Austin Journal of Forensic Science and Criminology

Open Access

Austin Publishing Group

Research Article

Shape Variations in Loop Pattern Fingerprints: Radial vs. Ulnar Loops

Králík M*, Kováčová V, Hupková A and Urbanová P

Department of Anthropology, Masaryk University, Czech Republic

***Corresponding author:** Králík M, Department of Anthropology, Laboratory of Morphology and Forensic Anthropology (LaMorFA), Masaryk University, Kotlářská 267/2, 611 37, Brno, Czech Republic, Tel: 00420-549-49-4966; Email: mirekkralik@seznam.cz

Received: October 21, 2014; **Accepted:** January 02, 2015; **Published:** February 16, 2015

Abstract

Loops are very common categories of fingerprint patterns found on terminal phalanges of the human hand. Their assessment is paramount in the process of police fingerprint identification. A detailed classification system capable of distinguishing between radial and ulnar loops, loops of right and left hand, or those of thumb and other fingers would largely benefit to cases where only a single loop is secured at crime scene. The aim of our pilot study was to assess differences in size and shape of radial and ulnar loops. We explored morphological variations in the sample of 489 loop ink fingerprints using 20 distance measurements and indices and Fourier shape analysis. Our results show that there are systematic size and shape differences between radial and ulnar loops on index fingers, primarily concentrated in the course of the distal type line. If developed further the proposed methodology, particularly if directed at advanced methods of geometric morphometrics, may find practical usage in differentiating fingerprint patterns in police/forensic fingerprint investigation.

Keywords: Fingerprint patterns; Ulnar loop; Radial loop; Radio-ulnar asymmetry; Shape variations; Fourier analysis

Introduction

Fingerprint patterns called *loops* (simple loops) characterized by one *triradius* (or *delta*) and one *core* are very common in most of the human populations. Moreover, for some human groups they represent the most frequent patterns of fingers´ terminal phalanges [1,2]. Based on their orientation towards axis of distal phalanx or according to the direction of the cauda of the pattern (Figure 1), two principally opposite categories of loops can be distinguished. In *ulnar loops* cauda is directed towards the ulnar side of the finger (the little finger), whereas in *radial loops* cauda is directed towards the radial side of the finger (the thumb).

Development of particular fingerprint pattern (large vs. small, symmetrical vs. asymmetrical, simple vs. complex) depends on the size and position of embryonic pads, as well as timing of regression of these pads at the time when the process of histological differentiation takes place. The differentiation of epidermis-corium connection which gives origin to epidermal ridges occurs in the 10^{th} to 16^{th} weeks of gestation ([3,4] for review). The legitimacy of this model of the formation of epidermal ridges was also confirmed by computer modeling [5]. Katzenmeier [6,7] found that in adults the radio-ulnar asymmetry of fingerprint patterns on the distal phalanges (as measured by radio-ulnar difference in fingerprint *ridge counts*) is closely related to the radio-ulnar cross-sectional asymmetry of the shape of the entire terminal phalanx. The phalanges asymmetrical to the ulnar side (larger ulnar side of transversal cross-section area of the finger) are typically associated with ulnar loops and whorls asymmetrical to ulnar side as opposed to radially asymmetrical phalanges, which bear radial loops and radially asymmetrical whorls. Moreover, radial loops are absent on symmetrical terminal phalanges and ulnar loops are never present on radially asymmetrical phalanges [7].

Radial and ulnar loops do not occur with the same frequency [2]. The vast majority of loops (among all loops of one person, as well as of a given finger in a population) are represented by *ulnar loops*. Ulnar loops are highly abundant in all fingers. In contrast, *radial loops* occur much less frequently, mostly on the index fingers and their frequency on other fingers is much lower with virtually zero frequency on the little fingers. The highest occurrence of the *radial loops* on the index finger was explained by radially asymmetrical position of the embryonic pad of the index finger, which is formed in a functional position against embryonic pad of the opposing thumb [8].

Due to their frequent presence on fingers, fingerprints of loops are important pieces of physical evidence in criminal investigation and forensic personal identification using fingerprinting. Assessment (presence, size) of loops is a part of some widely used fingerprint identification systems [9]. Frequently secured at crime scenes they also compose a large portion of fingerprints proceeded to automated

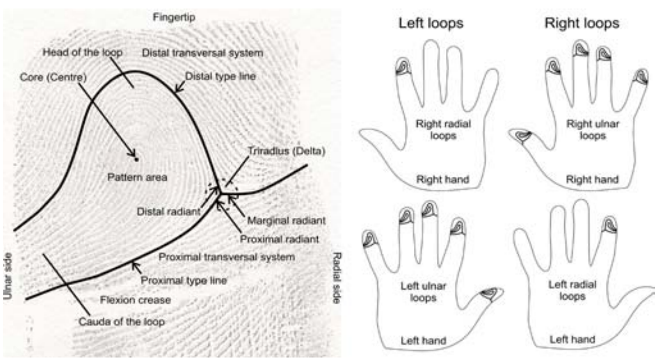

Figure 1: Left: Specification of points, lines and areas on loop patterns (fingerprint of left ulnar loop). Right: Differences between radial and ulnar loop pattern fingerprints depending on the hand side.

Citation: Králík M, Kováčová V, Hupková A and Urbanová P. Shape Variations in Loop Pattern Fingerprints: Radial vs. Ulnar Loops. Austin J Forensic Sci Criminol. 2015;2(1): 1013.

(AFIS) and manual fingerprint comparisons. With currently used scarce knowledge on side body differences it is impossible to differentiate radial from ulnar loops in crime-scene evidence. Radial loops from the right hand and ulnar loops from the left hand have the same orientation in fingerprints (with cauda oriented to the left) and *vice versa* (Figure 1). In result, each loop must be compared with all loops of the same orientation of cauda regardless their side origin. If, however, there were systematic shape differences between radial and ulnar loops, and these differences were large enough to create a practically (simply and quickly, with high probability) applicable method for differentiating radial and ulnar loops, it could largely beneficiate the fingerprinting workflow (labor and time-wise). In other words, if a radial loop were quickly determined in crime-scene evidence, it would be preferentially compared only with radial loops of a respective body side before proceeding in conjunction with a much larger pool of ulnar loops from the opposite body side.

The main goal of this study was to explore size and shape variations of loop patterns in terminal phalanges of the human hand and to assess possible differences between radial and ulnar loops. In doing so, we introduce a new method which is based on distance measurements and advanced outline-based shape analysis and thus allows describing the shape of the loops in a comprehensive and detailed manner.

Materials and Methods

Subjects

The present study is based on the 489 loop pattern ink rolled fingerprints archived at Department of Anthropology, Faculty of Science, Masaryk University. The sample was collected from 104 individuals from the former Czechoslovak Republic involved in previous projects ([10]; and a sample of fingerprints from 1950's and 1960's paternity tests). For each individual, sex, age, hand, and finger from which the fingerprint comes from has been documented. The males were represented in the number of 52 individuals with an average age of 23 years (from 17 to 46 years) and 223 loop pattern fingerprints; the females in the number of 52 individuals with an average age of 22 years (from 18 to 30 years) and total number of 266 loop pattern fingerprints. The loops were divided into radial and ulnar loops according to the direction of the cauda of the pattern.

Fingerprints scanning and measurements

All fingerprints were scanned by standard flatbed scanner HP PSC 1400 All-in-One series (the image resolution was 1200 ppi). In order to outline the skeleton of the pattern, a grid of thirty two radii (with 11°15´ angle between lines) was created in vector graphic editor (Open Office Draw 3.3) and placed into each image (Figure 2). The centrum of this raster was positioned in the core of the pattern and one of the radii connected the core with the triradius. To express the distance of the pattern from the flexion crease, a straight line was marked on the distal part of the flexion line.

On each image, thirty-three measurement points (landmarks) were placed using morphometric software tpsUtil version 1.47 [11] and tpsDig2 version 2.16 [12] and their *x* and *y* coordinates digitized (Figure 2). Images of the loops with the cauda on its right side were horizontally flipped in order to unify the orientation of all fingerprints and to avoid side-related cognitive biases. In result, all loops had identical orientation regardless of body side (right, left) and original orientation (radial, ulnar) and to facilitate the visual comparison so had resulting statistical models (visual schemes). All images were digitized blindly, in random order by the same investigator (V.K.).

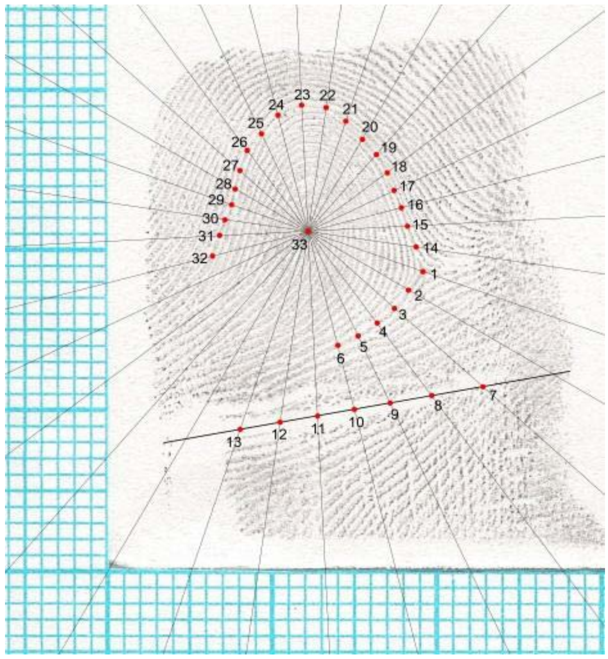

Figure 2: Determination of radial grid and measurement points on loop pattern.

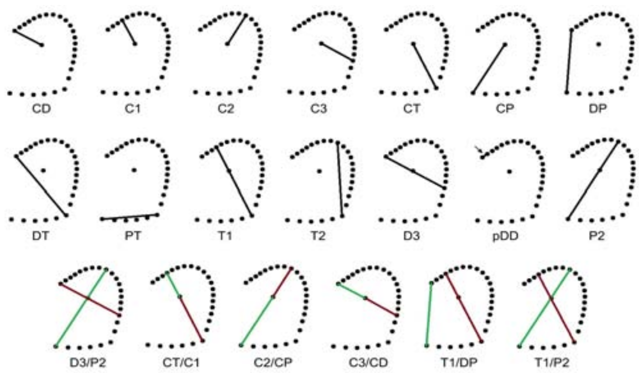

Figure 3: Measurements and ratios analyzed on loop fingerprint patterns.

Traditional morphometrics

Based on the collected landmarks, sixteen distances (14 length and width dimensions) were calculated using data analysis package PAST version 2.17c [13]. Following traits were defined as distances between two landmarks (Figure 3): CD (landmarks 32 and 33), C1 (29-33), C2 (24-33), C3 (16-33), CT (1-33), CP (6-33), DP (6-32), DT (1-32), PT (1-6), T1 (1-29), T2 (1-24), D3 (16- 32), pDD (31-32), P2 (6-24). Based on these dimensions, six ratios were calculated: D3/P2, CT/C1, C2/CP, C3/CD, T1/DP, T1/P2 (Figure 3).

For all twenty variables, differences between radial and ulnar loops were tested by two sample permutation test of differences in the R-software package [14] exact Rank Tests 0.8-27 [15], for males and females separately. Fingerprints were divided into groups

Table 1: Descriptive statistics of measured traits and results of permutation tests (right radial to left ulnar loops and left radial to right ulnar loops) on the index finger for females.

Females - Loops on the index finger														
	Left ulnar loops			Right radial loops			Perm. test	Left radial loops			Right ulnar loops			Perm. test
Trait	N	Mean	SD	N	Mean	SD	p	N	Mean	SD	N	Mean	SD	p
CD	17	2.67	0.93	8	4.51	2.35	0.009 *	14	4.41	2.80	15	3.94	2.67	0.592
C1	17	2.71	0.92	8	4.05	1.57	0.011 *	14	3.61	2.04	15	3.14	1.31	0.455
C2	17	3.72	1.31	8	4.47	1.80	0.261	14	4.16	2.19	15	4.03	1.25	0.833
C3	17	3.82	1.41	8	5.10	2.39	0.121	14	4.23	2.28	15	4.35	1.47	0.886
CT	17	6.08	2.18	8	7.27	2.66	0.237	14	5.84	2.89	15	5.86	1.91	0.964
CP	17	6.20	1.98	8	9.36	2.06	0.001 *	14	8.60	2.67	15	8.41	2.52	0.793
DP	17	7.83	2.51	8	10.43	2.27	0.020 *	14	8.65	3.20	15	7.80	2.09	0.429
DT	17	8.43	2.74	8	11.32	4.66	0.067	14	9.84	5.24	15	9.44	3.38	0.771
PT	17	6.55	2.22	8	8.40	1.87	0.074	14	6.70	2.63	15	5.91	1.77	0.398
T1	17	8.78	2.97	8	11.32	4.18	0.090	14	9.44	4.81	15	9.00	2.83	0.737
T2	17	8.73	3.00	8	10.41	3.86	0.258	14	8.78	4.32	15	8.76	2.50	1.000
D3	17	6.49	2.16	8	9.61	4.66	0.027 *	14	8.64	4.99	15	8.29	3.54	0.795
pDD	17	0.53	0.20	8	0.92	0.51	0.010 *	14	0.93	0.63	15	1.10	1.31	0.763
P2	17	11.02	3.52	8	13.67	3.06	0.084	14	11.39	4.31	15	10.34	2.67	0.433
D3/P2	17	0.61	0.18	8	0.69	0.29	0.413	14	0.73	0.27	15	0.85	0.40	0.341
CT/C1	17	2.26	0.56	8	1.83	0.24	0.052	14	1.84	0.57	15	2.02	0.76	0.390
C3/CD	17	1.46	0.39	8	1.18	0.18	0.077	14	1.14	0.39	15	1.34	0.55	0.229
C2/CP	17	0.53	0.14	8	0.50	0.21	0.650	14	0.60	0.31	15	0.69	0.28	0.401
T1/DP	17	1.13	0.22	8	1.08	0.30	0.638	14	1.07	0.27	15	1.16	0.21	0.343
T1/P2	17	0.80	0.14	8	0.82	0.21	0.859	14	0.80	0.19	15	0.88	0.15	0.293

Abbreviations: N - sample size, Mean - average value (in millimeters), SD - standard deviation, p - p-value (* marks statistical significant results at 5% level of significance), Perm. test - Permutation test.

Table 2: Descriptive statistics of measured traits and results of permutation tests (right radial to left ulnar loops and left radial to right ulnar loops) on the index finger for males.

Males - Loops on the index finger														
	Left ulnar loops			Right radial loops			Perm. test	Left radial loops			Right ulnar loops			Perm. test
Trait	N	Mean	SD	N	Mean	SD	p	N	Mean	SD	N	Mean	SD	p
CD	15	3.12	1.28	15	4.42	3.02	0.146	7	5.16	4.24	9	3.06	1.27	0.189
C1	15	3.14	1.16	15	3.96	2.57	0.269	7	4.26	3.24	9	2.96	1.29	0.266
C2	15	4.26	1.56	15	4.43	2.32	0.852	7	4.86	3.15	9	4.20	1.36	0.575
C3	15	4.47	1.57	15	4.86	2.67	0.632	7	5.10	3.54	9	4.31	1.68	0.583
CT	15	7.17	2.56	15	7.65	3.74	0.705	7	7.70	4.91	9	6.26	2.61	0.495
CP	15	9.00	2.62	15	7.04	2.51	0.056	7	7.45	2.76	9	8.93	2.29	0.298
DP	15	9.33	2.39	15	10.51	4.32	0.380	7	10.21	5.58	9	8.07	2.99	0.382
DT	15	9.92	3.36	15	11.63	6.19	0.373	7	12.37	8.49	9	8.96	3.60	0.333
PT	15	7.74	2.16	15	8.50	3.52	0.465	7	8.20	4.75	9	6.58	2.51	0.357
T1	15	10.31	3.53	15	11.61	6.07	0.481	7	11.96	7.92	9	9.21	3.82	0.382
T2	15	10.20	3.43	15	10.72	5.21	0.741	7	11.10	6.82	9	9.28	3.47	0.424
D3	15	7.60	2.68	15	9.28	5.55	0.292	7	10.27	7.73	9	7.36	2.90	0.327
pDD	15	0.63	0.28	15	0.87	0.60	0.157	7	1.05	0.86	9	0.61	0.25	0.176
P2	15	13.00	3.45	15	13.74	5.60	0.698	7	13.45	6.93	9	11.64	4.12	0.564
D3/P2	15	0.58	0.15	15	0.64	0.24	0.391	7	0.71	0.25	9	0.63	0.18	0.502
CT/C1	15	2.44	0.69	15	2.21	0.77	0.384	7	2.21	1.19	9	2.27	0.67	0.904
C3/CD	15	1.56	0.47	15	1.28	0.45	0.110	7	1.21	0.45	9	1.51	0.37	0.195
C2/CP	15	0.50	0.18	15	0.50	0.22	1.000	7	0.61	0.25	9	0.59	0.16	0.864
T1/DP	15	1.08	0.21	15	1.06	0.26	0.835	7	1.12	0.24	9	1.12	0.19	0.958
T1/P2	15	0.78	0.13	15	0.81	0.19	0.636	7	0.83	0.18	9	0.78	0.12	0.522

Abbreviations: N - sample size, Mean - average value (in millimeters), SD - standard deviation, p - p-value (* marks statistical significant results at 5% level of significance), Perm. test- Permutation test.

according to direction of cauda to the right directed and left directed and compared within each group (Figure 1). Thus, right hand radial loops were compared to left hand ulnar loops (both left directed in fingerprints) and left hand radial loops to right hand ulnar loops (both right directed in fingerprints). Statistically significant results were claimed at 5% level of significance and borderline results at 10% level of significance.

Table 3: Descriptive statistics of measured traits and results of permutation tests (right radial to left ulnar loops and left radial to right ulnar loops) on the pooled sample of loops from all five fingers for females.

Females - Loops from all five fingers														
	Left ulnar loops			Right radial loops			Perm. test	Left radial loops			Right ulnar loops			Perm. test
Trait	N	Mean	SD	N	Mean	SD	p	N	Mean	SD	N	Mean	SD	p
CD	122	3.25	1.42	10	4.11	2.26	0.084	16	4.43	2.84	118	4.07	2.19	0.523
C1	122	3.15	1.16	10	3.77	1.55	0.118	16	3.67	2.09	118	3.58	1.40	0.826
C2	122	4.32	1.61	10	4.26	1.72	0.913	16	4.23	2.29	118	4.81	1.51	0.188
C3	122	4.38	1.59	10	4.78	2.29	0.458	16	4.35	2.40	118	4.77	1.61	0.372
CT	122	6.57	2.22	10	6.88	2.68	0.631	16	5.94	2.82	118	6.57	2.04	0.293
CP	122	7.88	2.36	10	9.02	2.03	0.142	16	8.59	2.49	118	8.00	2.75	0.408
DP	122	8.39	2.37	10	9.64	2.93	0.115	16	9.31	3.62	118	8.81	2.49	0.489
DT	122	9.45	3.12	10	10.57	4.58	0.296	16	9.97	5.22	118	10.23	3.52	0.826
PT	122	6.96	2.11	10	7.79	2.37	0.245	16	7.28	3.14	118	6.96	2.02	0.583
T1	122	9.73	3.21	10	10.66	4.16	0.388	16	9.62	4.80	118	10.15	3.19	0.551
T2	122	9.67	3.21	10	9.89	3.82	0.835	16	8.95	4.36	118	10.05	2.91	0.194
D3	122	7.63	2.78	10	8.89	4.48	0.198	16	8.78	5.15	118	8.84	3.52	0.959
pDD	122	0.68	0.49	10	0.83	0.49	0.238	16	0.94	0.63	118	0.93	0.80	0.967
P2	122	11.94	3.47	10	12.81	3.73	0.444	16	12.10	4.48	118	12.41	3.22	0.723
D3/P2	122	0.66	0.22	10	0.69	0.26	0.682	16	0.71	0.30	118	0.73	0.26	0.846
CT/C1	122	2.20	0.68	10	1.85	0.25	0.111	16	1.85	0.57	118	1.97	0.70	0.361
C3/CD	122	1.45	0.44	10	1.22	0.19	0.089	16	1.15	0.37	118	1.31	0.45	0.167
C2/CP	122	0.59	0.20	10	0.53	0.20	0.350	16	0.59	0.33	118	0.67	0.22	0.230
T1/DP	122	1.16	0.23	10	1.12	0.29	0.610	16	1.04	0.31	118	1.16	0.21	0.055
T1/P2	122	0.82	0.15	10	0.83	0.19	0.809	16	0.79	0.22	118	0.82	0.15	0.480

Abbreviations: N - sample size, Mean - average value (in millimeters), SD - standard deviation, p - p-value (* marks statistical significant results at 5% level of significance), Perm. test- Permutation test.

Table 4: Descriptive statistics of measured traits and results of permutation tests (right radial to left ulnar loops and left radial to right ulnar loops) on the pooled sample of loops from all five fingers for males.

Males - Loops from all five fingers														
	Left ulnar loops			Right radial loops			Perm. test	Left radial loops			Right ulnar loops			Perm. test
Trait	N	Mean	SD	N	Mean	SD	p	N	Mean	SD	N	Mean	SD	p
CD	112	4.05	1.55	16	4.36	2.93	0.522	8	4.65	4.19	87	4.53	2.07	0.891
C1	112	3.96	1.36	16	3.99	2.48	0.944	8	3.88	3.19	87	4.09	1.65	0.749
C2	112	5.18	1.56	16	4.53	2.28	0.142	8	4.53	3.06	87	5.26	1.78	0.309
C3	112	5.33	1.75	16	4.91	2.58	0.398	8	4.70	3.47	87	5.19	1.93	0.531
CT	112	7.94	2.50	16	7.78	3.66	0.829	8	7.04	4.91	87	7.14	2.58	0.948
CP	112	8.65	2.69	16	6.99	2.43	0.022 *	8	7.74	2.68	87	9.65	6.93	0.202
DP	112	10.28	2.58	16	10.73	4.27	0.570	8	9.34	5.71	87	9.62	2.85	0.802
DT	112	11.53	3.54	16	11.70	5.99	0.873	8	11.25	8.48	87	11.20	4.06	0.980
PT	112	8.38	2.26	16	8.69	3.49	0.644	8	7.51	4.81	87	7.52	2.32	0.966
T1	112	11.91	3.64	16	11.77	5.90	0.901	8	10.92	7.90	87	11.23	4.00	0.859
T2	112	11.67	3.33	16	10.93	5.10	0.433	8	10.22	6.79	87	10.98	3.64	0.605
D3	112	9.38	3.10	16	9.27	5.36	0.899	8	9.34	7.62	87	9.72	3.76	0.825
pDD	112	0.83	0.34	16	0.86	0.58	0.782	8	0.94	0.85	87	0.95	0.49	0.992
P2	112	14.53	3.57	16	14.11	5.61	0.688	8	12.43	7.02	87	13.62	3.89	0.452
D3/P2	112	0.65	0.18	16	0.63	0.24	0.695	8	0.69	0.24	87	0.71	0.18	0.817
CT/C1	112	2.10	0.58	16	2.21	0.74	0.527	8	2.18	1.11	87	1.86	0.54	0.148
C3/CD	112	1.41	0.40	16	1.30	0.45	0.317	8	1.28	0.47	87	1.25	0.36	0.790
C2/CP	112	0.58	0.18	16	0.49	0.21	0.083	8	0.62	0.23	87	0.65	0.21	0.690
T1/DP	112	1.15	0.20	16	1.06	0.26	0.093	8	1.12	0.22	87	1.15	0.19	0.681
T1/P2	112	0.81	0.14	16	0.80	0.19	0.715	8	0.81	0.18	87	0.81	0.13	0.954

Abbreviations: N - sample size, Mean - average value (in millimeters), SD - standard deviation, p - p-value (* marks statistical significant results at 5% level of significance), Perm. test- Permutation test.

Shape analysis

Two dimensional (2D) Cartesian coordinates of 28 evenly spaced points along the loop outline were scaled according to values of metric scales. While 25 points (points 1-6 and 14-32) corresponded to the outline of each loop (skeleton of pattern), 1 point (point 33) corresponded to the pattern center (core) and was taken as the center of gravity to the studied shapes; two additional points corresponded to the endpoints of the flexion crease between middle and terminal phalanx (points 7 and 13). The set of Cartesian coordinates for each comparison was aligned so that endpoints of the flexion crease laidin the same line (not necessarily with an identical starting point). Once rotated the adjusted points were centered on the common center of gravity and scaled to the common centroid size (CS=1). The adjusted points corresponding to the loop outlines/curves were subject to Fourier analysis in order to extract Fourier coefficients. For traditional Fourier analysis a pair of Fourier coefficients (*a*, *b*) per harmonic is provided. For each shape the number of harmonics was set to 30 and altogether 61 coefficients (a constant and Fourier coefficients) per outline were computed. In addition to 25-point outline analysis, 19-point partial open outlines (points 1 and 14-32) which corresponded to distal loop curvatures (distal type line) were processed. The analysis was carried out separately for four sets of outlines grouped according to sex (males, females) and relevant loop categories (left ulnar/right radial, left radial/right ulnar).

The sets of Fourier coefficients per comparison were processed by principal components analysis (PCA). Shape-wise interpretation of principal components was conducted by visualizing shape deformations along principal axes. Shapes corresponding to positive and negative axis maxima were computed via a multivariate regression model constructed between a given principal component and original Fourier coefficients and a subsequent inverse Fourier transform allowing obtaining coordinates of points along predicted hypothetical outlines.

For the index finger analysis the first 5 principal components accounting for significant portions of the variance were compared by multivariate analysis of variance (one-way MANOVA) with the body side combined with the loop category taken for the factor. Testing loop shapes derived from all five fingers, one-way MANOVA was performed. In addition, after the finger order was added as the second factor, main-effect MANOVA, and nested design MANOVA was computed.

Univariate comparison was performed using Tukey HSD post-hoc tests. Assumptions underlying correctness of using parametric approach was tested by Levene's test. Statistical significant results were claimed at 5% level of significance.

In addition to pure shape variation size-on-shape dependence, i.e., allometry was investigated. Allometry was studied on a finger-pooled sample and on a sample of loops taken from the index finger. For each sample the sets of original size-invariant coordinates were multiplied by values of CT and P2 parameters respectively and then processed by Fourier analysis and principal components analysis in order to extract a common allometric component and residual shape components. In order to test for dependencies on sex, finger order and loop category, scores of common allometric component were tested by Mann–Whitney U test and Kruskal-Wallis non-parametric ANOVA.

The shape analysis and subsequent statistics were performed using Past 3.0 [13] and NTSYSpc 2.2 [16] software.

Results and Discussion

Traditional morphometrics

On the index finger, statistical significant differences were detected (Table 1 and 2) between right radial and left ulnar loops only in six traits (CD, C1, CP, DP, D3, pDD) and only in females. As seen from the diagrams of these variables in Figure 3, the largest size differences between the radial and ulnar loops were found in distances between core and the end of the distal type line (CD, C1), oblique transversal diameter of the loop (D3), distance between endpoints of the proximal and distal type line (DP), distance between core and the end of the proximal type line (CP) and distance between the penultimate and ultimate point on the distal type line (pDD). In females, the average values for right radial loops were significantly higher than for left ulnar loops (and thus the difference between radial and ulnar loops is negative) in all of these measurements. The average values in these variables (except of CP) were higher in radial loops also in males; however, none of these differences was statistically significant. In comparisons of right directed loops (left radial loops vs. right ulnar loops), significant differences were found neither in females nor in males. Generally, in most of the measurements radial loops had higher average values than ulnar loops in both males and females.

In pooled sample of all loops, only one significant difference was found (Table 3 and 4); in males, the average value of CP was higher in ulnar loops than in radial loops. No general tendency in differences between measurements on ulnar and radial loops was found in any of the compared groups.

Shape analysis

Sample of index fingers

The analyses provided sets of principal components of which the first five per set accounted for over 98% of the total variance (Table 5). In both sexes, MANOVA yielded statistically significant differences between right radial and left ulnar loops (in females, $\lambda = 0.4413$, p-value = 0.00521, Bonferroni corrected; in males, $\lambda = 0.3188$, p-value = 0.000237, Bonferroni corrected). Univariate tests showed that only PC2 exhibited statistically significant differences between compared shapes. Similar for both sexes, positive scores were associated with right radial loops, whilst negative scores were more typical for left ulnar loops (Figure 4, first and second row). In both sexes, the end of distal type line in ulnar loops was more closed (points 20 - 32)

Table 5: Results of Principal Component Analysis of the loop shape on the index finger.

Females					Males			
	Left ulnar to right radial loops		Left radial to right ulnar loops		Left ulnar to right radial loops		Left radial to right ulnar loops	
Trait	Eigenvalue	%	Eigenvalue	%	Eigenvalue	%	Eigenvalue	%
PC1	0.0213	73.75	0.0977	81.78	0.0658	91.37	0.0750	92.11
PC2	0.0043	15.10	0.0131	10.94	0.0036	5.40	0.0037	4.52
PC3	0.0020	7.50	0.0047	3.90	0.0013	1.80	0.0017	2.12
PC4	0.0005	1.77	0.0024	1.99	0.0006	0.87	0.0005	0.59
PC5	0.0002	0.85	0.0007	0.62	0.0002	0.28	0.0002	0.20

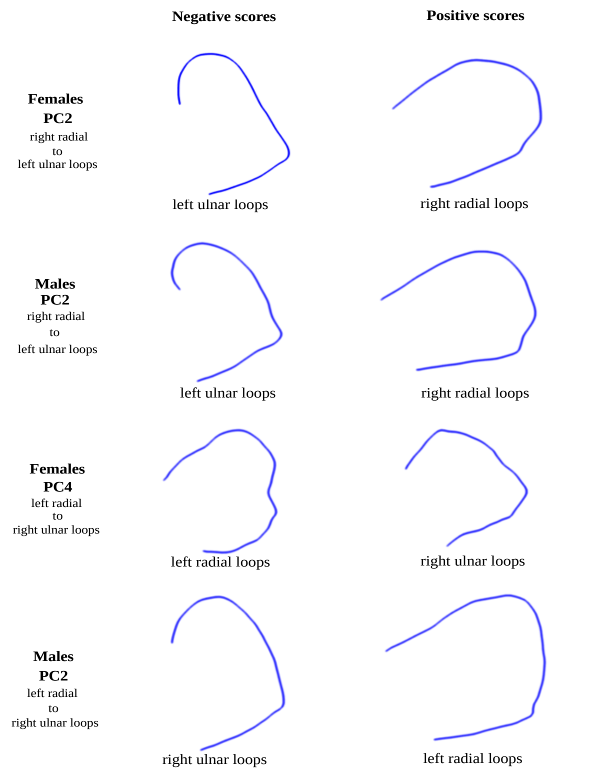

Figure 4: Shape representations of selected components resulting from Principal Component Analysis of the loop shape on the index finger.

while for radial loops the same portion of the distal type line was more opened (more radially oriented). Moreover, the initial part of the distal type line (near triradius) was more straight and oblique to the opposite side of the phalanx whereas in radial loops the shape was more curved and the direction was more distal/parallel with the axis of the phalanx.

The similar results were revealed for left radial to right ulnar loops (Table 5), (MANOVA, females, $\lambda = 0.5072$, p-value = 0.005435, Bonferroni corrected; males, $\lambda = 0.2602$, p-value = 0.0097, Bonferroni corrected). In males, only PC2 showed statistically significant results while in females PC4 was identified as the component responsible for statistically significant results. In female-related PC4, positive scores were commonly ascribed to right ulnar loops, whereas negative scores were in average associated with left radial loops. In male-related PC2, positive scores pointed to left radial loops, while negative scores were associated with right ulnar loops. In males, the shape differences between ulnar and radial loops are very similar to those described above in the reversely oriented loops (Figure 4, third and fourth row). In females (PC4), the differences in opening/closure of the end of

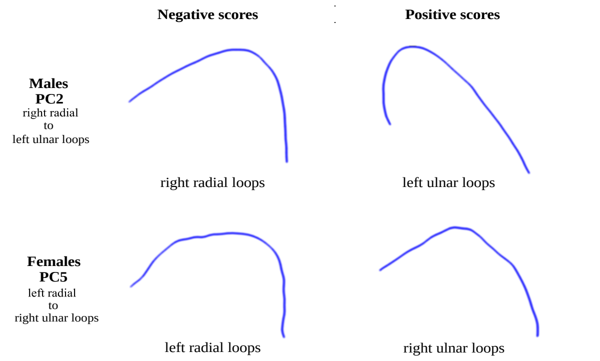

Figure 5: Shape representations of selected components resulting from Principal Component Analysis of the shape of the *partial* loop (distal type line) outlines on the index finger.

distal type line is absent, but the different direction of the initial part of the distal type line (near triradius) coincided with the reversely oriented loops.

PCA carried out on *partial loop outlines* yielded sets of principal components (Table 6) of which the first 5 principal components, again, accounted for more than 98% of the total variance. If subject to loop comparison by MANOVA, the only set of principal components that revealed statistically significant differences at 5% level of significance were the one comparing left ulnar loops to right radial loops in males ($\lambda = 0.4465$, p-value = 0.00103, Bonferroni corrected). Of the principal components, only PC2 differed between the studied groups. While positive scores were characteristic of left ulnar loops, negative scores were in average associated with right radial loops. At 10% of significance, the differences between right ulnar and left radial loops in females were shown to be statistically significant. Univariate tests showed again that only PC5 was statistically different between radial and ulnar groups- positive scores were linked to right ulnar loops; negative scores were linked to left radial loops. In both males and females, respective shape differences (Figure 5) between radial and ulnar loops were consistent with those associated with the entire outlines.

Pooled sample of all five fingers

In *females* and comparison of *right radial to left ulnar loops* (Table 7; Figure 6, upper row), main effect MANOVA yielded statistically significant results for both studied factors (finger, loop). Post-hoc comparisons specified that PC3 exhibited differences in loops while PC2 and PC3 showed differences among fingers. In PC2, loops on thumbs differed from the remaining fingers. In PC3, ring and little fingers differed in shapes of loops. Nested design MANOVA with loops nested in fingers showed statistically significant results

Table 6: Results of Principal Component Analysis of the shape of the partial loop outlines on the index finger.

Females					Males			
	Left ulnar to right radial loops		Left radial to right ulnar loops		Left ulnar to right radial loops		Left radial to right ulnar loops	
Trait	Eigenvalue	%	Eigenvalue	%	Eigenvalue	%	Eigenvalue	%
PC1	0.0285	67.43	0.0230	55.49	0.0144	67.86	0.0399	82.26
PC2	0.0073	17.34	0.0098	23.55	0.0039	18.15	0.0068	14.50
PC3	0.0058	13.65	0.0074	17.87	0.0022	10.20	0.0011	2.24
PC4	0.0002	0.58	0.0004	0.97	0.0003	1.36	0.0003	0.65
PC5	0.0002	0.41	0.0003	0.77	0.0002	0.88	0.0001	0.28

Table 7: Results of Principal Component Analysis of the loop shape on the pooled sample of loops from all five fingers.

Females					Males			
	Left ulnar to right radial loops		Left radial to right ulnar loops		Left ulnar to right radial loops		Left radial to right ulnar loops	
Trait	Eigenvalue	%	Eigenvalue	%	Eigenvalue	%	Eigenvalue	%
PC1	0.0175	54.28	0.0423	76.06	0.0206	73.82	0.0331	81.61
PC2	0.0091	28.14	0.0060	10.71	0.0037	13.46	0.0037	9.70
PC3	0.0031	9.73	0.0045	8.70	0.0019	6.79	0.0017	4.25
PC4	0.0012	3.68	0.0014	2.43	0.0007	2.39	0.0009	2.21
PC5	0.0005	1.45	0.0006	1.15	0.0003	1.16	0.0004	0.90

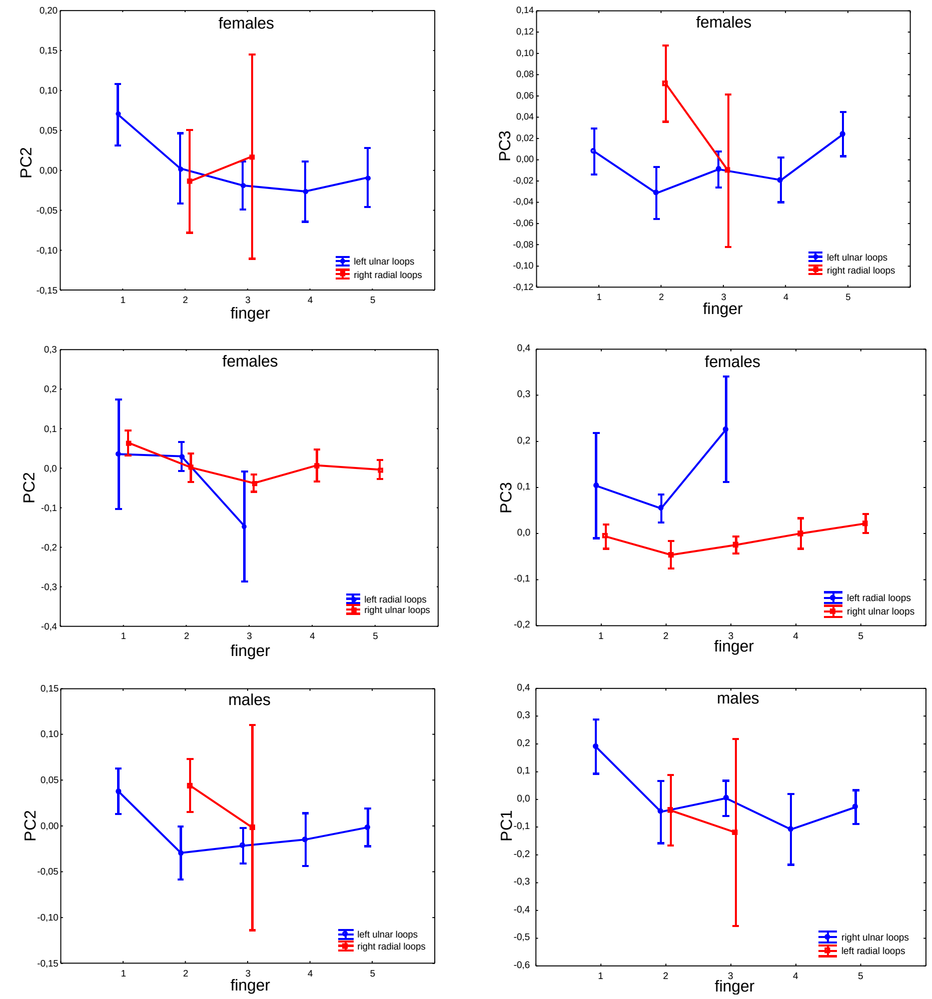

Figure 6: Selected results of MANOVA on shapes of loop patterns from all five fingers. Vertical bars denote 95% confidence intervals.

among fingers (λ = 0.760, p-value = 0.0256) as well as loops within each fingers (λ = 0.824, p-value = 0.0079). Post-hoc tests showed that of included principal components, only PC2 and PC3 showed statistically significant results. In PC2, left ulnar loops of the thumb differed from left ulnar loops of the middle and ring finger. In PC3, right radial loops of the index finger differed from left ulnar loops of the first, second, third and fourth finger, and so did left ulnar loops of the index finger from left ulnar loops of the little finger.

In *females* and comparison of *left radial to right ulnar loops* (Table 7; Figure 6, middle row), main effect MANOVA yielded statistically significant results for both studied factors (finger: λ = 0.488, p-value = 0.00001, loop: λ = 0.717, p-value = 0.00001). Univariate tests showed statistically significant differences among fingers in PC2-PC4 and between loop patterns in PC3. Nested design MANOVA with loops nested in fingers showed statistically significant results among fingers (λ = 0.728, p-value = 0.006) as well as loops within each fingers (λ = 0.647, p-value = 0.000002). According to post-hoc tests majority of differences are related to PC2 and PC3. In PC2, radial ulnar loops of the middle finger differed from the same patters in thumbs and index fingers. Additionally, the same pattern differed in shapes taken from the thumbs and little fingers. In PC3, right ulnar loops differed from their counterparts in the first, second and third fingers.

In *males* and comparison of *right radial to left ulnar loops* (Table 7; Figure 6, bottom left), main effect MANOVA yielded statistically

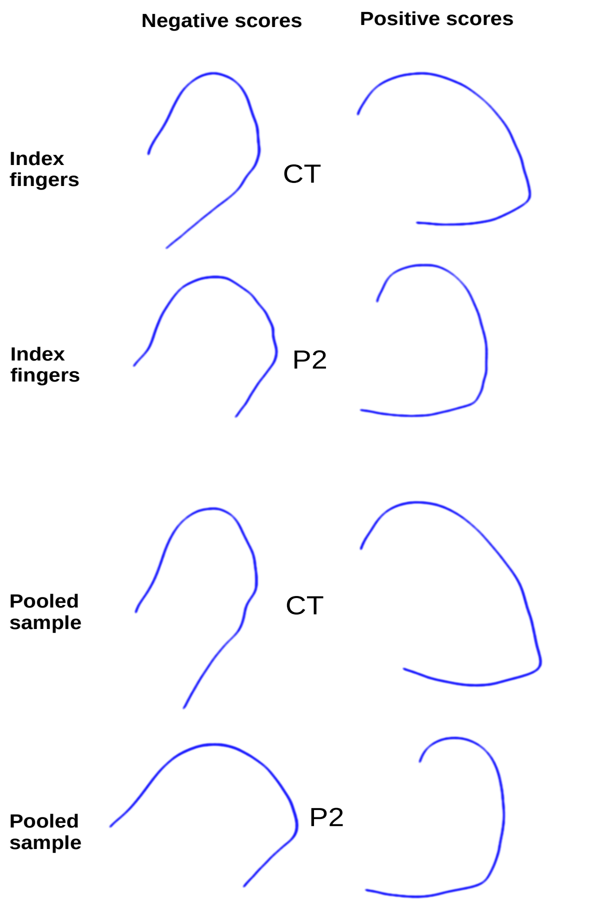

Figure 7: Allometric trends in the shape of loops; left column shapes are associated with low (negative scores) and the right column shapes with high (positive scores) values of the size measurements listed between them (CT, P2).

significant results for both studied factors (finger: λ = 0.551, p-value = 0.00001, loop: λ = 0.762, p-value = 0.00001). Post-hoc tests showed that PC1, PC2 and PC4 exhibited finger-specific differences in loop shape. In PC1, loops in thumbs differed from those of all other fingers. PC2 showed differences between the thumb and the third and fourth finger. In PC4, the middle finger varied from the first, second and fifth finger. In loops, differences were revealed for PC2 and PC3. Nested design MANOVA with loops nested in fingers showed statistically significant results among fingers (λ = 0.685, p-value = 0.00099) as well as loops within each fingers (λ = 0.712 p-value = 0.000014). Of included PCs, PC1-PC4 showed statistically significant results in univariate tests. In PC1, left ulnar of the thumb differed from the same pattern in the third and fourth finger. In PC2, left ulnar loops in the thumbs differed from left ulnar loops of the second and third finger. In addition, in the second finger they (left ulnar loops) also varied from the right radial loops. In PC3, right radial and left ulnar loops in the thumbs differed from each other. In addition, right radial loops in the thumbs varied from left ulnar loops of the second and third finger.

Allometry

Dependence of shape of loops on size is depicted in Figure 7. Allometric shape changes expressed in both the course and orientation of proximal and distal type lines were revealed in the index fingers as well as the pooled sample of all five fingers. Loops with small CT measures had oblique course of the proximal type line and longitudinal course of the distal type lines and were in general elongated, while loops with large values of CT had transversal course of proximal type lines and in general wide shape. Similar differences were observed also in the P2 measurement dependency.

No statistically significant differences in allometry were revealed between male and female loops for the pooled sample (p-value =0.456, p-value =0,869) nor for the index finger only (p-value =0.681, p-value =0.169). For the second finger, there were no differences among categories of loops (p-value =0.364, p-value = 0.149).

For the finger-pooled sample, in contrast, statistically significant differences were shown among fingers (p-value = 0.049, p-value = 0.0001). The multiple comparisons revealed that for CT-adjusted input data the first and fourth fingers differed while for P2-adjusted data the scores of allometric component in the thumb differed from the remaining fingers. If compared among loop categories, right ulnar and radial loops showed statistically significant differences (p-value = 0.0171).

Discussion

Our pilot study revealed that there are systematic differences in measurements of radial and ulnar loops originated in index fingers. Despite the limited sample size, in all four groups (defined by the combination of sex and direction of loops) radial loops were larger than the ulnar loops in most of the measurements. It is not clear, however, why the significant differences were limited to females and a small number (six of fourteen) of measurements in right directed group of loops (left ulnar vs. right radial). A reasonable explanation is that the results might have been biased due to the small number of right radial loops in the sample. Another plausible explanation is that there exists a difference in the extent of side asymmetry between radial and ulnar loops (right-left). If the side asymmetry in size were more pronounced in ulnar loops than in radial loops (which was indeed the case at least in some measurements in female index fingers in our sample), and at the same time, radial loops were in general slightly larger, then the differences between right radial and left ulnar loops would come out as larger than the differences between left radial and right ulnar loops. Still, when measurements of fingerprints from all five fingers were compared, statistically significant differences in females disappeared, and so did systematic trends towards larger average values in radial loops.

Our results seem to be inconsistent with knowledge of the size difference (as measured by ridge count between triradius and core) between radial and ulnar loops provided by Cummins and Midlo [2] on page 77. According to these data, radial loops have a lower ridge count in average and hence should be smaller. Ridge count (number of ridges), however, might not be a suitable measure of the absolute size of the pattern as ridges in different loops might vary in their breadth/thickness. Moreover, ridge count describes only the part of the pattern between the core and the delta and not the opposite part of the loop where we have just found the largest differences between the radial and the ulnar loops. Beyond this, we have almost no idea of inter-population diversity in the size of radial loops.

Systematic *shape* differences between radial and ulnar loops consistent for all four tested groups were also found on the index finger. Ulnar loops were more oblique in the initial part of the distal type line and more closed towards it send (the core), whereas radial loops were more curved in the initial part of the distal type line and more opened towards its end. Taking into account the size differences in one of the female groups and overall size trends in all four groups, the differences might be explained by variations in size and shape of embryonic pads according to the current ontogenetic model of the fingerprint formation [3-5,8]. While radial loops appear to come from larger and more asymmetrically oriented pads (towards the radial side), ulnar loops tend to originate in smaller and less asymmetrical (towards the ulnar side) pads of the index fingers.

The shape of fingerprint patterns has been traditionally studied throughout a feature called *pattern form index* ([2] for review). The pattern form index represents a simple width-to-height ratio of the pattern dimensions in the area located between core and delta. There have been several slightly different techniques developed to assess the pattern form [8,17-20]. From the methodological point of view, it should be stressed that, contrary to the Fourier shape analysis, none of the six traditional "shape" variables tested in our study (ratios, Table 1-4) revealed statistically significant differences between radial and ulnar loops in any of the studied groups. Thus, it appears that only advanced shape analysis exhibits the capacity to describe the complexity of the studied shapes.

When compared among different fingers, shapes of loops from the thumbs were frequently different from the remaining four fingers. This may become highly beneficial if the goal is set on the differentiation of radial and ulnar loops within a mixture of fingerprints from all fingers as it allows separating prints taken from thumbs from the rest of the fingers. For following studies, it might be useful to test whether there are also systematic radial/ulnar loop differences in radial and ulnar loops on the thumb and the third finger. Due to negligible frequencies of radial loops on these fingers this would, however, require a much larger database of fingerprints than the one utilized here.

Focusing on asymmetrical whorls represents another alternative approach towards studies of systematic shape differences between radial and ulnar patterns. Singh et al. [21] studied radio-ulnar asymmetry on a sample of fingerprints from 400 males on the basis of six features of whorl patterns (angles between the core and the delta, the perpendicular bisecting the two deltas, ridge tracing, the central rotation of the ridges, ridge counting and the slope of the apex ridges). Their results showed that most of the asymmetrical whorls were asymmetrical to the ulnar side (alike in loops). Similarly to radial loops, whorls asymmetrical to the radial side were the most frequent on the index fingers and thumbs. So far, there are no data available on whether or not the shape tendencies between whorls asymmetrical to radial and ulnar side on the index fingers are similar to the tendencies observed here in loops.

Conclusion

In this pilot study, we used two different methods (traditional measurements and Fourier shape analysis) to describe size and shape variations in loop pattern fingerprints and to analyze differences between radial and ulnar loops. We found systematic size and shape differences between radial and ulnar loops on index fingers. However, our preliminary results are based on limited sample size and far from being of immediate practical use in forensic fingerprint investigation. Further research conducted on larger samples of different origins is needed to confirm the results and to advance knowledge on size/shape systematic trends between different fingers and different fingerprint pattern categories.

Acknowledgement

This study was partly based on data and results of bachelor thesis [22] of one of the authors (V.K.); and was financially supported by Student Project Grant at Masaryk University, project No. MUNI/A/0988/2009 (M. Králík: Application of shape and image analysis in studies of human biology) and EU program FITEAMP CZ.1.07/2.3.00/20.0181 (Formation of International Team on Evolutionary Anthropology of the Moravian Populations). We thank to anonymous reviewer(s) for valuable comments.

References

1. Galton F. Finger Prints. London and New York: Mac Millan. 1892.
2. Cummins H, Midlo C. Finger prints, palms and soles. An introduction to dermatoglyphics. 2nd edn. New York: Dover Publications, Inc. 1961.
3. Loesch DZ. Quantitative dermatoglyphics: classification, genetics and pathology. 1st edn. Oxford: Oxford University Press. 1983.
4. Wertheim K, Maceo A. The Critical Stage of Friction Ridge Pattern Formation. J Forensic Ident. 2002; 52: 35-85.
5. Kücken M, Newell AC. Fingerprint formation. J Theor Biol. 2005; 235: 71-83.
6. Katzenmaier U. Relationships between fingertip patterns and shape of the Finger endglieder. Homo. 1979; 30: 12-23.
7. Katzenmaier U. Connections between Finger Print Patterns and the Form of Terminal Phalanges. J Hum Evol. 1980; 9: 631-636.
8. Bonnevie K. Studies on papillary patterns of human fingers. J Genet. 1924; 15: 1-111.
9. Hawthorne MR. Fingerprints. Analysis and Understanding. New York: CRC Press. 2009.
10. Býmová I. Dlaňové dermatoglyfy ve vztahu k barvě vlasů [Master Thesis]. Brno: Masaryk University. 1989.
11. Rohlf JF. tps Util program, version 1.47. Department of Ecology and Evolution, State University of New York, Stony Brook;2010.
12. Rohlf JF. tps Dig2 program, version 2.16. Department of Ecology and Evolution, State University of New York, Stony Brook. 2010.
13. Hammer O, Harper D, Ryan P. PAST, Paleontological Statistics software package for education and data analysis. Palaeontol Electron. 2001; 4: 9.
14. Dean CB, Nielsen JD. Generalized linear mixed models: a review and some extensions. Lifetime Data Anal. 2007; 13: 497-512.
15. Hothorn T, Hornik K. exact Rank Tests: Exact Distributions for Rank and Permutation Tests. R package version 0.8-27. 2013.
16. Rohlf JF. NTSYSpc: Numerical Taxonomy System, ver. 2.20. Exeter Publishing, Ltd. Setauket, NY. 2008.
17. Bonnevie K. Was lehrt die Embryologie der Papillarmuster über ihre Bedeutung alsRassen- und Familiencharakter? Zeitschrift für Induktive Abstammungs- undVererbungslehre. 1929; 50: 219-74.
18. Geipel G. Der Formindex der Fingerleistenmuster. Zeitschrift für Morphologie und Anthropologie. 1937; 36: 330-61.
19. Geipel G. Anleitung zur erbbiologischen Beurteilung der Finger- und Handleisten. München: J F Lehmanns. 1935.

20. Cummins H, Steggerda M. Finger-prints in a Dutch family series. Am J Phys Anthropol. 1935; 20: 19-41.

21. Singh I, Chattopadhyay PK, Garg RK. Determination of the hand from single digit fingerprint: a study of whorls. Forensic Sci Int. 2005; 152: 205-208.

22. Kováčová V. Veľkostné a tvarové rozdiely medzi radiálnymi a ulnárnymi kľučkami na prstoch ruky [Master Thesis]. Brno: Masaryk University. 2013.

Austin J Forensic Sci Criminol - Volume 2 Issue 1 - 2015
ISSN : 2380-0801 | www.austinpublishinggroup.com

Citation: Králík M, Kováčová V, Hupková A and Urbanová P. Shape Variations in Loop Pattern Fingerprints: Radial vs. Ulnar Loops. Austin J Forensic Sci Criminol. 2015;2(1): 1013.