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Distribution of the minutiae in palmprints: topological and sexual variability

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Distribution of the minutiae in palmprints: topological and sexual variability

ABSTRACT

Palmprints have been systematically less studied than fingerprints, despite being of great use in the identification process. In Spain, they were not included in Automated Fingerprint Identification Systems (AFIS) until 2009. Very few investigations performed within the field of palmprints have assessed the sexual and population variability of the number and distribution of minutiae on its surface, despite the fact that these particularities are the basis for personal identification in forensic science.

That is why a study was conducted to assess total, bimanual and sexual density per morphological regions (superior or distal, thenar and hypothenar) and per counting areas of $1cm^2$ on 120 palmprints obtained from 30 male and 30 female individuals of Spanish nationality. Also, the frequency in the location of each type of delta or triradius (a, b, c, d and t) per count area was calculated.

Results have shown a topological variability in the distribution of the density of minutiae, which is similar between sexes and a specular effect between both hands. The most frequent locations of the deltas coincide with areas of high minutiae density.

It has also been shown that there are sexual differences in the total number of minutiae, which cannot be due to sexual dimorphism in adult hand size, since minutiae are established at an early stage of fetal development and their number will not change during later postnatal growth. These differences can only be attributed to genetic factors related to the number and type of sex chromosomes.

KEYWORDS: minutiae, palmprints, identification, sexual differences, distal, thenar, hypothenar.

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HIGHLIGHTS:

This paper provides the first results in the Spanish population on the minutiae in palmprints.

The study contributes a new standardized methodology to manually compare the minutiae density of palmprints.

The average density of minutiae shows the presence of statistically significant differences, both sexual and topological.

The density of minutiae per area shows that minutiae are not distributed homogeneously throughout the palm surface.

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Dermopapillary ridges that cover the surface of the fingers, the palm and the sole of the feet, separated by furrows, are configured in patterns that, once formed in early stages of gestation, will be preserved throughout the individual's life, even after death if the skin is conserved. The inheritance of dermopapillary ridges is multifactorial, and thus determined by both genetic and environmental factors. It is a polygenic inheritance that interacts with environmental factors, but only during the fetal formation stage. For this reason, once developed, they are not modified by the environment, and remain unaltered, except for traumatic damage or skin wear, throughout the life of the individual [1-6].

Like fingerprint identification, palmprint identification is based on the comparison of information obtained from friction ridges between a print of known origin (fingerprint) and a print of unknown origin (fingermark). Variability can be compared in palmprints following the taxonomy based on the one proposed by Maltoni et al. [7], separating the features into three levels: Features extracted at a global level from the friction ridges and flexion creases. These include the orientation of the lines, the separation between them, the most prominent lines, and the places where the friction ridges bend, called singular points (Level 1 detail); Features extracted at a local level. These features are the salient points of the friction ridges, called minutiae. (Level 2 detail); and features extracted at a fine level such as the width, shape, contour, and sweat pores of the friction ridges (Level 3 detail).

Within the various dermatoglyph studies (from the Greek, *derma*, skin, *glyphs* engraving) that have been performed on human populations, we find that figerprints have been more studied than palmprints. Thus, in fingerprints, the type of main pattern or the ridges count between delta or triradius and core, has been widely studied in many human populations and its variability is well known (see bibliographic reviews of

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checklist with number 8 and 9). Studies of dermatoglyphs in palmprints are less frequent than those of fingerprints and have focused on the study of bimanual, sexual and population variability of the types of figures shown in the interdigital configuration areas, thenar and hypothenar; in the variability of the palmar formula established from the the main lines of the deltas or triradii, and the count of ridges between the deltas, mainly between a and b (see bibliographic reviews of checklist with number 8 and 9). More recently, the bimanual and sexual variability presented by ridge density, and thus their thickness, has been assessed in the different topological areas [10; 11], and applied to sex inference by calculating the likelihood ratio of prints of unknown origin.

However, the topological, bimanual, sexual and population variability of other dermatoglyphic features such as density and frequency of minutiae (level 2 detail) [12-17], or width, shape, contour, and sweat pores of the friction ridges (level 3 detail) [18-21] have been less studied in fingerprints, while in palmprints there are considerably fewer [10; 11; 22-25].

Although it was in 1980 when the Automated Fingerprint Identification Systems (AFIS) began to be implemented worldwide, it was not until the first decade of the 21st century that palmprints were introduced into these automatic search systems. In Spain, they were incorporated in January 2009, so that detainees are now not only given a ten-print set, but they also take the palmprints of both hands and the ulnar edge impressions or "writer's palm”, also from both hands [26; 27].

In the last few years, palm printing has been gaining more attention as a biometric identification feature, and recognition methods based on palm printing use, among other features, minutiae as peculiarities for feature extraction in database searches and recognition [28-30]. Nevertheless, it is difficult to extract minutiae effectively even from high-resolution palmprints, because the noise produced by folds, white lines etc.,

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makes observation difficult in many areas, leading to many pseudo-minutiae [31-34]. In addition, the large size of the palmprint image and the large number of minutiae also require many calculations [30; 32]. However, due to its forensic importance, since 25% of all crime scenes contain only latent palmprints and it is estimated that about 30% of the latents recovered at crime scenes are those of palms [35; 36], more and more investigations are focusing on it because of the abundance of information that can be gathered.

In fingerprints identification has been demonstrated that the combination of manual matching done by an expert and the matching done by an AFIS can outperform the expert and the system alone [37]. Results show high performance degradation in the automatic extraction of minutiae on fingerprints compared to manual extraction by human experts, which increases in the case of latents. Palmprint recognition is a challenging problem, which is why there is also a need for studies that evaluate, manually, topological, sexual and population variability, so that it can be used in comparison with the automatic extraction of these features, as well as in the subsequent evaluation by the expert regarding the evidence in drawing conclusions. The purpose of this paper is to locate and manually count the minutiae on the palmprints in a sample of both sexes.

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Material and methods

The material used in the following research was obtained from the palmprints of 60 individuals of Spanish origin, 30 males and 30 females, which allowed us to analyze 120 palmprints. The age range of the sample was between 21-30 years.

Palmprints were obtained from the database of the Teaching Unit of Physical Anthropology of the Department of Life Sciences of the University of Alcalá. The method of production was the graphite and adhesive paper [38].

The selection of the sample was based on the quality of the palmprint, discarding those prints that did not show the whole palm, had filled areas or numerous white lines, which made it difficult to locate the minutiae.

Once the sample was selected, the palmprints were scanned and then submitted to a quality improvement process through image processing (Adobe Photoshop 7.0). For a better visualization of the dermopapilar ridges in the palm of the hand, the contrast of the impressions was modified in order to better define the ridges. With this we manage to increase the quality and to promote its later study. Later, on the image, using the same program, a mesh or grid with areas of one square centimeter (1cm x 1cm) was added. On this grid, two perpendicular axes were defined, dividing the horizontal axis of the palm in the distal or upper area and in the proximal region, starting from the ulnar edge of the distal transverse furrow, and the vertical axis, located in the third interdigital space, between the ring and middle fingers, divided the thenar and hypothenar regions, in the proximal region, and the radial and ulnar areas in the distal region (Figure1). Thus, the distal region was formed by 60 count areas (30 radial and 30 ulnar) and the thenar and hypothenar regions with 48 areas each.

The following process consisted on locating, identifying and quantifying, on each palmprint, the found minutiae by grid. The results were collected on a technical sheet, prepared for the study in Excel.

The following criterion was used to quantify the points as it follows:

- Each particularity of the ridge, or minutia, was counted as minutia without taking into account the different types that these can form.

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- Concerning the deltas or triradii, the area of 1cm2, on which they were located, was indicated.
- When a white line interrupted the route of a ridge, these interruptions were not counted as minutiae, considering that the route of the ridge was continuous.
- The samples were checked twice, by the same person, separated in time, to verify the total quantification of minutiae and to elaborate the database using the statistical software IBM SPSS v.25, which included the quantitative and qualitative variables chosen to perform the study.

The quantitative variables were designed from the Cartesian coordinate axes (x, y), identifying each of the 1cm^2 areas of the template according to the following criterion:

- In each palmprint, in the distal region, each of the areas were identified per hand (ridge-R and left-L), per hand area (radial-r or ulnar-u), followed by the area number assigned according to its X and Y coordinates. For example, Rr_21 would correspond to the right hand, the radial zone and the area of coordinates (2,1) (Figure 1).
- The thenar region was identified with the letter T, while the hypothenar was identified with the letter H. For example, RT_33 would correspond to the right hand, the thenar region and the coordinate area (3,3) (Figure 1).

In addition, the location of the different palm deltas, both distal (a, b, c and d) and proximal (t), were analyzed. In order to indicate the position or area of the palmprint in which each delta appears, the same nomenclature was applied as for the quantitative analysis. For example, delta *d* in position Ru_42, means that it corresponds to the right hand and is in the ulnar area, in the coordinates (4,2).

Based on these quantitative and qualitative variables, a descriptive statistic was made and the results were statistically compared with parametric tests, using t Student for

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both independent and paired data, as required. To evaluate the association between the location of the deltas and the palm areas, a correspondence analysis and a Chi-square were carried out.

Results

Full recount of minutiae

Table 1 shows the values obtained for the total *minutiae* count per sex, in both hands, and over the total sample. As can be seen, the total number of minutiae discovered out of the 120 palmprints was 103,689; male obtaining a total of 56,974, and female a total of 46,715 minutiae.The range of variation for the minutia counting was between 675 and 1613 for males and between 522 and 1012 for females. Regarding the total count per hand, in both sexes, the left palms had a greater number of minutiae than the right palms, the difference being 1400 in female and 381 in male.

Density of minutiae per morphological regions

Figure 2 shows the average of minutiae and their standard deviation, per sex, hand (right and left), and region (distal, thenar and hypothenar). The results showed that the total average of minutia for both sexes and both hands was 864.07. Males showed a higher average of minutiae, in all morphological areas, than the average found in females. In both sexes, and in both right and left hands, the region with the highest number of minutiae was the distal, followed by the hypothenar; the thenar region had the lowest average of minutiae (Figure 2). Also, in both sexes, the average number of minutiae per region was higher in the left hand than in the right hand, except in the hypothenar region.

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The values obtained per sex, for both distal areas, ulnar and radial, and both proximal, thenar and hypothenar, are shown in Figure 3. Results showed that, in both sexes and in both hands, the ulnar area had a higher number of minutiae than the radial area. The density of minutiae in the radial and ulnar areas was higher in the left hand than in the right hand, except in the ulnar area in females. In the thenar region, in both males and females, a greater density of minutiae was observed in the left hand. Nevertheless, in the hypothenar region, in both sexes, the highest density was found in the right hand.

For each sex, per hand, the topological comparison between regions was conducted through a parametric statistical analysis (t student of paired data). For this purpose, the distal and thenar regions of each hand were compared independently, and statistically significant differences were found (p-value<0.001) for the average of minutiae in both sexes. Likewise, the distal and hypothenar regions and the thenar and hypothenar regions were compared and statistically significant differences were found between them in both sexes (p-value< 0.001) (Table 2). The distal region was assessed in both radial and ulnar areas, which only showed significant differences in the female sample.

The bimanual statistical comparison of the average minutiae per morphological regions was also performed using the t student test for paired data (Table 3). When comparing the distal region between the right and left hand, both globally and per area, radial and ulnar, no statistically significant differences were observed for either sex. In the hypothenar region, no differences were found either, while in the thenar region, statistically significant differences were found in male (p-value<0.05), but not in female.

The comparison of the average of minutiae between sexes, per morphological regions, was undertaken by means of a parametric test (t Student) (Table 4). Results showed statistically significant differences between sexes, in both hands, between the distal,

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thenar and hypothenar regions, (p-value<0.05). However, the sexual differences in the distal, radial and ulnar areas were only statistically relevant for the radial area (p-value<0.05). The average number of palmar minutiae also showed statistically significant differences between sexes, both globally and per hand.

Density of minutiae per counting area (1cm²)

Table 5 shows the number of counting areas that had minutiae per area, hand and sex. The palmar surface on which they were found in the distal region was 49 cm^2 in male and 45cm^2 in female, which means a sexual difference of 4cm^2. While in the thenar region the surface area on which minutiae were found was 42cm^2 in males and 28cm^2 in females, which is a difference of more than 14cm^2; and in the hypothenar region that surface area was also 42cm^2 in males, but 38cm^2 in females, which is a difference of 4cm^2 as in the distal region.

The average in the distribution of minutiae per counting area (1cm^2), on each palmprint, for each sex, was obtained. The results are shown on a color density map in Figure 4. This color map indicates through a gradient the density of minutiae, ranging from dark red (higher number of *minutiae*) to dark green (lower number of *minutiae*).

In the color maps it is evident that, in both hands and in both sexes, the counting areas with the highest average density of minutiae were found in the ulnar zone of the distal region, followed by the radial zone and the hypothenar region. The range of distribution of minutiae per cm^2 in the right hand varied, in the ulnar zone from 3 to 19 in males, and from 2 to 20 in females, and in the radial zone from 1 to 16 in males and from 4 to 18 in females. In the hypothenar region in males, the range is from 3 to 17, while in females the range is from 2 to 16. Finally, in the thenar region, the minimum and maximum *minutiae* in males were 1 and 11 per cm^2 respectively, and in females 4 to 11.

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In the left hand, in the ulnar area, the average density of minutiae per cm^2 ranges from 3 to 21 in male and from 3 to 22 in female. In the radial area, a range of 4-17 in males and 3-17 in females was identified. In the hypothenar region, in males it ranged from 3 to 17 minutiae per cm2 and in females from 2 to 14. Finally, in the thenar region, males had a range from 3 to 11 minutiae per cm^2, while females had a range from 1 to 11.

The average density of minutiae per area shows that minutiae are not distributed homogeneously throughout the palm surface, finding areas of higher and lower concentration, which coincide in both sexes, and between the right and left hand, thus presenting a specular image of density, in which no statistically significant bimanual differences have been found per area.

The sexual differences per area ($1cm^2$) were assessed using the student t over the selected areas in each of the different topological regions (Figure 5). Thus, in the radial and ulnar zone, 12 areas were selected in each of them, from three horizontal and four vertical areas from the coordinate axis. In the hypothenar and thenar regions, 15 areas per region were compared one by one, establishing three horizontals by five vertical areas from the coordinate axis. This meant the intersex comparison of 54 areas of $1cm^2$, individually. The results showed statistically significant differences between sexes for four areas in the radial zone, and another four in the thenar region, reaching five in the hypothenar, which would be equivalent to 24.07% of the area compared. Peripheral areas were not statistically compared between sexes, considering that the evident differences shown between the averages per areas are due to the larger size of the male hand.

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Deltas' location

Both four distal deltas, *a*, *b*, *c* and *d*, and the proximal delta *t*, were identified and located for their quantification. The results obtained for the location area of each type of delta were evaluated per hand and sex, finding no statistically significant differences between their bimanual and sexual frequencies, so the sample was grouped, and its results are shown in Figure 6.

The frequencies of occurrence of the deltas were the following:

- Delta a located over the radial zone of the distal region, the variation in spatial surface at its origin was approximately 11cm^2. The area of location with the highest percentage of occurrence was r_33 with 40%, found in 17% of the palmprints in the area r_34, and the rest of the locations had a frequency under 9% (Figure 6).
- Delta *b* was found in both the radial and ulnar area of the distal region, with a spatial range of occurrence of approximately 5cm^2. The area with the highest frequency of occurrence of delta b is r_14 with 63%, followed by r_15 with 13%, with the rest of the locations having frequencies equal to or less than 10% (Figure 6).
- Delta *c* was found in all cases in the ulnar area of the distal region, presenting a spatial range of occurrence of approximately 8cm^2. The most common location was in quadrant u_23, with 37%, and in u_24 with 22%, followed by u_14 and u_13 with 19% and 18% respectively, with the remaining areas showing values of 1% (Figure 6).
- Delta *d* was found in all cases in the ulnar area of the distal region, showing a spatial range of occurrence of approximately 6cm^2. The area of location with the highest percentage was u_32 with 52% of cases, followed by u_42 and u_33

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with 21% and 19% respectively, the rest of them with values lower than 5% (Figure 6).

- Delta *t* was found in the proximal zone of the palmar impression, varying its location between the thenar and hypothenar regions, showing a spatial distribution of 18 cm^2. The counting area with the highest appearance was h_15 with 24%, followed by h_16 with 18%, showing the rest of the areas values lower than 10%. (Figure 6).

To assess the association between the types of palm deltas and the area of location, a correspondence analysis was performed, which is shown in Figure 7. The correspondence analysis showed, with an inertia of 58.9%, a statistically significant association ($Chi^2=1880.4$ gl=164 $p<0.0001$) between the deltas and the location areas, separating the first dimension, with 38.68% of the inertia, deltas a, b and d, located in the lateral areas of the hand, both radial and ulnar, from deltas c and t, located in the central areas of the hand.

Discussion

In recent years palmprints have attracted more attention as a relevant and secure biometric method of personal identification, both in the civil and criminal fields. But while prints produced under controlled conditions, with ink or livescan methods provide high quality images (high-resolution), although not always free of noises (disturbance of principal lines, wrinkles) that degrade the quality of some portions of the image, latent prints often give rise to low-resolution images [30; 32; 33;37].

Furthermore, due to the large amount of minutiae, approximately ten times more than a fingerprint, the research process requires much more time [33; 39]. It should also be stressed that the quality of palmprints is usually not as good as that of fingerprints, due

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both to the deformation and concave structure in the center of the palmprint, and to the greater number of wide creases, white lines and wrinkles, especially numerous in some palm areas, which means that, even in high-resolution palmprints, many pseudo minutiae may be extracted and it is difficult to extract reliable minutiae effectively.

In palmprints, some algorithms for the extraction of features are based on first-level features, such as the existing lines and creases in palmprint images; others use second level features, such as minutiae, which are more reliable, while level 3 features have not been used in latent palmprint identification [30]. Nevertheless, the extraction of stable and robust features from palmprints is still a problem, not only because of the low quality of the patterns of palmprints, but also because of the computational complexity for the large image size. Puertas et al, [37] showed that the combination of manual matching done by an expert and the matching done by an AFIS has shown that can outperform the expert and the system alone, because high performance degradation happens in the automatic extraction of minutiae compared to the manual extraction done by human experts. This could be even more relevant in palmprints. Therefore, many problems in high-resolution palmprint recognition still need to be solved and more research is required.

Forensic experts determine the identity of persons involved in the crime scene by comparing characteristics, such as minutiae, extracted from palmprints based on a collection of possible suspects provided by Automated Fingerprint Identification Systems (AFIS), the result of comparing the latent to be investigated with the system's database. The expert must decide from the list of candidates provided by the system (generally 50), whether the print or latent to be studied corresponds to any of them, which is not always the case. The quality assurance system [40], requires two experts to carry out the comparison with the candidates, and if they are among them, to draw their

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conclusions separately. Therefore, any information on the topological, sexual or population variability of minutiae density could be useful to establish the evidence in each particular case when drawing conclusions. This paper aims to highlight this under-studied aspect of human populations.

Thus, the average number of minutiae obtained in the palmprints was 864.07, with an average of 949.56 for males and 778.58 for females, also showing that the minutiae are not distributed homogeneously throughout the palm surface and that there are topological differences between regions (distal, thenar and hypothenar), not only due to their different size. The topological variability for the density of minutiae matches the topological variability found regarding the width of ridges on the palmprints in different studies, both with those obtained in a sample of Spanish population [10] and with those obtained in a sample of Indian population [11] as well as preliminary studies in North American population [22; 23]. Hence, the areas with the highest density of minutiae coincide with those with the highest density of crests and thus with thinner ridges, the thenar region being the one with the thickest ridges and the lowest density of minutiae.

In addition, sexual differences have been found both over the total area of the palmprints, and between the topological regions. This evident sexual dimorphism cannot be attributed to the different size of the adult hand between sexes, because the number of minutiae is established at an early stage of fetal development and, once formed, neither their number nor their morphology within the ridge will be affected by later fast growth or the postnatal environment. These differences can only be attributed to genetic factors related to the number and type of sex chromosomes.

The methodology used in this work for the counting of minutiae by 1cm^2 areas, has allowed to evaluate the average density of minutiae in a detailed way, after establishing a standardized comparative method of its own, which will make possible a better

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comparison of the results per areas for future investigations. The average density of minutiae on the palm surface showed areas of higher density, especially in the distal and hypothenar, associated in the distal region to the delta locations, and in the hypothenar, increased by the higher frequency of figures or pattern in this zone regarding the thenar. Results have shown how the topological distribution of the average density of minutiae has a similarity between sexes, and a specular effect between both hands.

On the other hand, as the regions (distal, thenar and hypothenar) were methodologically established for their evaluation, we found that there are a higher number of counting areas with minutiae in the distal region (males: 49cm^2; females: 45cm^2) than in the thenar (males: 42cm^2, females: 28cm^2) and in the hypothenar (males: 42cm^2, females: 28cm^2). But the most interesting fact was that the relationship between the surfaces covered by these three areas on the palm print was different between sexes. Thus, while in male the thenar and hypothenar regions cover an equal area of 42cm^2, only 7cm^2 less than the distal (49cm^2), in female a gradient is established with the largest area also occupied by the distal region (45cm^2), followed by the hypothenar region, also 7cm^2 less, followed by the thenar region, with 10cm^2 less compared to the hypothenar, and 17cm^2 less than the distal. These differences reveal a different morphological distribution of the palmar areas between sex, marked by the presence of a relatively smaller thenar region regarding the distal and hypothenar area in female. This would be a consequence of the reduced muscular development in the female thenar region compared to the rest of the palmar musculature, which, however, in males would be more homogeneous. Furthermore, sexual dimorphism affecting hand size was lower in the distal and hypothenar regions, with 4 cm2 difference between the sexes in each of these zones, and higher in the thenar region, where the difference was 14 cm^2. This pronounced difference in the size of the thenar region between the sexes is most likely

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due to a greater development of the musculature in males derived from the manipulative activity exercised by the thumb compared to the rest of the fingers.

To assess the sexual differences in the average density of minutiae on a $1cm^2$ area and avoid those due to the larger hand size of males in the peripheral areas, a central area covering a $54cm^2$ surface was selected ($24cm^2$ in the distal region and $30cm^2$ in the proximal region, distributed between the thenar and hypothenar area, with $15cm^2$ surface in each), finding statistically significant sexual differences in 24.07% of the compared area. This shows the sexual differences in the average density of minutiae per standardized area, beyond those strictly derived from the size of the hand.

The results achieved in our study can be compared with those provided by Okajima and Ukusura [24] in a sample of 12-year-old Japanese schoolchildren, given that the morphologies of dermopapillary ridges and those of their particularities such as minutia, once they are formed during early fetal life, remain even after death if the tissues are preserved. These authors carried out a counting of *minutiae* in a japanese population, formed by palmprints of 15 pairs of male and 5 pairs of female monozygotic (MZ) twins and 15 pairs of male and 5 pairs of female dizygotic (DZ) twins (60 males and 20 females). Average bimanual and sexual differences, standard deviation and *minutiae* total counting range were assessed on this sample. The range of variation for minutia counts recorded in the Japanese population [24], ranged from 726 to 1310 in males, and from 705 to 1178 in females, while in our study this range was wider, with a maximum count of 1613 minutiae in males and 1012 in females, and a minimum of 675 in males and 522 in females. This higher homogeneity in the amount of minutiae in Okajima and Ukusura's [24] study could be due to the fact that the study was performed with twin pairs.

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The average number of minutiae found in the Japanese palmprints [24] was 992.95 for male and 916.25 for female; the averages in our study are slightly lower for male (949.56) and significantly lower for female (778.58), thus showing a higher sexual dimorphism in our sample for this feature. Concerning the sexual differences, our results match those of Okajima and Ukusura [24] by showing statistically significant differences between sexes for the average of minutiae; males showed a higher average number than females. In relation to bimanual differences, these were not found in the sample of Japanese population [24], matching our results.

The results in both studies, regarding the absence of significant bimanual differences and the existence of sexual differences in the amount of minutiae, are consistent, and as discussed above only due to genetic factors determined by sex. Also, the difference found between the two samples of population, Japanese and Spanish, in terms of the reduced number of minutiae in the Spanish population, especially in females, can only be explained by differences derived from the different population origin that affected an early stage of development and not by a later differential growth in the size of the hand.

Jain and Demirkus [35] collected on 100 unique palmprints an average of minutiae after post-processing 700, although they do not show the sex of the sample nor other characteristics such as bilaterality or population origin. This value is lower than those found as an average in our sample, both globally (864.07) and per sex (males: 949.56, females: 778.58). They also provided data per region equivalent to those evaluated in our study extracted automatically, which after post-processing gives lower values than those obtained per region in our sample with manual extraction, except in the thenar region where they are higher. This could be caused by greater difficulty in extracting minutiae in the thenar region, due to the increased presence of white lines.

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As for the variability of the locations of the different delta types, the results obtained in this paper are the first data provided on this subject, so they cannot be compared with other studies. The standardized methodology used in this work has allowed us to assess, for the different types of palm delta, the variability in their location. The results show a more constant location, over a small area, for deltas *b* and *d*, followed by *a*, with the most variable being *c* among the distal deltas, although it is delta t, the one that shows the greatest variability in its location. Results have shown that the location of deltas is associated with areas of high concentration of minutiae.

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Conclusions

This study provides a new methodology for the manual standardization analysis of minutiae density in palmprints.

The results for the average density of minutiae in the Spanish sample show the presence of statistically significant differences, both sexual and topological, but the appearance of bimanual differences is not confirmed.

The density of minutiae per area shows that minutiae are not distributed homogeneously throughout the palm surface, finding areas of greater and lesser concentration of minutiae, which coincide in both sexes and have a specular density distribution between hands. In addition, it has become evident that the location of the deltas corresponds to areas of high density of minutiae.

Morphological differences in the palm of the hand, regarding muscular development, show different relative areas in the hands of males and females, highlighting the inferior development of the thenar region in females.

The sexual differences in minutiae density found in total and per areas on the palmprints cannot be due to sexual dimorphism in the size of the hand in adults, since the hand of a newborn male will contain the same number of minutiae as the hand of the adult male that he will become. Thus, the average minutiae of the male sample to which he would belong would be higher and statistically significant, as demonstrated in this study, than the average shown in the adult female sample. Therefore, these sexual differences would be caused by genetic factors associated with sex chromosomes, and not by the sexual dimorphism produced during adult growth and hand size differences.

Finally, as mentioned above, the importance of palmprints in the identification process requires an increase in knowledge of the variability, at all levels, of the features involved in the process, in order to optimize their use both in automated identification systems and in the subsequent judgement of the expert when drawing conclusions.

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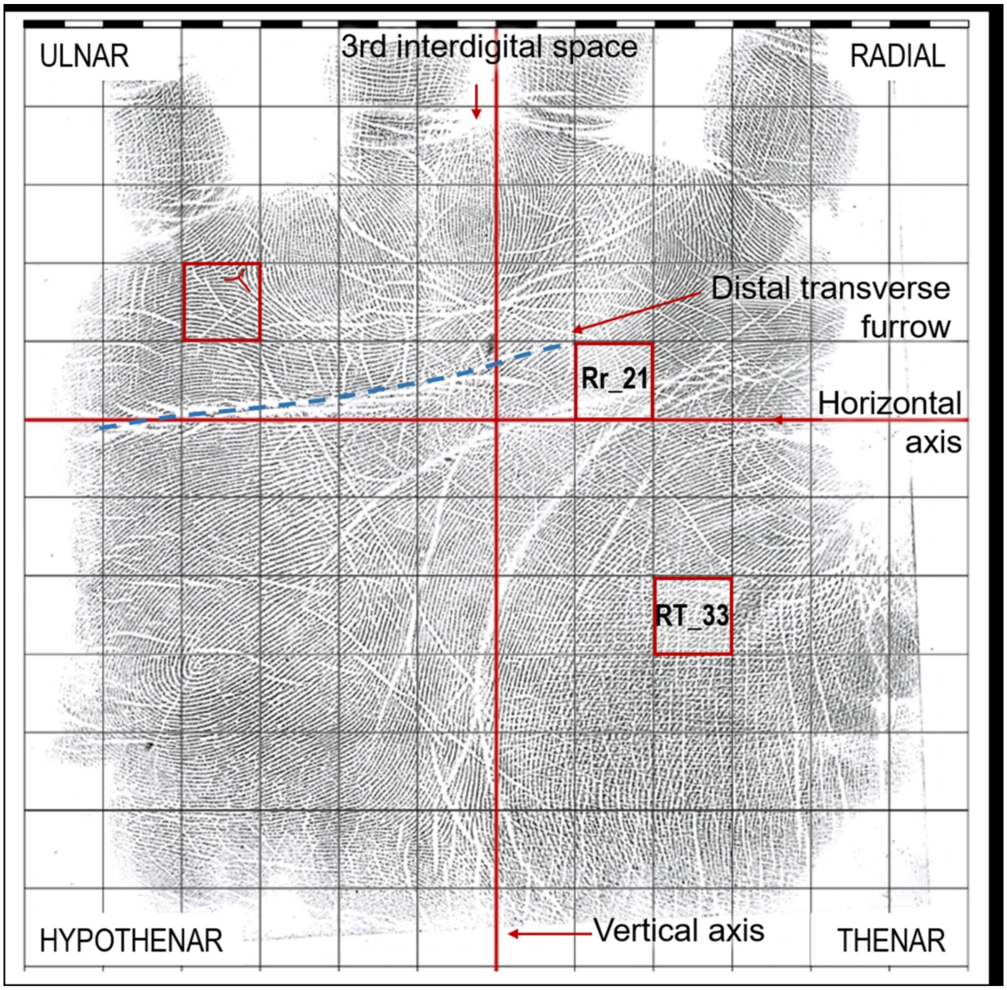

Figure 1.- Palmprint of a right hand with mesh designed for the count of minutiae with the identification of the axes and the different areas and regions valued. In addition, the name for the used coding of the quadrants is shown in two grids, and the delta d is marked on the palmprint.

508x499mm (150 x 150 DPI)

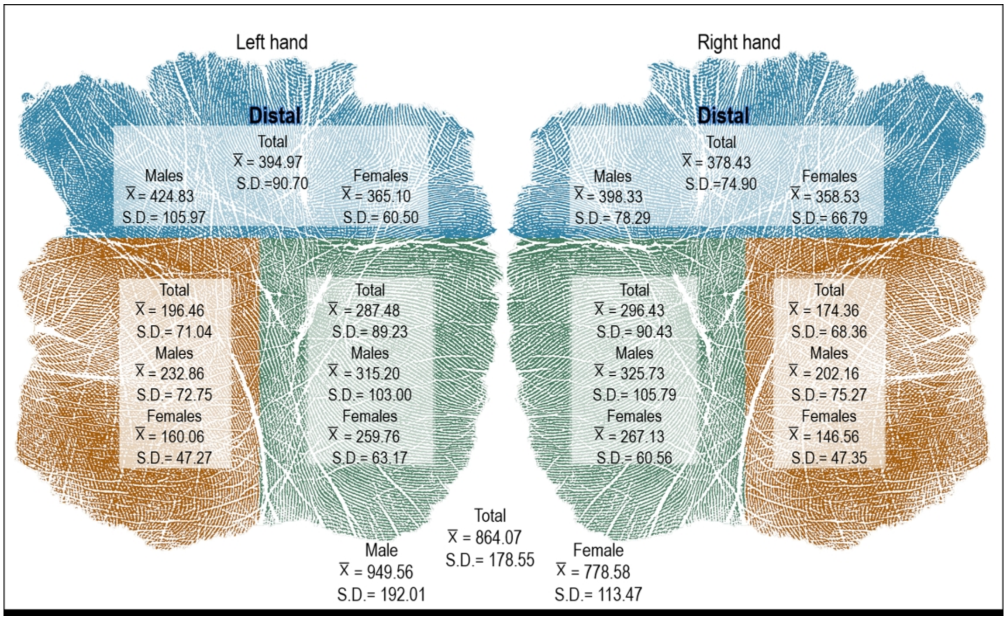

Figure 2.- Mean and standard deviation of minutiae per hand, sex and region.

508x311mm (150 x 150 DPI)

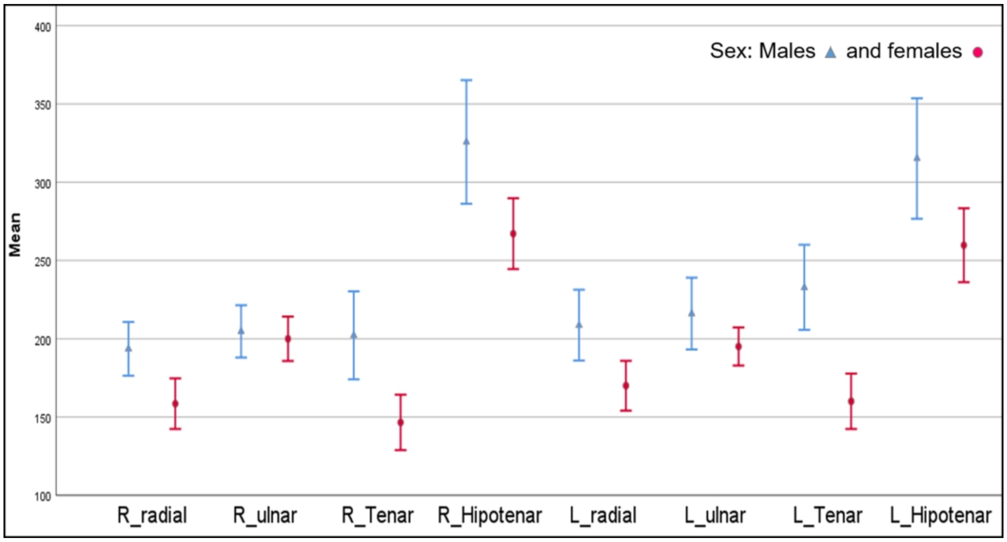

Figure 3.- Representation of the mean minutiae and its error bars at 95% confidence, per counting area, hand and sex. R: right hand; L: left hand.

508x272mm (150 x 150 DPI)

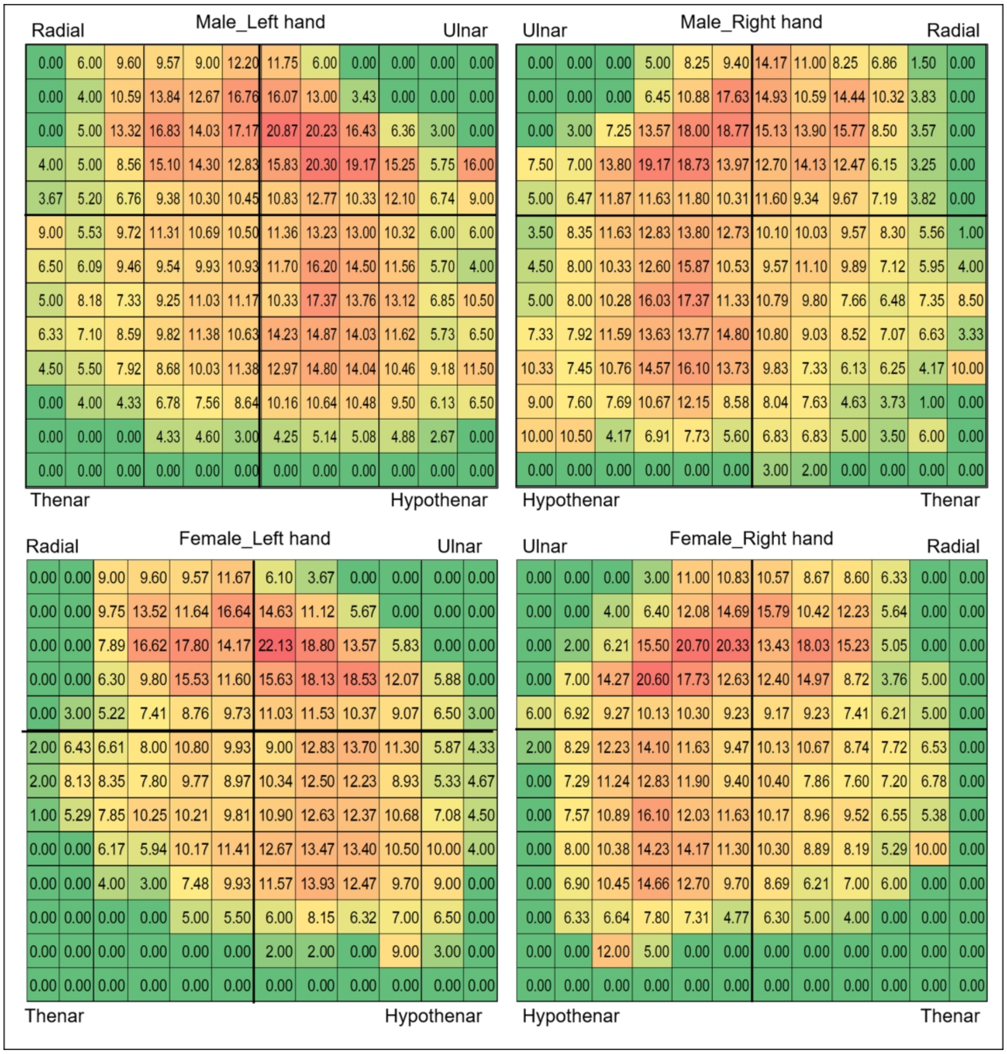

Figure. 4.- Average density of minutiae per counting areas in each hand and by sex.

508x531mm (150 x 150 DPI)

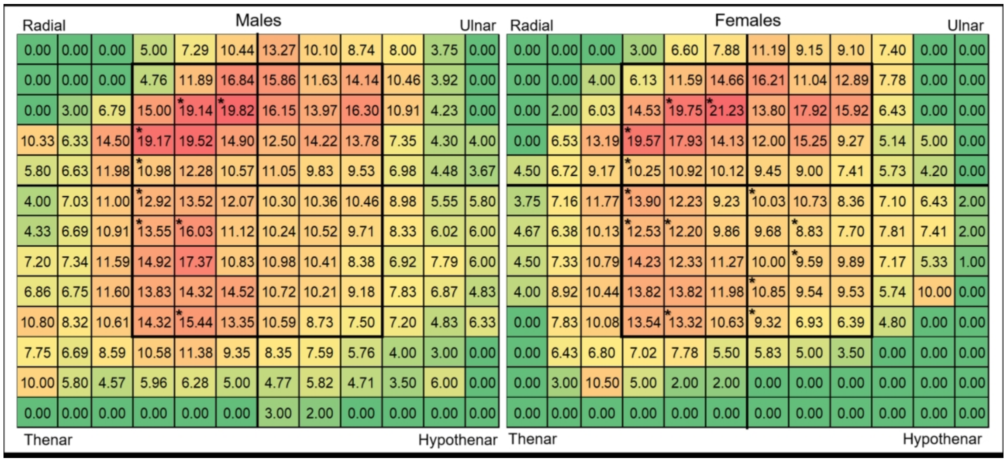

Figure. 5.- Average minutiae density per counting areas and sex.

508x230mm (150 x 150 DPI)

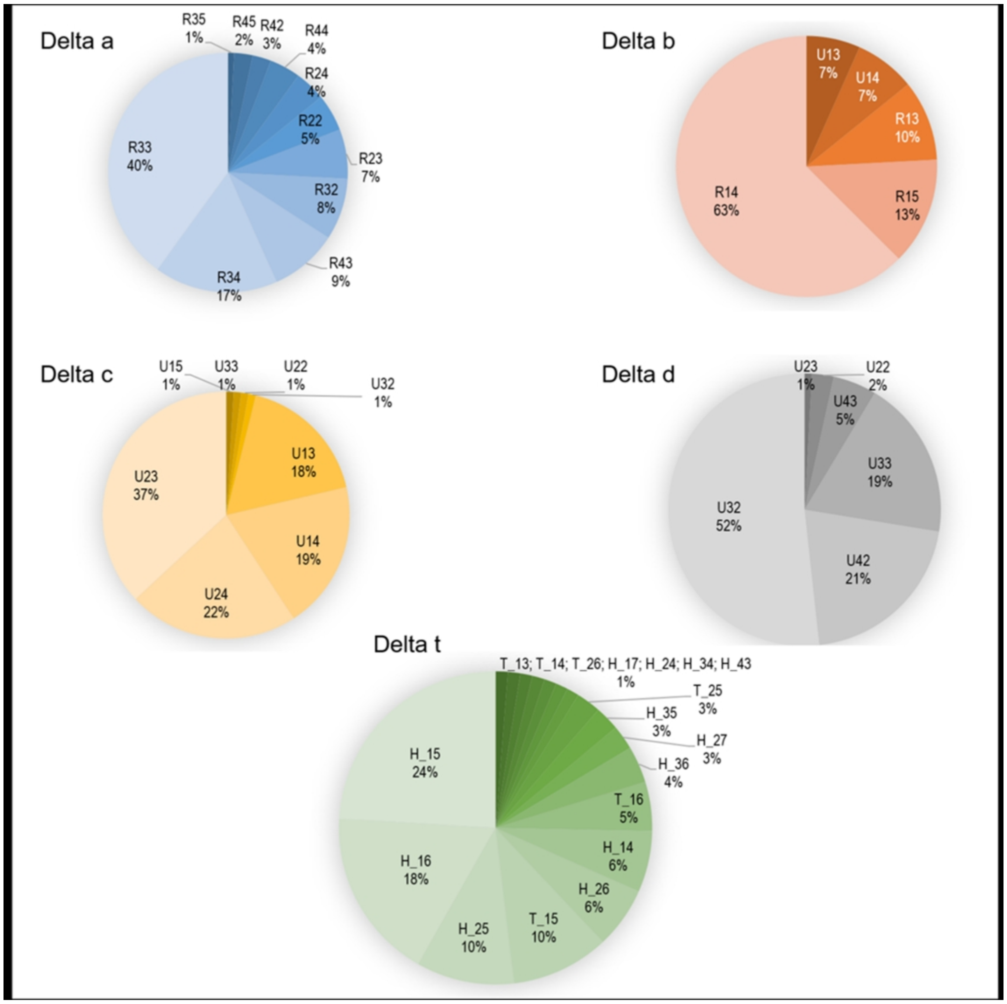

Figure. 6.- Frequency distribution of the location areas of each type of palmar delta.

511x509mm (149 x 149 DPI)

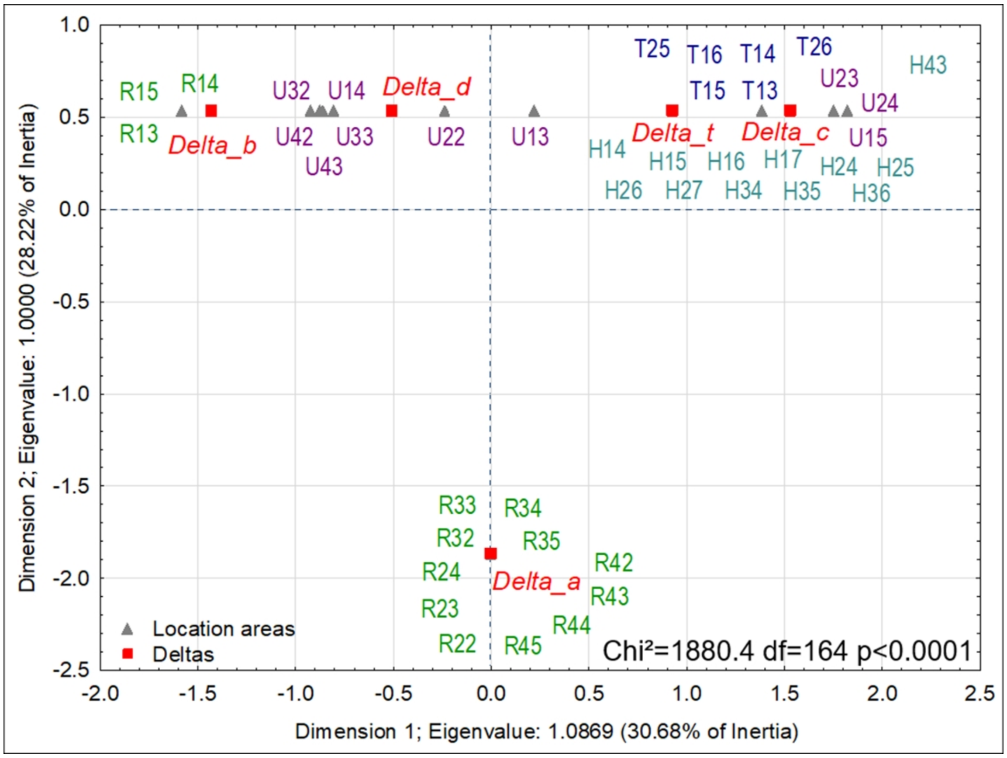

Figure. 7- Correspondence analysis between the types of deltas and their location areas.

508x380mm (150 x 150 DPI)

Table 1.-Total count of minutiae in palmprints per hand and sex for each area and region assessed.

	Radial	Ulnar	Distal	Thenar	Hypothenar	Total palm
Males						
Right hand (n=30)						
Sum	5809	6141	11950	6065	9772	27787
Maximum	321	311	632	377	689	1574
Minimum	125	130	271	70	181	708
Left hand (n=30)						
Sum	6261	6484	12745	6986	9456	29187
Maximum	355	428	748	411	553	1613
Minimum	131	133	288	76	112	675
Total hand (n=60)						
Sum	12070	12625	24695	13051	19228	56974
Maximum	355	428	748	411	689	1613
Minimum	125	130	271	70	112	675
Females						
Right hand (n=30)						
Sum	4756	6000	10756	4397	8014	23167
Maximum	268	275	543	238	385	987
Minimum	85	115	236	57	155	522
Left hand (n=30)						
Sum	5101	5852	10953	4802	7793	23548
Maximum	247	263	501	244	405	1012
Minimum	99	107	237	81	162	526
Total hand (n=60)						
Sum	9857	11852	21709	9199	15807	46715
Maximum	268	275	543	244	405	1012
Minimum	85	107	236	57	155	522
Total						
Right hand (n=60)						
Sum	10565	12141	22706	10462	17786	50954
Maximum	321	311	632	377	689	1574
Minimum	85	115	236	57	155	522
Left hand (n=60)						
Sum	11362	12336	23698	11788	17249	52735
Maximum	355	428	748	411	553	1613
Minimum	99	107	237	76	112	526

	Total hand (n=120)					
	Radial	Ulnar	Distal	Thenar	Hypothenar	Total palm
Sum	21927	24477	46404	22250	35035	103689
Maximum	355	428	748	411	689	1613
Minimum	85	107	236	57	112	522

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Table 2.- Statistical comparison of the mean minutiae by regions, two to two, for each sex. R: right hand; L: left hand.

	Males					Females				
Region	Mean	S.D.	t	df	Sig.	Mean	S.D.	t	df	Sig.
R_Thenar	202.17	75.28	-6.51	29	p<0.001	146.57	47.35	-9.24	29	p<0.001
R_Hypothenar	325.73	105.80				267.13	60.56			
L_Thenar	232.87	72.76	-4.20	29	p<0.001	160.07	47.28	-6.62	29	p<0.001
L_Hypothenar	315.20	103.06				259.77	63.17			
R_Thenar	202.17	75.28	-10.87	29	p<0.001	146.57	47.35	-16.37	29	p<0.001
R_Distal	398.33	78.29				358.53	66.80			
R_Hypothenar	325.73	105.80	-3.39	29	p=0.002	267.13	60.56	-6.48	29	p<0.001
R_Distal	398.33	78.29				358.53	66.80			
L_Thenar	232.87	72.76	-12.61	29	p<0.001	160.07	47.28	-24.36	29	p<0.001
L_Distal	424.83	105.97				365.10	60.50			
L_Hypothenar	315.20	103.06	-5.35	29	p<0.001	259.77	63.17	-6.68	29	p<0.001
L_Distal	424.83	105.97				365.10	60.50			
R_radial	193.63	45.96	-1.32	29	p=0.197	158.53	43.36	-4.87	29	p<0.001
R_ulnar	204.70	44.81				200.00	37.94			
L_radial	208.70	60.57	-0.67	29	p=0.506	170.03	42.53	-3.01	29	p=0.005
L_ulnar	216.13	61.45				195.07	32.60			

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Table 3.- Descriptive statistics and bimanual comparison of the minutiae quantity by sex and morphological regions. R: right hand; L: left hand.

	Males					**Females**				
Region	Mean	S.D.	t	df	Sig.	Mean	S.D.	t	df	Sig.
R_radial	193.63	45.96	-1.31	29	p=0.201	158.53	43.36	-1.41	29	p=0.169
L_radial	208.70	60.57				170.03	42.53			
R_ulnar	204.70	44.81	-1.07	29	p=0.294	200.00	37.94	0.70	29	p=0.488
L_ulnar	216.13	61.45				195.07	32.60			
R_Distal	398.33	78.29	-1.40	29	p=0.173	358.53	66.80	-0.64	29	p=0.528
L_Distal	424.83	105.97				365.10	60.50			
R_Thenar	202.17	75.28	-2.62	29	p=0.014	146.57	47.35	-1.85	29	p=0.074
L_Thenar	232.87	72.76				160.07	47.28			
R_Hypothenar	325.73	105.80	0.81	29	p=0.427	267.13	60.56	0.62	29	p=0.542
L_Hypothenar	315.20	103.06				259.77	63.17			

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Table 4.- Comparison between the sexes of the minutiae means by morphological regions. R: right hand; L: left hand.

	t	df	Sig.	Differences between means
R_radial	3.043	58	p=0.004	35.10
R_ulnar	0.438	58	p=0.663	4.70
R_Distal	2.118	58	p=0.038	39.80
R_Thenar	3.424	58	p=0.001	55.60
R_Hypothenar	2.633	58	p=0.011	58.60
L_radial	2.862	58	p=0.006	38.67
L_ulnar	1.659	58	p=0.103	21.07
L_Distal	2.681	58	p=0.010	59.73
L_Thenar	4.596	58	p<0.001	72.80
L_Hypothenar	2.512	58	p=0.015	55.43
Mean_radial	3.548	58	p=0.001	36.88
Mean_ulnar	1.307	58	p=0.196	12.88
Mean_Distal	2.833	58	p=0.006	49.77
Mean_Thenar	4.434	58	p<0.001	64.20
Mean_Hypothenar	2.806	58	p=0.007	57.02
Right palm	3.788	58	p<0.001	154.00
Left palm	4.083	58	p<0.001	187.97
Total mean	4.199	58	p<0.001	170.98

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Table 5.- Number of minutiae count areas that have presented statistically significant sexual differences.

	Right hand			Left hand			Total		
	Distal (n=60)	Thenar (n=48)	Hypothenar (n=48)	Distal (n=60)	Thenar (n=48)	Hypothenar (n=48)	Distal (n=60)	Thenar (n=48)	Hypothenar (n=48)
Males	48	42	42	49	38	41	49	42	42
Females	45	27	33	41	28	38	45	28	38

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