Digital Dermatoglyphic Heritability Differences as Evidenced by a Female Twin Study

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The genetic and environmental contributions to determine digital dermatoglyphic traits were investigated by using female dizygotic and monozygotic twin pairs to estimate heritability indexes (h^2). The evaluated sample was composed by 20 monozygotic twin pairs and 13 dizygotic twin pairs. A significant heritability ($h^2 = 0.65$ to 0.96) was observed for 12 dermatoglyphic characteristics (delta indexes and ridge counts for right hand, left hand and both hands, and ridge counts for most individual fingers). A negative correlation between the ridge counts and heritability indexes from individual fingers was found for the left hand, which appears to be associated to a higher arch pattern frequency in most left-hand fingers, since this frequency was negatively correlated with ridge counts and positively correlated with heritability indexes. Heritability indexes of right-hand fingers were positively correlated with loop pattern frequency and negatively correlated with whorl pattern frequency. The low heritability of ridge counts from left thumb, ring and little fingers ($h^2 = 0.11$ to 0.32) indicates a higher chance that the chorion type had an influence in the intra-pair variance of monozygotic twins. Results confirmed the predominant genetic influence on the total ridge count. The heritability indexes varied in up to 8 times between different fingers and its association to ridge counts and pattern frequency was very variable between hands, evidencing that the use of dermatoglyphic traits from individual fingers as indicators of genetic influences to other human traits should consider this variability.

Keywords: dermatoglyphics, twin method, heritability, pattern frequency

The digital dermatoglyphics used for one of the most mature biometric technologies (fingerprints) have their general characteristics determined mainly by genes (Holt, 1960; Jain et al., 2002; Reed et al., 2006; Reed & Young, 1982; Sengupta & Karmakar, 2004).

Morphogenesis of digital dermatoglyphics pattern is most commonly understood with reference to the ridge-formation/pad-regression model, in which the size and shape of volar pad at the time of ridge differentiation are considered as factors influencing the ultimate ridge pattern (Babler, 1987; Jantz, 1987; Mulvihill & Smith, 1969). Alternatively, Kücken & Newell (2005) reported that a mechanical instability in the fetal epidermis is the most likely candidate for the physical process that creates digital dermatoglyphic traits, being the patterns created as the result of a buckling instability in the basal cell layer of the fetal epidermis, buckling direction is perpendicular to the direction of greatest stress in the basal layer, as this stress is induced by resistance of furrows and creases to the differential growth of the basal layer and regression of the volar pads during the time of ridge formation. However, even considering that each finger is influenced by the same genetic factors, it is important to note that they are not affected in the same way (Nagy & Pap, 2005).

Dermatoglyphic characteristics arise when the finger skin starts to become differentiated, being totally formed by 7 months of fetal development, and the finger ridge configuration does not change during the lifetime of an individual except in the case of accidents (Jain et al., 2002). Consequently, their characteristics are useful for the analyses of environmental and genetic factors that influence prenatal development (Cantor et al., 1983). On the other hand, the amniotic fluid flow around the fetus and its position in the uterus change during the differentiation process and the cells from the tip of the fingers grow

in a microenvironment that are somewhat different from hand to hand and from finger to finger (Jain et al., 2002). The thinner dermatoglyphics details are partly determined by this changing microenvironment. Small variabilities in the microenvironment are amplified by the cells differentiation process. Because of this, it is noteworthy that a genetic analysis based only in the total number of dermatoglyphic ridges do not consider the differences between fingers, since individuals and populations with the same total ridge counts must have significant differences between the ridge counts of different fingers (Roberts & Coope, 1979).

Many works in biology, psychology and medicine have employed the classical twin study method, which play an important role in evaluating the genetic and environmental causes of individual differences, since the components of the intra-pair variance and between-pair variance of twins involve different proportions of the environmental and genetic contributions in the monozygotic and dizygotic pairs (Martin et al., 1997; Neale, 1998). This method has allowed a quantitative statistical evaluation of the heritability of characteristics that show high or low stability during human lifetime, for example, considering recent studies involving blood pressure (Greenfield et al., 2003; Hernelathi et al., 2004), physical qualities (Calvo et al., 2002; De Mars et al., 2007), somatotype (Peeters et al., 2003; Reis et al., 2007) and psychological characteristics (Bratko & Butkovic, 2007; Lykken, 2007).

The same principles may be applied to studies evaluating the heritability of dermatoglyphic traits (Martin et al., 1982a; Reed et al., 2006). This may be particularly interesting because dermatoglyphics can be used as indicators of genetic influences to other variables when they are related, for example, when studying anthropometric characteristics related with human health (Godfrey et al., 1993; Kahn et al., 2001). Therefore, the present study aims to investigate the digital dermatoglyphics heritability, calculating heritability indexes by using measures from pairs of monozygotic (MZ) and dizygotic (DZ) female twins.

Material and Methods

Subjects

The sample for this study was 33 Caucasian female twins pairs, being 20 MZ pairs and 13 DZ pairs, aged between 6 and 26 years. The participants average ages (± standard deviation) were 16.6 ± 6.6 years (MZ) and 13.4 ± 5.4 years (DZ). This work followed Research Rules for Humans Beings, as indicated by the Brazilian National Health Council. The procedures were approved by the Castelo Branco University Ethical Committee (UCB/RJ protocol 012/2004), all in accordance with the 1975 Declaration of Helsinki.

Procedures

The fingerprints were obtained and analyzed by using the Cummins & Midlo (1961) protocol, passing the fingerprint collector on distal phalanges of each fingers from both hands, taking care that a regular ink

layer had the surface covered. The delta (or triradius) index was calculated by the sum of the deltas from the ten fingers (D10). A delta is formed by three ridge systems converging to each other at an angle of approximately 120°. The sum of deltas from the right hand (D5R) and left hand (D5L) were also calculated. For these calculations, the following values for the drawing types were considered: value 0 (zero) for arch pattern (drawing without deltas), value 1 for the loop pattern (drawing with 1 delta) and value 2 for the double loop and for the whorl patterns (drawings with 2 deltas). Figure 1 demonstrates the dermatoglyphic patterns found in this study. More complex patterns (e.g., more than two deltas on a finger) were not found in the studied twins. The total ridge counts for both hands (TRC), the ridge counts of right (RCR) and left (RCL) hands, and ridge counts of the thumb (RCR1 and RCL1), index (RCR2 and RCL2), middle (RCR3 and RCL3), ring (RCR4 and RCL4) and little (RCR5 and RCL5) fingers were calculated, counting the ridges intercepted by a line joining the delta and the core. Dermatoglyphic minutiae was accounted when intercepted by this line. All dermatoglyphic counts were accomplished twice and the test-retest analyses reliability was ~0.99.

The zygosity has been determined by a parental questionnaire. The heritability was evaluated by the twin method. The heritability index (h^2) was calculated by using the intra-pair mean variance of MZ (σ^2_{MZ}) and DZ (σ^2_{DZ}) twins, through the formula (Clark, 1956):

$$h^2 = (\sigma^2_{DZ} - \sigma^2_{MZ}) / \sigma^2_{DZ}$$
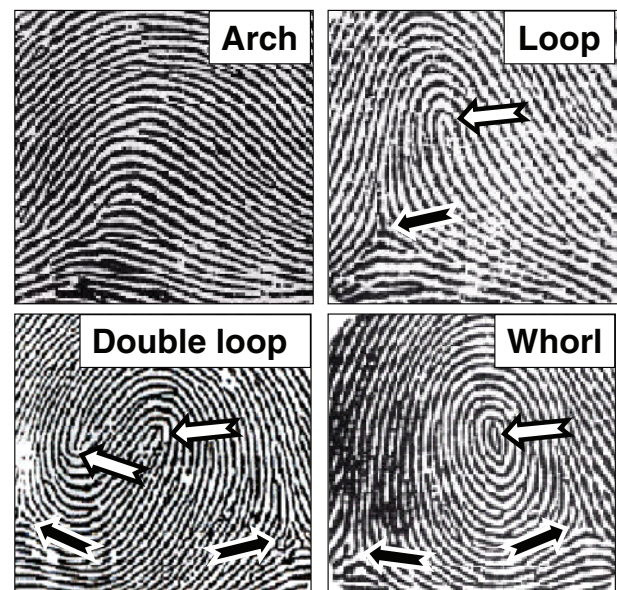
Figure 1

Pattern types of fingerprints found in this study. The white arrows indicate the cores and the black arrows indicate the deltas (or triradius).

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Statistics

Possible relationships between variables were evaluated with the Pearson's correlation coefficient and the Student t test was used to compare results from MZ and DZ twins. For the significance estimation of heritability indexes, the differences between intra-pair variabilities of MZ and DZ twins were analyzed by a F statistics, calculated as the ratio between the mean variance of DZ pairs and the mean variance of MZ pairs (Clark, 1956; Ghio et al., 1989; Reis et al., 2007). The significance threshold was the 0.05 p level.

Results

The results observed for D10, D5R, D5L, TRC, RCR, RCL and the ridge counts of each finger, found for MZ and DZ twins, are shown in Table 1. The groups MZ and DZ showed mean values with significant statistical differences only for the variables RCR5, RCL2 and RCL5, which presented higher values in DZ twins.

Table 2 shows the intra-par mean variance (σ^2) of results found for MZ and DZ twins, F statistics and heritability indexes (h^2). The MZ twins showed intra-par variances significantly lower than DZ twins for most variables. Significant heritability was observed for D10 ($h^2 = 0.87$), D5R ($h^2 = 0.80$), D5L ($h^2 = 0.71$), TRC ($h^2 = 0.96$), RCR ($h^2 = 0.92$), RCL ($h^2 = 0.84$), RCR2 ($h^2 = 0.66$), RCR3 ($h^2 = 0.74$), RCR4 ($h^2 = 0.70$), RCR5 ($h^2 = 0.84$), RCL2 ($h^2 = 0.65$) and RCL3 ($h^2 = 0.74$). These results indicate that variables derived from sums of data from individual fingers show higher heritability than data from each finger, except for RCR5 that showed a heritability index equal to that presented by RCL. The variables RCR1,

RCL1, RCL4 and RCL5 did not show significant differences among the twin groups, although RCR1 showed a predominant genetic influence ($h^2 = 0.57$), while the other three presented a higher environmental influence ($h^2 = 0.11$ to 0.32).

A significant negative correlation was found between the mean ridge counts of each finger and its heritability for left-hand fingers ($r = -0.92$; $p = .026$, Figure 2A), but not for right-hand fingers ($r = -0.52$; $p = .365$, Figure 2B) and when fingers from both hands were considered ($r = -0.29$; $p = .409$, Figure 2C). These results show a general tendency of an inverse relation between the ridge counts of each finger and its heritability, which was stronger for the left hand.

The frequencies of dermatoglyphic patterns in individual fingers and all pooled fingers were generally variable between hands, particularly for the thumb and little fingers (Table 3). Arch pattern frequency was negatively correlated with ridge counts ($r = -0.91$; $p = .03$, Figure 3A) and positively correlated with heritability indexes ($r = 0.97$; $p = .006$, Figure 4A) for the left-hand fingers. Right-hand fingers presented no significant correlation between pattern frequencies and ridge counts (Figure 3B), while their heritability indexes (Figure 4B) were positively correlated with loop pattern frequency ($r = 0.94$; $p = .02$) and negatively correlated with whorl pattern frequency ($r = -0.96$; $p = 0.01$). Pooled dermatoglyphic pattern frequencies from both hands did not show any significant correlation with ridge counts and heritability indexes (Figures 3C and 4C).

Table 1

Mean and Standard Deviation (SD) Values for Delta and Ridge Counts from Monozygotic (MZ) & Dizygotic (DZ) Groups, and Results of a t-test Comparing These Results

| | MZ | | DZ | | t test | |
	Mean	SD	Mean	SD	t value	p
D10	11.03	3.52	11.65	3.69	-0.70	0.49
D5R	5.59	1.82	6.04	1.87	-1.01	0.32
D5L	5.45	2.01	5.62	1.92	-0.33	0.74
TRC	85.06	42.99	103.81	46.40	-1.68	0.10
RCR	45.35	22.23	53.96	24.62	-1.47	0.15
RCL	39.71	22.25	49.85	23.24	-1.78	0.08
RCR1	12.98	5.29	13.38	6.32	-0.28	0.78
RCR2	6.89	5.69	9.06	6.09	-1.47	0.15
RCR3	7.33	5.67	8.46	6.07	-0.77	0.44
RCR4	9.65	6.25	11.90	5.30	-1.52	0.13
RCR5	8.51	4.31	11.54	5.41	-2.52*	0.01
RCL1	10.88	5.96	11.44	5.90	-0.38	0.71
RCL2	5.16	5.56	8.81	5.73	-2.57*	0.01
RCL3	6.36	5.12	7.73	5.79	-1.01	0.32
RCL4	8.69	6.47	10.54	6.35	-1.14	0.26
RCL5	8.63	5.10	11.33	4.42	-2.21*	0.03

Note: * Statistically significant ($p < .05$)

Table 2

Intra-Pair Mean Variance (σ^2) Found for Delta and Ridge Counts from Monozygotic (MZ) and Dizygotic (DZ) Groups, *F* Statistics and Heritability Indexes (h^2)

	σ^2_{MZ}	σ^2_{DZ}	F	h^2
D10	1.23	9.12	7.44*	0.87
D5R	0.48	2.42	5.10*	0.80
D5L	0.70	2.38	3.41*	0.71
TRC	31.5	838.3	26.6*	0.96
RCR	26.8	326.6	12.2*	0.92
RCL	28.7	179.4	6.24*	0.84
RCR1	9.01	20.8	2.30	0.57
RCR2	8.38	24.9	2.97*	0.66
RCR3	5.23	20.3	3.89*	0.74
RCR4	5.99	20.2	3.37*	0.70
RCR5	3.68	22.5	6.10*	0.84
RCL1	6.00	7.47	1.25	0.20
RCL2	8.13	23.0	2.83*	0.65
RCL3	4.21	10.5	2.50*	0.60
RCL4	14.2	20.9	1.47	0.32
RCL5	6.58	7.39	1.12	0.11

Note: * Statistically significant ($p < .05$)
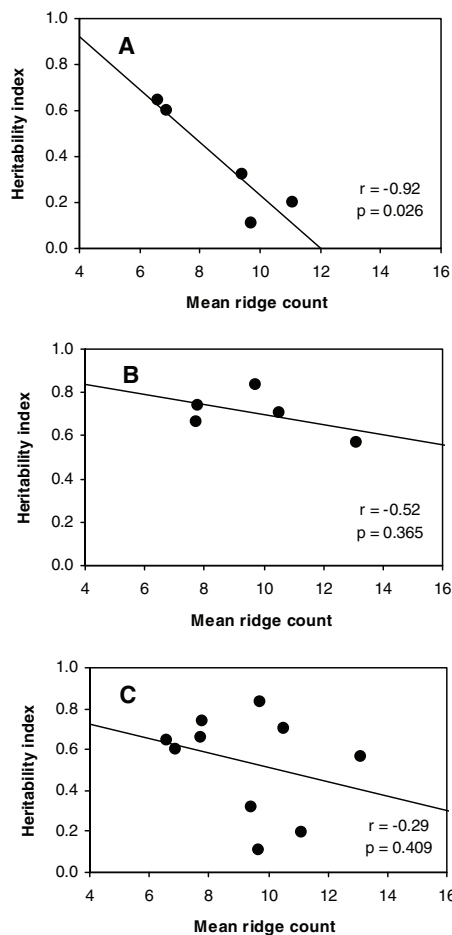
Figure 2

Correlations of heritability indexes with the mean ridge counts from the left hand (A), right hand (B) and both hands (C).
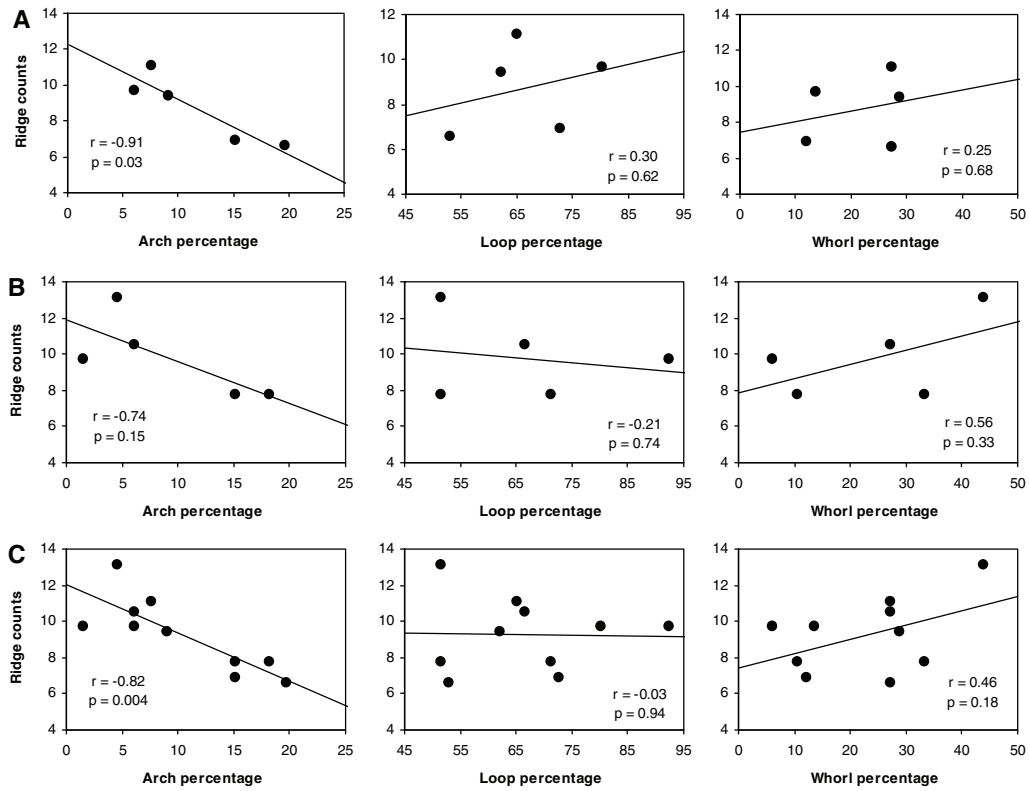
Table 3

Occurrences of Dermatoglyphic Patterns in Each Finger (F1-F5) and All Fingers From Right and Left Hands of the 66 Twins Studied — Percent Frequencies are Showed Between Parentheses

|	Arch		Loop		Whorl	
	Right	Left	Right	Left	Right	Left
F1	3 (4.5%)	5 (7.6%)	34 (52%)	43 (65%)	29 (44%)	18 (27%)
F2	10 (15%)	13 (20%)	34 (52%)	35 (53%)	22 (33%)	18 (27%)
F3	12 (18%)	10 (15%)	47 (71%)	48 (73%)	7 (11%)	8 (12%)
F4	4 (6.1%)	6 (9.1%)	44 (67%)	41 (62%)	18 (27%)	19 (29%)
F5	1 (1.5%)	4 (6.1%)	62 (94%)	53 (80%)	3 (4.5%)	9 (14%)
All	30 (9.1%)	38 (11.5%)	221 (67%)	220 (67%)	79 (24%)	72 (22%)

Discussion

The present study evaluated the genetic and environmental influences on dermatoglyphic traits, generally demonstrating an elevated importance of the genetic effect, in agreement with previous studies (Cantor et al., 1983; Holt, 1979; Martin et al., 1982a; Reed et al., 2006; Sengupta & Karmakar, 2004). It was shown that there were substantial differences in the dermatoglyphic heritability among fingers. These differences between fingers are expected, because there are so many variations during the dermatoglyphics formation that would be virtually impossible to observe two similar dermatoglyphics, influencing the proportion between genetic and environmental effects.

The left-hand thumb, ring and little fingers and right-hand thumb presented the lowest heritability values. Even considering that dermatoglyphics are differentiated by the same gene they also will not have

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Figure 3

Correlations of mean ridge counts from the left hand (row A), right hand (row B) and both hands (row C) with the dermatoglyphic pattern percentage.
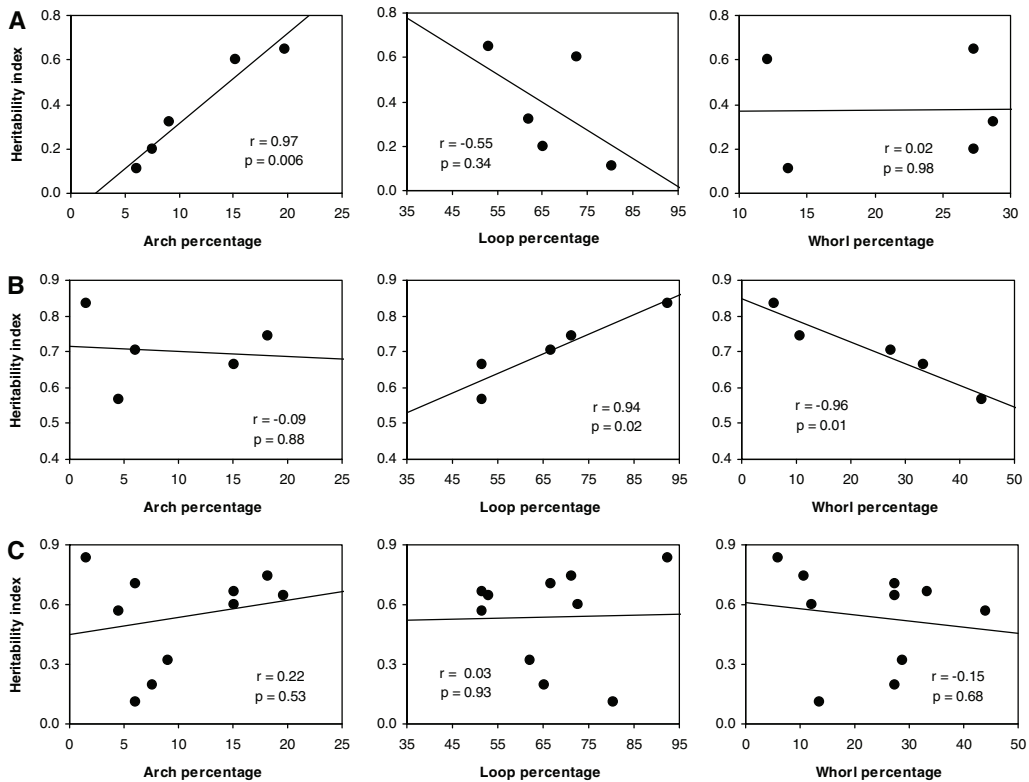
Figure 4

Correlations of heritability indexes from the left hand (row A), right hand (row B) and both hands (row C) with the dermatoglyphic pattern percentage.

totally random patterns and each fetus find different intra-uterine environments, resulting in different microdetails (Jain et al., 2002), being the environmental effects on individual finger ridge counts largely uncorrelated (Cantor et al., 1983). Reed et al. (1979) suggested that the thumb and little fingers on the lateral border of the hand may be in closest contact with the intrauterine environment. Cantor et al. (1983) concluded that these fingers were each controlled by different additive genes from those involved in other fingers and were vulnerable to environmental impacts (maternal effects) within the uterus. Maternal influences in the thumb traits were pointed out by Reed & Young (1982), considering that thumb dermatoglyphics showed unequal total variance in MZ versus DZ twins, differences in within pair mean squares between dichorionic and monochorionic MZ twins, and evidence for maternal effect in half-sibships. The unequal total variance in MZ versus DZ twins was also noted for other fingers by the same authors, except for the left little finger pattern. At least to our knowledge, the variability in the exposure time to intra-uterine environment between fingers is unknown, but such variability is a potential additional concern in understanding the environmental effects on the studied traits.

The h^2 values found in the present study were lower than those from the Martin et al. (1982a) study for male (0.94) and female (0.97) twins, with some few exceptions. The RCR3 and RCR5 showed higher heritability than those of the compared male group, RCR5 presented similar heritability to that of the compared female group, while RCL2 showed higher heritability than that of the compared female group. Heritability values of TRC found in the Martin et al. (1982a) study for male and female twins and the Sengupta & Karmakar (2004) study for male and female siblings, evidenced that there was a higher heritability in females in both twin and sibling studies. This elevated heritability presented by females was also found in the present study ($h^2 = 0.96$), similarly to the heritability index ($h^2 = 0.97$) found for the female twin pairs studied by Martin et al. (1982a).

Cantor et al. (1983) indicated that the total ridge counts have a higher heritability than the ridge counts of each hand, and ridge counts from each hand have a higher heritability than those of the individual fingers. The only exception to this tendency in the present study was observed for the ridge counts of the little finger from right hand, which showed a h^2 value equal to that of the left-hand ridge counts ($h^2 = 0.84$). Following the general tendency, the total ridge counts showed a heritability value higher than was found for each hand, as was observed in relation to deltas.

Dermatoglyphic traits may present considerable asymmetry (Kimura & Carson, 1995; Martin et al., 1982b). The correlations between heritability indexes, ridge counts and pattern frequencies (Figures 2–4) appear to reflect a deviation from bilateral symmetry.

The negative correlation between the ridge counts and heritability indexes from individual fingers found for the left hand is in agreement with the expected high heritability associated to the arch pattern (Reed et al., 2006), since arch pattern frequency was negatively correlated with ridge counts and positively correlated with heritability indexes. This was not the case of right-hand fingers, for which there was no significant correlation of arch pattern frequency with ridge counts and heritability, which is attributable to a tendency of lower arch frequency in these fingers than observed for left hand, except for the middle finger (Table 3). In this case, the frequencies of loop and whorl patterns have a much more important association to heritability indexes.

Previous studies that employed much larger samples have reported much higher heritabilities for RCL4 and RCL5 (Martin et al., 1982a), and significant correlations (0.76 to 0.82) between homologous digits from different hands (Medland et al., 2007). The preliminary results found for the ring and little fingers from the left hand in the present study were quite low, in disagreement with Martin et al. (1982a), and appear to be highly influenced by a low ach pattern frequency. Although the correlations between ridge counts from homologous digits have been also significant for the female twins studied (0.61 to 0.87; $p < 0.01$), these correlations were more variable than those reported by Medland et al. (2007). These differences may be reflecting a higher data heterogeneity in the smaller sample studied.

These results indicate that care is necessary in applying dermatoglyphic traits of individual fingers as indicators of genetic influences to other human traits. The variability of possible correlations between dermatoglyphics from different fingers and other traits should be taken into account in order to investigate their application (Kahn et al., 2001), considering that dermatoglyphic traits asymmetry can be largely affected by environmental effects, as pointed out by Martin et al. (1982b) for ridge counts.

There are many evidences that intra-uterine influences related to placental proximity can cause differences between MZ twins, creating a necessity of evaluate the type of chorion in that twins have been developed, in relation to various human characteristics, such as anthropometric indexes (Loos et al., 2001; Race et al., 2006). However, the effect can occur in both directions, making the monochorionic MZ (MCMZ) twins more or less similar than the dichorionic MZ (DCMZ) twins (Martin et al., 1997), as it was observed in relation to dermatoglyphics by Reed et al. (1978). These authors found that for 84 dermatoglyphics variables, 19 showed significant intra-pair differences between MCMZ and DCMZ twins.

There is little information about the chorionicity in studies of dermatoglyphic heritability, for example, in relation to ridge counts (Reed et al., 1978), a-b ridges counts (Bogle et al., 1994) and arch pattern (Reed et

al., 2006). The Reed et al. (1978) study indicated that there was no chorionicity influence on the twin method in relation to left-hand thumb, since no significant difference between MCMZ and DCMZ twins was observed, whereas for the right hand thumb there was a significant difference between MCMZ and DCMZ twins and a chorionicity influence could occur. In relation to index and middle fingers, it could be expected that there is a chorionicity influence on the using of twin method in both hands. These differing trends between fingers may possibly contribute in the explanation to why in the present study the thumb heritability was highly contrasting in different hands.

Although the chorion type can influence the intra-pair differences between MZ and DZ twins, when the environmental variances are a small portion of total variance, this effect will not cause major disturbance in the twin study estimates (Martin et al. 1982a). However, although there is no information about the chorion types of the studied MZ group, the ridge counts of the thumb, ring and little fingers from the left hand had a low heritability (h^2 = 0.11 to 0.32), suggesting a higher chance that chorionicity affects the intra-pair variance in MZ twins. An evaluation of this possible influence in future studies would be useful for a better comprehension of the intra-uterine environment effects on dermatoglyphic traits of moderate and low heritability levels.

Acknowledgments

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