, showing the configuration of primary ridges (i.e., the darkly stained cells, arrow) in the basal epidermal layer. This represents a portion of a whorl pattern. At this time ridges are not visible on the skin surface.

abortions limited to the 17- to 25-week post-fertilization period. Only specimens free of gross or chromosomal defects and with no confirmed clinical indication of abnormality were included in the sample.

Although bimanual differences in both ridge patterns and ridge count have been reported (Plato et al., '75; Holt, '68), the present study was restricted to right hands because of the availability of right hands for the study and to control for possible developmental differences associated with right-left hand asymmetry.

Techniques

Since epidermal ridges develop first in the basal epidermal layer and are not visible on the surface, hands from 55 specimens of 11 to 21 weeks post-fertilization which lacked visible surface ridge patterns were fixed in 10% formalin, paraffin embedded and serially thin-sectioned in a plane parallel to the volar surface. The 10- μ sections, stained in a Masson trichrome stain, were then examined with light microscopy. Serial sections (fig. 1) were projected from an overhead "Projektiskop"

and ridge patterns were then serially reconstructed.

In the remaining 25 specimens, the volar skin of the fingers was examined through a stereo dissection scope for the presence of ridge patterns (fig. 2).

Arch, loop and whorl ridge patterns of histological sections and volar skin were classified according to Penrose ('68).

In some instances, ridge patterns for all five digits of the hand could not be determined. In some younger specimens, ridges were not always present on all digits, reflecting differential timing in the appearance of ridges. In addition, questionable reconstructed patterns were omitted from the final analysis. Due to technical factors the latter case applied primarily to thumb patterns.

Analysis

Data were statistically analyzed as follows: Frequencies of arches, loops and whorls of the fetal sample were compared first on a finger-by-finger basis and secondly on a sex-specific basis. Thirdly, frequencies of arches, loops and whorls were compared between abortuses de-



Fig. 2 The volar surface of the second digit of an 18-week (158-mm CRL) fetus. An *ulnar loop* ridge pattern is visible. Note that the digit is only about 2 mm in width at this time, yet the dermatoglyphic pattern is similar to that on an adult.

rived from spontaneous abortions matched for age. Fourth, the fetal sample was subdivided into two age groups dependent on whether ridge differentiation was ongoing (60- to 140-mm CRL) or terminated (141- to 260-mm CRL). Finally, the role of time of initial primary ridge differentiation was examined by subdividing fetuses into either early (60- to 85-mm CRL) or late (86- to 115-mm CRL) initial ridge differentiation groups. All statistical analyses employed contingency chi-square tests for three degrees of freedom.

RESULTS

Finger-by-finger comparison

The finger-specific frequencies of ridge patterns in 81 American White fetuses between 11 and 28 weeks post-fertilization are given in table 1. Ulnar loops were most frequent on the fifth digit (73.7% for males and 70.3% for females) and least frequent on the second digit (28.2% and 30.8% for males and females, respectively). Radial loops were confined primarily to the second digit. Whorls were most prevalent on the second digit (41.0% for both sexes) and least prevalent on the fifth digit

(13.1% and 18.9% for males and females, respectively). Arches were most frequent in males on the first (18.5%) and second (18.0%) digits while in females high frequencies of arches were observed for the second (18.0%) and third (18.0%) digits. In males the frequency of arches was greater than 10% for all digits as compared to only the second, third and fifth digits in females. The prenatal frequency of arches was greater than published postnatal frequencies of arches for five of five digits in males and four of five digits in females. The increased frequency of arches was reflected in a decreased frequency of ulnar loops, primarily on the fifth and third digits. Similarly, the frequency of radial loops was less than published postnatal frequencies for that pattern type (Plato et al., '75).

Sex comparison

Males had a higher frequency of arches than females (14.8% versus 12.2%) overall and a lower frequency of whorls in two of five digits. There was no difference in the overall frequency of whorls. Females had a slightly higher frequency of ulnar loops than did males

TABLE 1

Digit-specific frequencies of patterns in white fetuses

Digit		Males (N = 41)				Females (N = 40)			
		Arch	Loop		Whorl	Arch	Loop		Whorl
			Radial	Ulnar			Radial	Ulnar	
I	N	5	0	14	8	3	0	25	8
	%	18.5	0.0	51.9	29.6	8.3	0.0	69.4	22.2
II	N	7	5	11	16	7	4	12	16
	%	18.0	12.8	28.2	41.0	18.0	10.2	30.8	41.0
III	N	6	1	26	6	7	0	23	9
	%	15.4	2.6	66.7	15.4	18.0	0.0	59.0	23.0
IV	N	4	1	18	17	2	0	22	14
	%	10.0	2.5	45.0	42.5	5.3	0.0	57.9	36.8
V	N	5	0	28	5	4	0	26	7
	%	13.2	0.0	73.7	13.1	10.8	0.0	70.3	18.9
Total ¹	N	27	7	97	52	23	4	108	54
	%	14.8	3.8	53.0	28.4	12.2	2.1	57.1	28.6

¹ Frequency of patterns does not differ significantly between males and females ($\chi^2 = 1.66$, d.f. = 3, $p < 0.40$).

(57.1% versus 53.0%) while radial loops were more frequent in males. However, when the overall frequencies of pattern types for males and females were compared, no significant difference was found (table 1). Accordingly, in the remaining analyses males and females were grouped.

Spontaneous-elective abortus comparison

When fetuses of 17 to 25 weeks are subdivided into elective and spontaneous abortion subgroups, the results (table 2) show that the two differ significantly ($p < 0.005$). The frequency of arches in the spontaneous abortion group is 17.7% versus only 6.4% in the elective abortion group. This 6.4% frequency of arches in the elective abortion group is slightly higher, but not significantly different from observed postnatal frequencies. Abortuses spontaneously aborted, however, show an unusually high frequency of arches in association with a marked decrease in the frequency of ulnar loops (from 65.7-48.7%).

Age comparison

The period of epidermal ridge development can be divided into two basic phases, a phase of primary ridge and pattern formation and a phase of ridge maturation after primary ridge formation has terminated. If the frequencies of patterns in these two phases did not differ, it would support the contention that ridge patterns are unchangeable from the initial appearance of primary ridges. A second question is whether differences in the time of ridge differentiation within the phase of primary ridge

formation may produce differences in the frequencies of patterns. If ridge pattern is indeed determined by the topography of the volar pad at the time of ridge differentiation, as has been suggested by Mulvihill and Smith ('69), then early ridge formation should be associated with whorls. In the following two sections, these two questions are addressed.

A. Ongoing versus terminated ridge formation

Studies by Hale ('49, '52) and the present study indicated 140-mm CRL as approximating the end of primary ridge formation. Using this criterion, abortuses were subdivided into ongoing and terminated ridge formation groups.

There was no difference in the frequency of patterns between ongoing and terminated ridge formation groups for elective abortuses (table 3). However, fetuses spontaneously aborted during ongoing primary ridge formation had a significantly higher frequency of whorls than did spontaneous abortions after ridge formation had terminated. In the ongoing ridge formation group for spontaneous abortuses, the frequency of whorls was 39.0% versus 17.4% after ridge formation had ceased. At the same time, the frequency of arches was greater in abortuses with ridge formation terminated (18.9% versus 15.2%). The difference between groups was highly significant ($p < 0.005$).

B. Time of ridge differentiation

The role of time of initial primary ridge differentiation on the frequencies of patterns

TABLE 2

Greater frequency of arches in spontaneous versus elective abortuses

Abortion	No. hands	Arch	Loop		Whorl	
			Radial	Ulnar		
Elective ¹	30	N	9	3	92	36
		%	6.4	2.2	65.7	25.7
Spontaneous	51	N	41	8	113	70
		%	17.7	3.4	48.7	30.2

¹ Elective and spontaneous abortuses differ significantly in frequency of arches ($\chi^2 = 13.9$, d.f. = 3, $p < 0.005$).

TABLE 3

Frequencies of patterns for ongoing and terminated ridge formation

Primary ridge formation	No. hands	Arch	Loop		Whorl	
			Radial	Ulnar		
<i>Elective abortuses</i>						
Ongoing ¹	13	N	4	2	38	18
		%	6.5	3.2	61.3	29.0
Terminated	15	N	5	0	44	24
		%	6.8	0.0	60.3	32.9
<i>Spontaneous abortuses</i>						
Ongoing ²	26	N	16	3	45	41
		%	15.2	2.9	42.9	39.0
Terminated	27	N	25	6	78	23
		%	18.9	4.5	59.1	17.4

¹ No significant difference between ongoing and terminated ridge formation ($\chi^2 = 2.52$, d.f. = 3, $p < 0.60$).

² Difference between ongoing and terminated ridge formation is significant ($\chi^2 = 13.99$, d.f. = 3, $p < 0.005$).

TABLE 4

Association of increased frequency of whorls with early ridge differentiation

Crown-rump length	No. hands	Arch	Loop	Whorl	
55-85 mm ¹	7	N	0	1	20
		%	0.0	4.8	95.2
86-115	6	N	4	12	7
		%	17.4	52.2	30.4

¹ Difference between early ridge differentiation (55- to 85-mm CRL) and late ridge differentiation (86- to 115-mm CRL) is significant ($\chi^2 = 19.5$, d.f. = 2, $p < 0.001$).

was investigated by subdividing younger abortuses into either an early (55- to 85-mm CRL) or late (86- to 115-mm CRL) initial ridge differentiation group. The late ridge formation group did not necessarily preclude early ridge differentiation, but rather should be considered to consist of both early and late ridge differentiation individuals.

As shown in table 4, early ridge differentiation was associated with an exceedingly high frequency of whorls (95.2%) and an exceedingly low frequency of arches (0.0%) as compared to the sample as a whole. The frequency of loops (4.8%) was intermediate. In contrast,

late ridge differentiation was associated with a frequency of loops similar to that seen postnatally, a frequency of whorls (30.4%) that was one-third that for early ridge differentiation, and an exceedingly high frequency of arches (17.4%). This difference was highly significant with a chi-squared value in excess of 19.

DISCUSSION

The frequencies of patterns for elective abortuses did not differ from published postnatal frequencies for American Whites (Plato et al., '75). For this reason, the lack of a prenatal-postnatal difference in frequency of pat-

tern type suggests that ridge patterns do not change once ridge differentiation begins around the eleventh week post-fertilization. The similarity in pattern frequency between elective abortuses with ongoing or terminated ridge formation supports this idea.

The similarity of elective abortuses and adults in frequency of patterns emphasizes the difference in frequency of pattern, particularly arches, between spontaneous and elective abortuses.

The next question is why do spontaneous abortuses, which have no clinical indication of abnormality, differ from elective abortuses in respect to frequency of arches. That the frequency of arches is high on all digits in males and three of five digits in females suggests that the elective-spontaneous difference is not due solely to fingers known to have a high frequency of arches (i.e., the second digit). Similarly, although bilateral asymmetry has been reported for ridge patterns (Plato et al., '75) with a greater frequency of arches on the left hand (5.2 versus 4.2%), the postnatal frequency of arches on the left hand does not approach the 14.7% observed for only right hands in spontaneous abortuses.

One explanation for such an association may be that clinically "normal" abortuses may have congenital defects undetected by screening methods presently employed. Unusual dermatoglyphics including higher frequencies of arches have been associated with a variety of chromosomal defects, i.e., Trisomy 18 (Uchida et al., '62), Trisomy D (Penrose, '66), Klinefelter's syndrome (Uchida et al., '64), and Rubinstein-Taybi syndrome (Padfield et al., '68), with congenital heart disease (Casco, '64), and with environmentally-induced defects, i.e., prenatal rubella (Alter and Schulenberg, '66).

However, a more likely explanation for the association of prenatal death (spontaneous abortion) with a higher incidence of arches may be that stabilizing selection is operating on ontogenetic factors associated with epidermal ridge differentiation and pattern formation. Evidence further suggests that developmental timing may be one of these factors. Mulvihill and Smith ('69) hypothesized that pattern type was determined by shape of the volar pad at the time of ridge formation. Ridges developed transversely to the lines of growth stress. Accordingly, a high ball-like pad would produce a whorl while a low pad would result in an arch. An intermediate pad

height offset to the to the side of the digit would result in a loop. Since the volar pads regress during the period of ridge differentiation, the hypothesis predicts whorls to be associated with early ridge differentiation and arches with late differentiation relative to pad regression. Results from the present study confirm this prediction. Selection in this case, then, appears to involve deviations, including timing of ridge differentiation, from a common developmental pathway. Whether the high frequency of arches reflects early pad regression or late ridge differentiation can not yet be determined. An alternative explanation may be that pad height is reduced in fetuses that spontaneously abort. In either case, selection during the fetal period appears to involve deviations, including developmental timing and/or pad height, from a common developmental pathway. Since organogenesis is relatively complete by the time of ridge formation, these data provide some evidence of selective pressures on the fetus during a period of maturation and somatic growth.

A second observation concerning prenatal selection is the significant difference in frequency of patterns between spontaneous abortuses with ongoing versus terminated ridge formation. This suggests that fetuses that abort at early ages may be genetically distinct from fetuses that abort at later stages of pregnancy. This suggests that selective forces may act differentially on different phenotypes at different times during the fetal period.

While van Valen ('63) found no association between natural selection and the dermatoglyphic trait of total ridge count postnatally, the present study suggests that dermatoglyphic traits seen postnatally reflect, in part, selective pressures on the developing fetus. Although genetic factors no doubt play a major role in ridge configuration (Reed et al., '75), dermatoglyphic traits must be viewed as products of developmental processes encompassing the fetus as a whole. Indeed, dermatoglyphic traits may provide an additional tool for examining fetal development.

The prenatal association of dermatoglyphic traits with differential survival suggests that postnatal individual and populational variation in dermatoglyphic patterns may be by-products of varying genetic and environmental factors interacting at an early developmental stage. In any event, the application of dermatoglyphics to the understanding of human prenatal developmental variation and

natural selection opens new thought in interpreting dermatoglyphics in both populational and clinical perspectives.

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