Babler, W. J.:

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M. Pijade 158
41000 ZAGREB
Yugoslavia

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Prenatal Development of Dermatoglyphic Digital Patterns: Associations with Epidermal Ridge, Volar Pad and Bone Morphology

W. J. Babler

ABSTRACT

Although variation in human dermatoglyphic traits has been studied extensively, questions concerning the prenatal origins of this variation remain. The present study examines developmental relationships among epidermal ridges (the fundament of dermatoglyphic traits), volar pads and long bones of the hand. Data were derived from the hands of 165 human fetuses judged to be typical for age. Fetuses ranged in age from 8.5 weeks fertilization age through term. In addition to measurements of pattern type, epidermal ridge dimension (ridge width, separation and depth) and ridge maturation, measurements of bone dimension, ossification, and volar pad size were obtained. Results of this study indicated that digital pattern type (arch, loop or whorl) is associated with the shape of the volar pad at the time of ridge formation. However, this association is related only to pad width. Pattern type is also associated with shape of the bony distal phalanx. These data underscore the importance of understanding the developmental basis of dermatoglyphic variation.

Introduction

Dermatoglyphic traits have their developmental origins in the third month after fertilization. The configurations which comprise dermatoglyphics are, in many respects, a history of the developmental period during which the ridges form since ridge configurations do not change through time. Although variation in human dermatoglyphic traits has been studied extensively, questions concerning the prenatal origins of this variation remain. Recent interest in the use of dermatoglyphics as indicators of prenatal development[1,2] requires an understanding of the developmental origins of dermatoglyphic traits.

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Epidermal ridge development

The development of epidermal ridges is preceded by the formation of localized eminences, volar pads, on the ventral apical region of the digits as well as on the interdigital, thenar and hypothenar regions of the palm.[3,4] The importance of volar pads in the morphogenesis of epidermal ridges and their configurations is underscored by the fact that the volar pad is the site of initial ridge formation. Volar pads first appear on the digits around 6 weeks post-fertilization (22 mm CRL). Volar pads exhibit marked growth and individualization through 10—11 weeks post-fertilization (60 mm CRL) after which they begin to regress. This involution continues until pads are comparable in appearance to the pads of the infant.[3]

The initial regression of volar pads corresponds to the initial formation of epidermal ridges. Epidermal ridges first appear as localized cell proliferations in the basal layer of the epidermis around 10—11 weeks postfertilization. These cell proliferations form shallow primary ridges that project into the superficial layer of the dermis.[5] The number of primary ridges increases as new ridges are formed between or adjacent to existing riges. Around 14 weeks post-fertilization sweat glands anlagen begin to develop at uniform intervals along the apices of the ridges. At approximately 15—17 weeks, secondary ridges, lacking sweat gland anlagen, begin to form. Concomitant with secondary ridge formation is the termination to primary ridge formation and the initial appearance of epidermal ridges on the volar surface. Therefore, the development of ridge configuration or pattern precedes the appearance of epidermal ridge configuration on the volar surface. Rather it initiates with primary ridge development at the epidermal-dermal junction as early as the 10th week epidermal post-fertilization.[6]

While we generally believe that dermatoglyphic traits are highly hereditable, we know little of the developmental factors which are important in the determination of ridge configuration. Mulvihill and Smith[7] have hypothesized that digital ridge pattern reflects the shape of the volar pad at the time of primary ridge formation. This hypothesis recently has been examined further by Elie.[8] This study examines the developmental relationships of volar pad size and shape, bone development, digit size and ridge configuration during early primary ridge development.

Materials and methods

The present study used data collected from 165 human abortuses from the Patten Human Embryology Research Collection of the University of Michigan, School of Medicine. After initial analysis, this sample was reduced to 94 prenates in which maturation of the epidermal ridge system was incomplete. This subsample ranged in age from 8.5 to 16 weeks post-fertilization, 45 to 120 mm Crown-Rump Length (CRL). Specimens were free of gross body and chromosomal defects and had no clinical indication of abnormality, e. g. exposure to rubella or maternal ingestion of known teratogenic drugs during pregnancy. Generally complete medical documentation and histories of pregnancy for each specimen allowed assignment to a sample subgroup categorized as to a variety of parameters including sex, racial group, and pregnancy outcome (i. e. spontaneous or elective abortion).

All specimens were fixed in 10% neutral, buffered formalin. The right hand from each specimen was first examined grossly under a stereo microscope for the presence or absence of epidermal ridges on the apical pad of the digits. If ridges were visible, their configuration or patterns were determined. Pattern was recorded as whorl, radial or ulnar loop, or arch according to criteria established by Penrose.[9] After gross examination, all hands were histologically prepared. Hands were serially sectioned at 10u in a plane parallel to the volar surface of the hand. The thin sections were then stained with a modified Masson trichrome connective tissue stain and examined with light microscopy. Serial sections were projected from an overhead »Projektiskop« and ridge patterns were then serially reconstructed. Ridge configurations were then classified as whorl, loop, or arch as described above.

Measurements of epidermal ridge dimension as well as various volar pad and bone dimensions were made on individual sections using a Vicker's image-splitting eyepiece micrometer. Multiple measurements of epidermal ridge dimensions were taken adjacent to distal to and proximal to the core. From their initial appearance approximately 10—11 weeks post-fertilization, growth of primary ridges can be divided into three basic components, the actual width of the primary ridge (PRW), the depth of penetration of the primary ridge into the dermis (PRD), and the width of separation between adjacent primary ridges (IRW).

The size and shape of the volar pad was measured using two methods. First, the width of the pad was made using the maximum width of digit at the midpoint of the distal phalanx. The height of the volar pad was measured as the maximum distal from the volar surface to the midpoint of the underlying distal phalanx. Asymmetry of the volar pad was determined by measuring the width of dermis both radial and ulnar to the midpoint of the distal phalanx. The ratio of ulnar dermal width to radial dermal width, then, defined the asymmetry of the volar pad. A higher ratio indicates asymmetry of the pad to the ulnar side of the digit.

The potential role of the underlying distal phalanx was examined using the measures of maximal length and width of the distal phalangeal tuft. A ratio of these two measures defined an index of distal phalangeal shape. Three measures of overall skeletal size were computed. These were maximum length of the metacarpal, length of the bone collar surroundings the metacarpal and width of the metacarpal at midshaft.

Results

Dermal ridge dimension and digit morphology

The three epidermal dimensions — primary ridge width, primary ridge, depth and interridge width — define the basic morphology of the primary ridge Previously, we have shown that specific ridge dimensions, i. e. ridge depth and interridge width, may vary in respect to population and pregnancy outcome.[10] Since ridge dimensions demonstrate significant variability, the relationship of epidermal ridge dimension to other dimensions of the digit, in particular to the size and shape of both the volar pad and distal phalanx, may provide insight into the origins of human variability in dermatoglyphic traits. Pearson product-moment correlations were computed between each ridge dimension and the dimensions of the volar pad, distal phalanx as well as the corresponding metacarpal of each digit. All dimensions were significantly correlated with each other as well as with age, i. e. CRL. Therefore, partial correlation procedures ere used to adjust for increasing age (CRL). Partial correlations for epidermal dimension and digit dimension are shown in Table 1. Length of the distal phalanx and metacarpal are significantly correlated with primary ridge

TABLE 1.

PARTIAL CORRELATIONS BETWEEN RIDGE DIMENSIONS AND THE GROWING HAND (ADJUSTED FOR CROWN-RUMP LENGTH)

	PR Width	IR Width	PR Depth
	Distal Phalanx		
Length	.318*	.361*	.157
Tuft Width	.040	.129	—
	Metacarpal		
Length	.346*	.469*	.596*
Bone Collar Length	.247	.309*	.226
Width	—.133	.136	—
	Volar Pad		
Height	.251	—.025	—.163
Width	.334*	.449*	.279

* Statistical significance at $p < .01$.

dimensions. Width of the tuft or metacarpal was not significantly correlated with ridge dimension. Interestingly, volar pad width but not height was significantly correlated with ridge dimension. These data suggest that epidermal ridge morphology is significantly related to size and/or shape of the digit.

The volar pad and ridge configuration

Recent studies have suggested that volar pad shape may be an important factor in determination of ridge configuration. In order to examine this hypothesis, only young prenates with active primary ridge formation were included. Active primary ridge formation was defined as no secondary ridges present. In Table 2, the mean volar pad height and width for each type of pattern are given. As can be seen, there was no significant difference in volar pad height associated with pattern type. There was a trend toward a low pad associated with arches, however, this was not significant at the $p < .05$ level. Volar pad width, however, did show a significant association with pattern type. Specifically, narow pads were associated with whorls. The mean pad widths for arches and loops, respectively, were 2.01 and 1.53 mm while the mean pad width for whorls was 1.14 mm. To test this association between volar pad width and pattern type, an analysis of covariance (adjusted for CRL) for volar pad width and pattern type was computed to adjust for the possible effects of increasing size with age. Analysis of covariance also supports significant differences in volar pad width associated with pattern type (Table 3).

TABLE 2.

VOLAR PAD DIMENSION AND PATTERN TYPE DURING EARLY RIDGE DEVELOPMENT

	Arch		Loop		Whorl	
	Mean*	SE	Mean	SE	Mean	SE
Pad Height	.73	.10	.94	.09	.94	.10
Pad Width	2.01	.11	1.53	.07	1.14**	.06

* Measurement in mm.
** Statistically different from the other patterns at $p < .01$.

The association of volar pad asymmetry and pattern type is shown in Table 4. Both arches and whorls show no significant differences in the volar pad index, index values of .95 and .95, respectively. However, a significant difference in pad index is found between radial and ulnar loops. The lower volar pad index for radial loops suggests that the volar pad may be displaced to the radial side of the digit.

The distal phalanx and ridge configuration

The significant correlations between length of the bony distal phalanx and primary ridge dimension suggests that shape of the underlying bony skeleton may be a factor in determining ridge configuration. In order to examine this hypothesis, only young prenates with active primary ridge formation were included. Using analysis of covariance procedures to adjust for increasing size due to age, no significant differences between pattern types was found for either length of the distal phalanx or width of the tuft. To examine the potential role of bone shape, the distal phalanx (DP) shape index was used. This index was defined as the ratio of tuft width to distal phalanx length. The shape of the distal portion of the digit was described

TABLE 3.

ANALYSIS OF COVARIANCE (ADJUSTED FOR CRL) FOR VOLAR PAD WIDTH DURING RIDGE DEVELOPMENT

Source	df	SS	F-ratio	P
Pattern	2	.812	4.908	.009
CRL	1	27.254	329.336	.000
Error	122	10.096		

TABLE 4.

VOLAR PAD SHAPE AND PATTERN TYPE

	Radial Loop (N = 5)		Ulnar Loop (N = 60)	
	Mean*	SE	Mean	SE
Pad Symmetry	.85	.04	.97**	.07
DP Shape	.35	.02	.44**	.02

* Measurement in mm.
** Statistically different from radial loop at $p < .05$.

by two additional indices. The digit shape index was defined as the ratio of volar pad width to distal phalanx length. The tuft shape index was defined as the ratio of volar pad width to tuft width. The mean ratios for pattern type during active primary ridge formation are given in Table 5. No significant differences among patterns was found.

Additional analysis of the distal phalanx shape index, however, suggests that radial loops may reflect a unique shape of the distal phalanx (Table 4). The mean ratio of tuft width to phalanx length was .35 for radial loops versus .44 for ulnar loops. The ratio for radial loops is also significant less than mean ratios for arches and whorls. It should be noted that interpretation of the analyses on asymmetry of loops must be guarded since the sample size for radial loops is small (N = 5).

Discussion

Variation in dermatoglyphic traits is well documented. Similarly, we have previously demonstrated prenatally not only differences in digital patterns but also population and pregnancy outcome differences in the growth of specific epidermal ridge dimensions as well as in the development of dermal ridges.[10,11] Cummins[12] first suggested that ridge

TABLE 5.

DIGIT SHAPE AND PATTERN TYPE DURING EARLY RIDGE DEVELOPMENT

	Arch		Loop		Whorl	
	Mean*	SE	Mean	SE	Mean	SE
DP Shape	.46	.04	.44	.02	.42	.04
Digit Shape	.97	.11	.89	.03	.93	.04
Tuft Dermis I	2.15	.18	2.10	.12	2.36	.15

* Measurement in mm.

configuration was determined by the shape of the volar pad. Mulvihill and Smith[7] proposed a similar model to explain the development of ridge configuration. Recently, Elie[8] elaborated on this theory. The results of this study suggest that the volar pad, indeed, may play an important role in determination of digital ridge configuration. What is surprising, however, is the finding that it is not necessarily the height of the volar pad that determines pattern type, but rather the width of the pad. In this light, the height of the pad must be considered relative to pad width. These findings in concert with the recent theoretical work of Elie[8] underscore the need for an understanding of the developmental factors underlying ridge configuration.

Due to the method of preparation, the data of this study did not include height and widths of each pad. Rather one or the other measurement was taken. Therefore, these findings reflect sample means. Nevertheless, these data strongly support the hypothesis that volar pad shape is a factor in the determination of ridge configuration. Similarly, pad asymmetry appears to play a role in determination of radial or ulnar loops. It is interesting to note that the mean pad asymmetry index values for all pattern types were all less than 1.0, suggesting that there is a »natural asymmetry« to the volar surface. This typical situation is consistent with the high frequency of ulnar loops observed on the digits.

If volar pad topography is basic to ridge pattern, then our next questions must ask what factors influence pad shape. The significant association of radial loops with significantly unique shape of the distal phalanx as well as significant correlations between epidermal ridge dimension and size of the distal phalanx suggest that the underlying bony skeleton at the time of ridge formation is also a factor in determination of ridge configuration. Obviously this is an area in need of further research.

While shape of the volar pad and bony morphology may play a role in determining ridge configuration, recent work by Dell and Munger[13] suggests that the dermatotopic map of the developing cutaneous innervation of the volar surface may also play a role in ridge configuration. However, it is unclear what factors may determine the dermatotopic map of innervation. While shape of the volar pad may not be the sole determinant of ridge configuration, it apparently is critical at the time of ridge formation in influencing the course of ridges. The delineation of factors which may influence pad shape is the logical next step.

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W. J. Babler

Department of Anatomy, Baylor College of Dentistry, 3302 Gaston Avenue, Dallas, Texas 75246, USA