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Barefoot Impressions—A Preliminary Study of Identification Characteristics and Population Frequency of Their Morphological Features

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ABSTRACT: Footprint impressions of 107 male adults ranging in age from 19 to 67 years were recorded and examined. Included in this study were foot impressions from a pair of monozygotic twins as well. The impressions were recorded and converted into a set of indices which essentially are width-versus-length ratios of prominent features of the human foot. These indices were then correlated to yield probability values for use in this study and for comparison to data published by previous investigators Qamra, Abbott, Lovejoy, Cassidy, and Robbins. Friction ridge minutae were not considered in this study. Crease marks, well impressions, and toe step measurements were considered, but not incorporated in the probability values, because of the unique aspect of these features and the inability, at present, to convert these features to mathematical indices. These features do, however, introduce a subjective nature to the analysis scheme. This study uses the combined index probabilities of foot impressions so that the data generated can be used to assign a given probability that a particular foot impression, even without clear definable individual features, can be linked to the person who made the impression.

KEYWORDS: criminalistics, barefoot impressions, footprints, human identification, comparison, population indices

Fingerprints are generally the primary source of evidence in linking a suspect to a particular crime scene. Friction ridge minutae patterns are so unique that they identify individuality to a particular person no matter how large the population data base. Footwear impressions also play a major role in linking a suspect to a crime scene, though the job of doing so is difficult due to the number and types of mass produced shoes currently available. Identification becomes even more difficult if the footwear track is encountered in a medium that does not register detail of the shoe tread particularly well.

Although encountering barefoot tracks and their impressions in criminal matters is rare in Western countries [*1*], their presence cannot be overlooked because often it is the type of evidence that is crucial to linking the suspect to the crime scene. Barefoot impressions are distinguishable from footprints, in that the surface upon which the bare foot has tread has not necessarily registered the friction ridge minutae which contain the primary source of individual identification [*2*]. Footprints also register the plantar surface of the sole, which may not necessarily reflect the true size of the foot nor the entire prominence as well [*3*].

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Barefoot impressions are usually found in soil in which there is a considerable diversity of that medium's ability to capture and retain an accurate representation of the foot. Cassidy [*4*] demonstrated that the detail of footwear tracks diminishes up to 50% in a matter of hours under relatively mild environmental conditions. The foot impressions observed in the insoles of footwear that include dress shoes, athletic shoes, thongs, sandals, boots, and even socks are subject to the same detail variations that are observed with soil, though there are lighting and chemical processes that can enhance their visibility [*5*]. Analysis of barefoot impressions has an additional problem in that the footwear often can cause changes in toe positions. This can result in an altered imprint of the foot when compared to a track produced by an unshod foot.

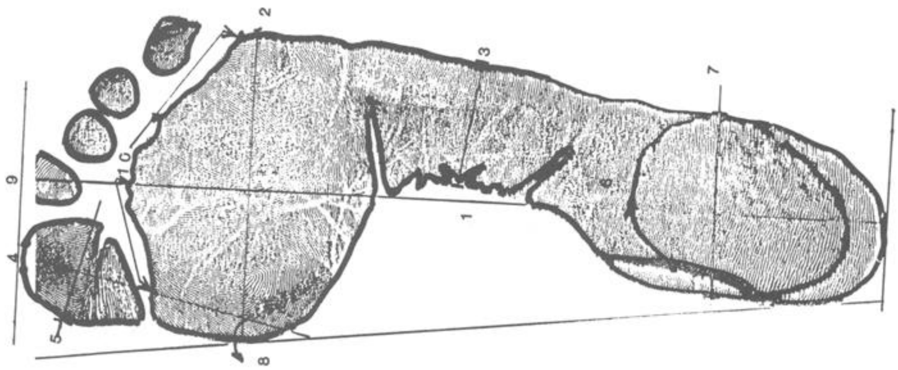
As has been suggested by previous investigators [*4,6*], when analyzing foot impressions in shoes, it is best to obtain additional and similar pairs of shoes from the suspect and compare those impressions. It is readily apparent to those of us who work in law enforcement that it is not always possible to obtain similar shoes from the suspect. The suspect either simply does not have an additional pair of such shoes or is unwilling to cooperate and provide an additional pair for comparison purposes. Thus, the investigator must rely on the impressions collected from the subject. Furthermore, there may be one and only one opportunity to collect a set of control impressions.

Historically, the analysis of footprint and foot impressions is not new to criminalistics. As early as 1888, in the case of LeDru, identification of a criminal through the analysis of footprints was successfully conducted [*1*]. A bloodstained footprint comparison was upheld by the Supreme Judicial Court of Massachusetts in *Commonwealth v. Bartolini* in 1938. Impressions in footwear were linked to a suspect in 1949 in Canada in the Donald and William Kett case [*4,6*]. A more recent example of barefoot comparison occurred in New Jersey in 1981 [*7*]. A bloody footprint clothed in a sock was successfully identified to an individual [*7*]. So, the use of this type of evidence is not new to forensic science, yet, there is little published data regarding the uniqueness of the impression made by human feet. Some of the literature we encountered made statements such as: "no two persons have identical feet" [*4*] or "no two people walk alike or wear their shoes in the same manner" [*6*], and "there is no such thing as a 'pair' of feet" [*4*]. There is, however, little or no published data that support these conclusions. These statements have either gone unnoticed, or have been accepted without equivocation by a large part of the forensic science community. It is our intention to provide statistical data to support these conclusions.

Materials and Methods

One hundred seven male adults, ages nineteen to sixty-seven, had their barefoot impressions recorded in a comparator, a wooden tray containing a mixture of fine clay, fingerprint powder, and bathroom scouring powder. Depth of impressions did not exceed 1/2 in. (12.7 cm). The foot impressions were then photographed with a scaler on 4 by 5 Tri X cut film and printed. Measurement equipment consisted of metric rulers, a compass, a protractor, and acetate grids. The following measurements were then conducted based partially on studies by Qamra [*1*], Abbott [*6*], and Cassidy [*4*] (see Fig. 1).

1. Foot length—the maximum distance measured from the base of the heel to the tip of the longest toe.
2. Maximum foot width—maximum width at the ball, this is the region of the first and fifth metatarsal bones of the foot.
3. Minimum foot width—an area generally measured across the arch of the foot.
4. Toe length—maximum length of the big toe measured from the tip prominence to the ball line of the foot.
5. Toe width—maximum width of the big toe.



1-FOOT LENGTH, 2-MAXIMUM FOOT WIDTH, 3-MINIMUM FOOT WIDTH,
4-TOE LENGTH, 5-TOE WIDTH, 6-HEEL LENGTH, 7-HEEL WIDTH,
8-GREAT TOE ANGLE,, 9-LONGEST TOE, 10-HUMPS.

FIG. 1—*Barefoot track measurements.*

6. Heel length—maximum length of the heel prominence that can be recorded in the impression. This may be artificially marked for measurement.
7. Heel width—maximum width of the heel.
8. Great toe angle—the angle measured from the intersecting vertices passing through the center of the great toe and along the medial (inner) site of the foot.
9. Humps—the number of protuberances, ignoring minor variations, that is, peaks and dips, projecting from the ball line observed at the anterior portion of the foot.

Foot Indices

As suggested by Qamra [*1*], the measurements recorded from the foot impressions were converted into indices so that registration faults and observational errors could be overcome. Registration faults could be attributed to the types of surface upon which the impression or track is recorded and whether one is observing only the plantar registration or the outline of the entire foot. These indices provide a set of ratios that tend to reduce the effect of the differences or errors. In addition, the probability values obtained by the multiplication of those indices should be independent. The separate measurements that were used to convert the different indices are considered to be interdependent.

Listed below are the following foot indices incorporated in the study:

$$\text{Instep-foot index} = \frac{\text{Minimum foot width}}{\text{Foot length}}$$

$$\text{Ball-foot index} = \frac{\text{Maximum foot width}}{\text{Foot length}}$$

$$\text{Heel-ball index} = \frac{\text{Heel width}}{\text{Maximum foot width}}$$

$$\text{Heel-foot index} = \frac{\text{Heel width}}{\text{Maximum foot width}}$$

$$\text{Toe index} = \frac{\text{Toe width}}{\text{Toe length}}$$

$$\text{Toe-ball index} = \frac{\text{Toe width}}{\text{Maximum foot width}}$$

"Well" index = A polygon derived from the area between the impression of the toe and the ball line.

Longest toe = A numerical identification assigned to the longest toe with the "greater" toe having an assigned number of one. This feature was determined by placing a compass at the base of the heel and scribing an arc across the toe tips. All indice ratios were multiplied by 100 for calculation convenience [*1*].

Results

The preliminary aspect of our study has been to correlate the data points recorded from the barefoot impressions and assign probability values based upon morphological features without the use of specific features or peculiarities, such as toe step patterns, well configurations, creases, or plantar weight distribution. Probability values generated from our study, included with those of other investigators, were then used to determine the degree of confidence in determining the source of a barefoot impression without the use of subjective individual characteristics.

Our basic premise in conducting this study was that the indices and the resulting multipliers were independent of each other, and our measurements were separate and distinct for each area of the foot. This has been established by previous investigators [*1,2,8*]. The first five indices, ball-foot, heel-ball, heel, toe, and toe-ball were based on an individual measurements that could be objectively measured with a standard scaling device (see Figs. 2 through 7). "Well" index values were obtained by quasisubjective analysis. This analysis required outlining the area of the well and subjectively converting the perimeter outline into a polygon based upon the intersection or junctures of toe and ball line features.

Although some interesting results were obtained, the subjective nature of this analysis did not lend itself to mathematical reproducibility; thus, we had to abandon this as an index. The "well" impression, however, is a prominent feature of barefoot impressions, and retains a higher degree of individuality. No replications were observed in the 107 individuals, even when transparent reproductions of opposite feet were reversed.

Great toe angles yield a broad range of values, including negative toe angles. This has yielded some interesting data regarding toe positions. Negative toe angles result when the "greater" toe points in the direction of the medial foot line. In this study, great toe angle probability values of zero and less than zero were rare, less than 0.01 for left feet, but were much higher for right feet.

Angles measured in this study found that the most common angles for left feet in the range of 7 and 10° and 10 and 17° for right feet. These angles are considerably different from those published by Cassidy [*4*] who reported the most common angles of 21 and 30° for 90 right feet. Cassidy also never reported negative angles (see Fig. 8).

Longest toe indices for left and right feet demonstrated a wide variability between left and right feet and those reported by Cassidy [*4*] and Robbins [*9*]. In this study, the greater toe was the longest toe for 56 and 51% of the individuals for right and left feet, respectively.

The second toe was the longest toe for 40.2% of the right feet and 27% for left feet. A wide disparity existed between right and left feet when the lengths of the greater and second toe

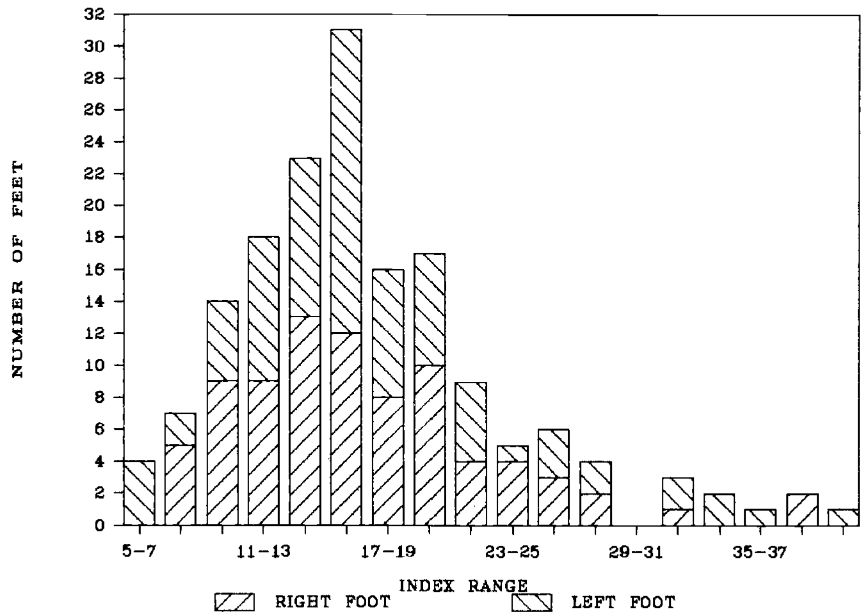


FIG. 2—*Graph of index distribution—instep width/foot length.*

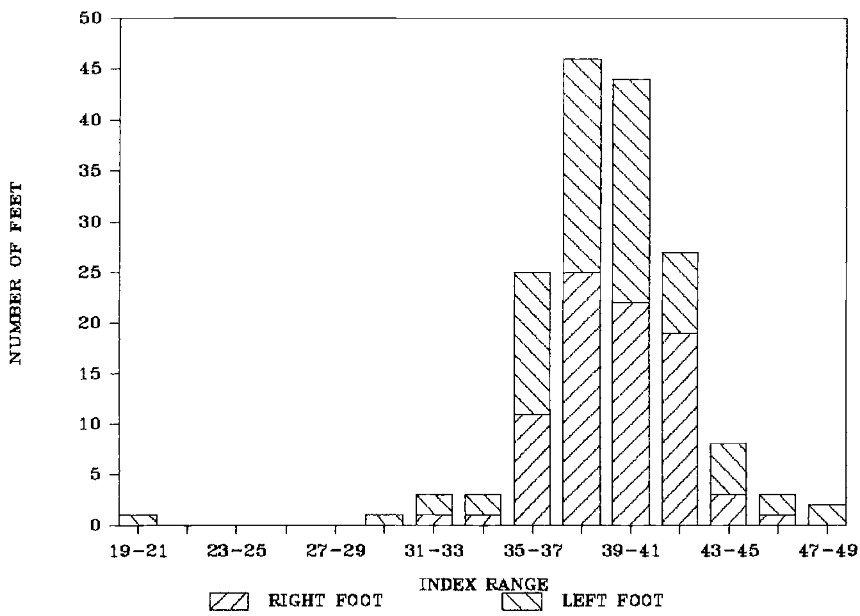


FIG. 3—*Graph of index distribution—ball width/foot length.*

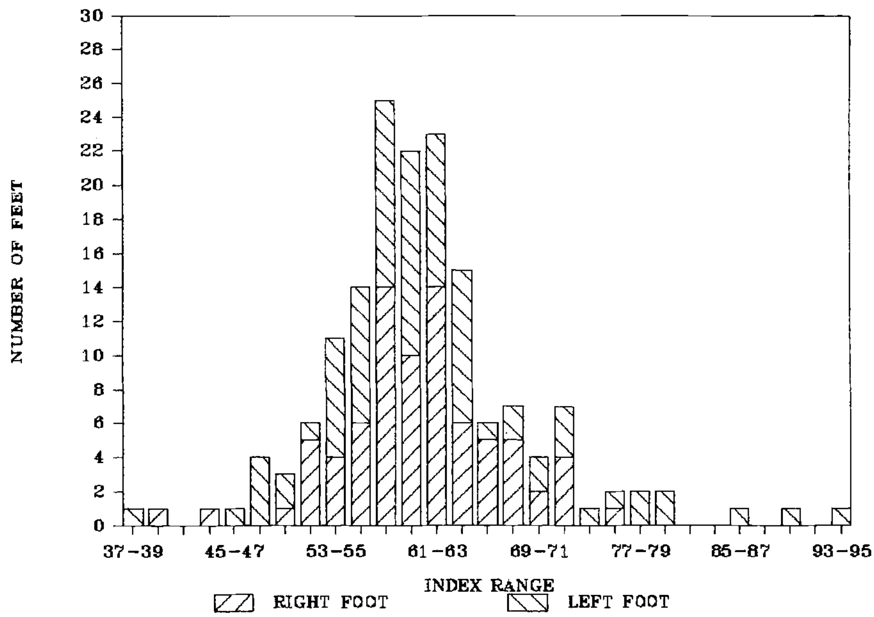


FIG. 4—*Graph of index distribution—heel width/ball width.*

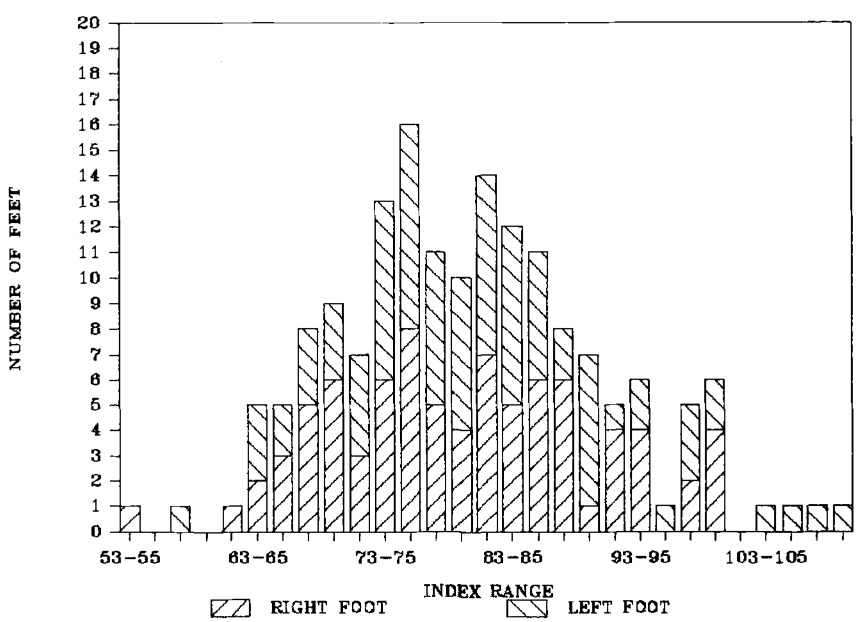


FIG. 5—*Graph of index distribution—heel width/heel length.*

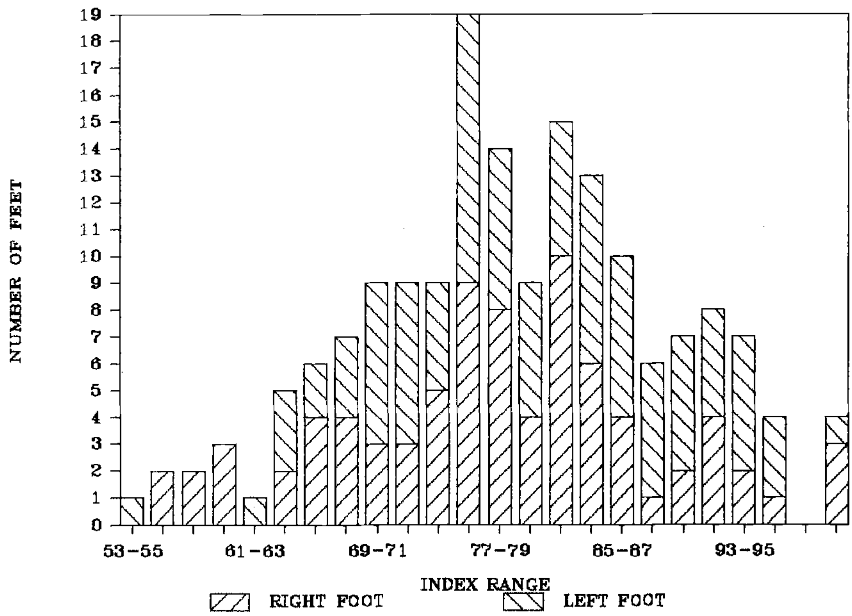


FIG. 6—*Graph of index distribution—toe width/toe length.*

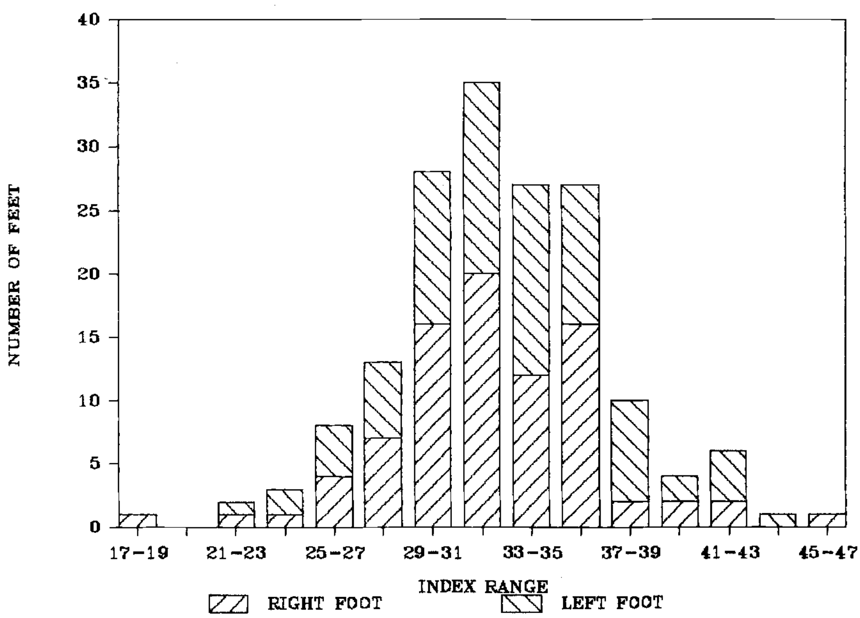


FIG. 7—*Graph of index distribution—toe width/ball width.*

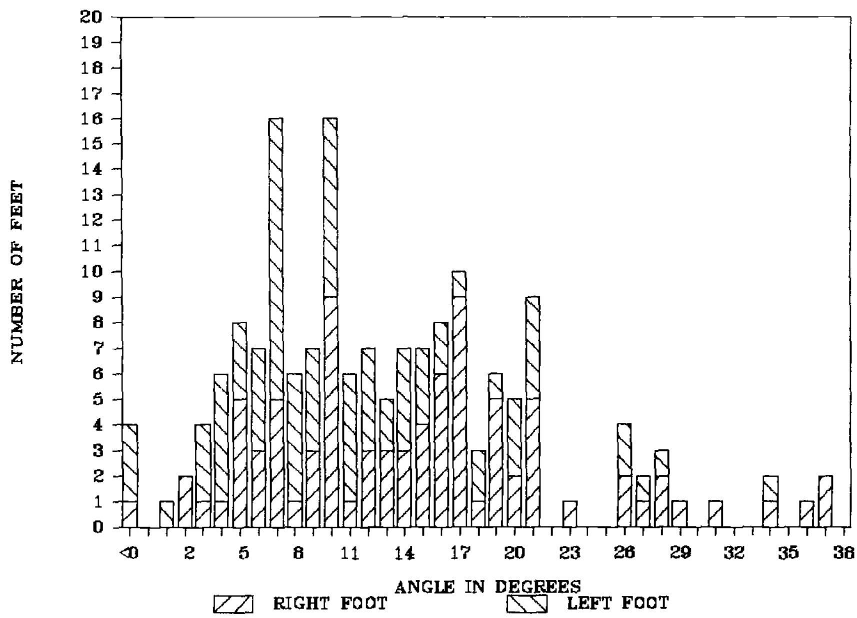


FIG. 8—*Graph of angle distribution—medial toe angle.*

were equal. Values of 3% for left feet and 20% for right feet were observed. One unusual feature noted in our study was that one individual's third toe was the longest toe. This was observed on an impression from his left foot. The frequency of the third toe being the longest appears to be relatively high (about 1%) in our study. We feel that its occurrence in the general population is much lower (see Fig. 9).

Hump indices between left and right feet showed a greater correlation. The number of humps in this study ranged from zero (a lack of humps) to seven, with median number of humps for left and right feet centered at three with fairly even distribution descending in both directions from that number. This data closely agrees with Qamra. Measurement of the number of protuberance along the ball line of the foot was relatively simple, and their location in that area appears to be another feature that aids in conferring individuality to a particular foot. There is tendency of humps not to register on certain surfaces or at times during sequential imprinting. Hump impressions are the result of the soft dermal tissues on the plantar side of the foot spreading on the imprint surface, and some variation is expected (see Fig. 10).

Overall foot length measurements indicated that the right foot was generally within 0.95 to 0.99 of the left. These values closely agree with those of Robbins [*10*], as well. Foot length measurements can be used to estimate an individual's height and weight [*10*]. With the small difference in foot sizes between left and right feet, this apparently does not pose too much of a problem.

Values for the primary measured foot indices demonstrated interesting patterns of variation. Utilizing Qamra's index nomenclature and method, a wide variety of data points were achieved.

A range of approximate points were observed in our toe, heel ball, heel, and instep index data. These points closely agree with that study. The distribution of the clustering subdivision also agreed. Ranges for the heel index did tend to be greater than those of Qamra's,

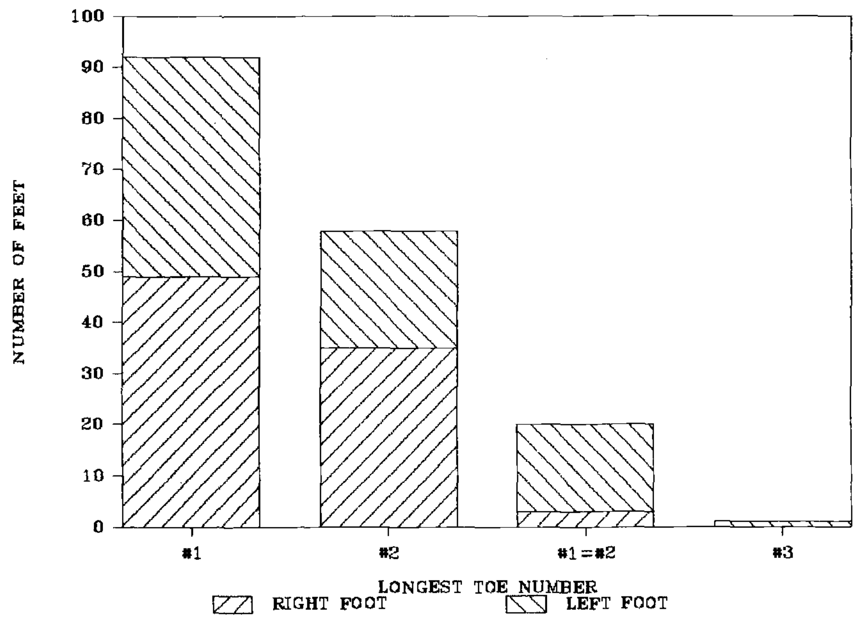


FIG. 9—*Graph of index distribution—longest toe as measured.*

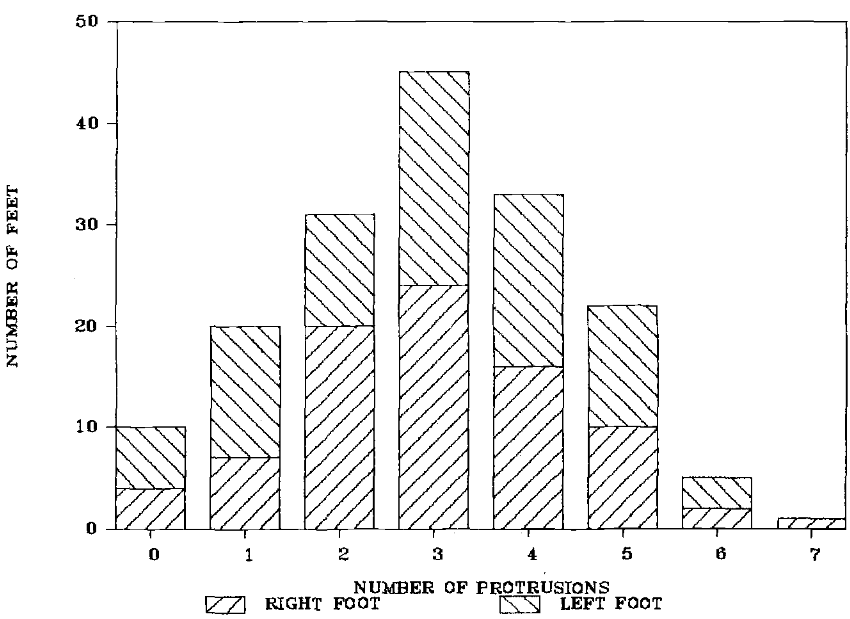


FIG. 10—*Number of humps—protrusions on ball.*

with evidence that in rare cases the width of the heel can be greater than its length. Overall, this data seems to reflect trends for a general population distribution.

To assign a probability value to a given barefoot impression that may be lacking specific individual features as a result of the nature of the individual track, the probabilities for the various indices must be obtained. They can be obtained by the relativity of $P = M/N$ [1], where N is the number of subjects in the study and M is the number of subjects in a particular subdivision. These values are valid when M is established in relation to its maximum probability. Minimum probabilities will have a small value of M and in a small population group a higher degree of uncertainty exists.

Maximum probabilities of calculated foot indices range between 0.2 and 0.3. Minimum probabilities are in the range of 0.01. These closely agree with the results obtained by Qamra [1]. The maximum probabilities of "humps" and "longest toe" are 0.28 and 0.56, respectively, with minimum probabilities for the two indices approximately 0.01.

Using the assumption that the nine indices used are not interdependent, the maximum probabilities range in the order of 10^{-5} and minimum probabilities equating to $0.01^9 = 10^{-18}$. These probabilities would have to be modified depending on the visible and measurable features observed with a given track. However, even with minimum observable features present, a good deal could be said about the track with the calculable population frequencies.

This study also afforded us the opportunity to study the foot impressions of a pair of monozygotic twins. These impressions were obtained while these two individuals were in their early thirties. Both individuals led similarly active lives. Both had had surgery performed on their greater toes, and their physical appearance is similar, yet, the foot impression of these two individuals differ considerably. The differences noted are in foot length, degree of flatfootedness, number of humps, great toe angle, and well impression. Robbins [3] noted that she observed differences in the feet of twins as well. This data lends support to the fact that human feet are unique and that the impressions made by these feet can be used to identify a particular individual.

Conclusions

The data and results obtained from the analysis of human feet and their impressions have yielded a tremendous amount of information regarding the physical characteristics of human feet. This information has provided us with probabilities of particular morphological characteristics and their occurrence in the human population. These probabilities can still be utilized even when only a partial impression of a foot exists. In the case of a crime, a suspect can either be eliminated, statistically included as a possible source of a track, or identified to a track. With the large number of morphological variables and features which as yet defy "mathematical manipulation," a foot track impression in soil or in footwear can be used to identify a particular person. These features, when visible, can be photographed or cast and compared directly to controls. A "perfect fit" would identify the individual.

In conducting this study, we have discovered that previous investigators (Abbott, Cassidy, Qamra, and Robbins) have generally come to the same conclusions regarding the uniqueness of human feet. We feel, however, that for the forensic science community to use this information, standard measuring techniques and methods must be employed. Methods used to measure great toe angle and minor toe patterns, as well, have had the greatest degree of variability.

We must come to an agreement as to whether the great toe angle will be recorded as the intersecting vertex of a line down through the second toe and the medial (inner) side of the foot or as a series of angles measured from a single point, such as the base of the heel.

Foot size measurements have historically been measured under the English system. We feel that conversion to metric system would allow for more uniform results and greater ease in calculating statistical data.

In addition, we feel that some of the morphological features that do not lend themselves to mathematical measurement such as "well impression" could be, perhaps, converted to area measurement with a planimeter, and given a rough description by conversion to a polygon. These features could then be included as additional foot indices when attempting to assign probabilities.

Lastly, more data needs to be collected around the country with emphasis on male and female feet. Racial and cultural aspects of foot morphology must also be considered. With a large data base, footprint examiners could use population frequencies in their analytical approaches and testify to their relative probabilities in the courtroom, thereby allowing this type of analysis to be considered a true science.

Computers with high resolution graphic capabilities could be used to study the effects of foot distortion in footwear or on uneven surfaces so that identification could still be made even under the most difficult environmental circumstances, or if sliding tracks are analyzed. Digital image processing could be used on very tenuous or partially obliterated tracks, as well.

The future holds promising, if not very interesting, possibilities in analytical techniques for the shoe track (footprint) identification technician. With a lot more work and cooperation in the forensic science community, footprint analysis can become as readily accepted in the courts as fingerprint and firearms identification.

Acknowledgments

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References

[1] Qamra, S. R., "Naked Foot Marks—A Preliminary Study of Identification Factors," *Forensic Science International,* Vol. 16, 1980, pp. 145–152.
[2] Lovejoy, O. C., "Methods of Footprint Analysis," Seminar in Footprint and Shoeprint Identification, Federal Bureau of Investigation, 29 April 1984, pp. 1–39.
[3] Robbins, L. M., "The Individuality of Human Footprints," *Journal of Forensic Sciences,* Vol. 23, No. 4, Oct. 1978, pp. 775–778.
[4] Cassidy, M. J., "Footwear Identification," Public Relations Branch of the Royal Canadian Mountain Police for "L" Directorate, Ottawa, Ontario, 1980.
[5] Laskowski, G. E., "An Improved Technique for the Visualization of Footprint Impressions in the Insoles of Athletic Shoes," *Journal of Forensic Sciences.* Vol. 32, No. 4, July 1987, pp. 1075–1078.
[6] Abbott, J. R., *Footwear Evidence: The Examination, Identification, and Comparison of Footwear Impressions,* Charles C Thomas, Springfield, IL, 1964.
[7] Smerecki, C. J. and Lovejoy, C. O., "Identification via Pedal Morphology," *The Police Chief,* April 1984.
[8] Robbins, L. M., *Footprints: Collection, Analysis and Interpretation,* Charles C Thomas, Springfield, IL, 1985.
[9] Robbins, L. M., "Foottracks and Shoes," presented at the First InterAmerican Congress of Forensic Sciences, Sacramento, CA, Nov. 1982.
[10] Robbins, L. M., "Estimating Height and Weight from Size of Footprints," *Journal of Forensic Sciences,* Vol. 31, No. 1, Jan. 1986, pp. 143–152.

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