JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, January 2012, Vol. 57, No. 1
doi: 10.1111/j.1556-4029.2011.01960.x
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

ANTHROPOLOGY

Kewal Krishan,[1] M.Sc., Ph.D.; Tanuj Kanchan,[2] D.F.M., M.D.; Neelam Passi,[1] M.Sc.; and John A. DiMaggio,[3] D.P.M.

Heel–Ball (HB) Index: Sexual Dimorphism of a New Index from Foot Dimensions*

ABSTRACT: The present research is aimed to introduce Heel–ball (HB) index from foot dimensions and determine whether this index exhibits sexual dimorphism. The study was conducted on a sample of 303 North Indian individuals (154 men, and 149 women) aged between 13 and 18 years. The stature, body weight, foot breadth at the ball (BBAL), and foot breadth at heel (BHEL) were measured. The HB index was derived by the formula BHEL × 100/BBAL. Although the mean HB index was larger in women in both feet it showed statistically significant sex differences in the right foot only. The study shows that while the foot dimensions show a positive correlation with stature and weight, the HB index is independent of the stature and weight of an individual. This novel index (HB index) may be utilized in sex determination when a part of the foot is brought for medico-legal investigation.

KEYWORDS: forensic science, forensic anthropology, forensic podiatry, sex determination, foot dimensions, Heel–ball index

The widespread use of biological evidence to identify victims and criminals in the course of law enforcement investigations, criminal court proceedings, and victim service provider issues has had a significant bearing in recent years and hence, new subdisciplines of forensic science became an essential part of crime investigations. Forensic podiatry is one such subdiscipline of forensic science to have emerged in the recent past. One of the essential tasks of the forensic podiatrist is to identify human remains from the feet by analyzing foot measurements or foot characteristics of the deceased (1,2). "Sex" is considered as one of the "big four" parameters in forensic identification besides, race, age, and stature (3).

The issue of personal identification from feet is very pertinent as feet are often recovered from the site of mass disasters, both natural as well as man made (4). Studies have been conducted with regard to personal identification from feet in forensic examinations (5–9). Previous studies have calculated regression formulae for the estimation of stature from various dimensions and segments of feet (4,10,11) and have classified sex on the basis of foot measurements and observations made on some of the parameters of feet (12–15). Grivas et al. (16) attempted to formulate a kind of anthropometric data bank for its future use in forensic identification. Krishan et al. (12) and Moudgil et al. (17) determined the foot index and studied its reliability in sex determination. The foot index, however, cannot be estimated in cases where a part of foot is brought for medico-legal investigations.

[1]Department of Anthropology, Panjab University, Chandigarh, India.
[2]Department of Forensic Medicine and Toxicology, Kasturba Medical College (Affiliated to Manipal University), Mangalore, India.
[3]Forensic Podiatry Consulting Services, PLLC, 1450 Polaris Ln. SW, Bandon, OR 97411.
*Funding provided by the Department of Anthropology, Panjab University, Chandigarh, India.

Received 9 Aug. 2010; and in revised form 17 Nov. 2010; accepted 22 Dec. 2010.

The present research introduces a novel index from foot dimensions: the Heel–ball (HB) index, which may be useful in sex determination when a part of the foot is brought for medico-legal investigation. The aim of the present study is to determine whether the HB index exhibits sexual dimorphism and to find if it can be used as a tool for sex determination in forensic examinations.

Material and Methods

The study was conducted on a sample of 303 North Indian adolescents comprising 154 men and 149 women. The subjects belonged to three villages in Tehsil Kalka, District Panchkula in Haryana state of Northern India. The age of the subjects ranged from 13 to 18 years (mean age in men and women was 15.8 ± 1.7 and 15.5 ± 1.6 years, respectively).

Besides stature and body weight, anthropometric measurements that were taken on the subjects included foot breadth at the ball (BBAL) and foot breadth at heel (BHEL). The foot measurements were taken on both the right and left sides. Different landmarks on the foot are described in Table 1 and illustrated in Fig. 1. The following measurements were taken with standard procedures and landmarks defined by Krishan (4), Robbins (18), and Vallois (19).

Stature

Stature is the vertical distance between the point vertex (highest point on the head when the head is held in Frankfurt horizontal plane) and the floor. The stature was recorded after the subject was made to stand in an erect posture barefoot and without any head coverings. The subject was asked to stand up against the wall with hands hanging down, feet axis parallel or slightly divergent, with the head in Frankfurt horizontal plane. The stature was recorded using the anthropometer. No pressure was exerted because this is a contact measurement.

TABLE 1—*Landmarks used in foot measurements, and their description.*

Landmark	Description
Metatarsal medial (mt.m)	Most medial point of the metatarso-phalangeal joint of toe-1
Metatarsal lateral (mt.l)	Most lateral point on the metatarso-phalangeal joint of toe-5
Calcaneal tubercle lateral (ctu.l)	Most lateral side of the calcaneum
Calcaneal concavity medial (cc.m)	Most medial side of the calcaneum

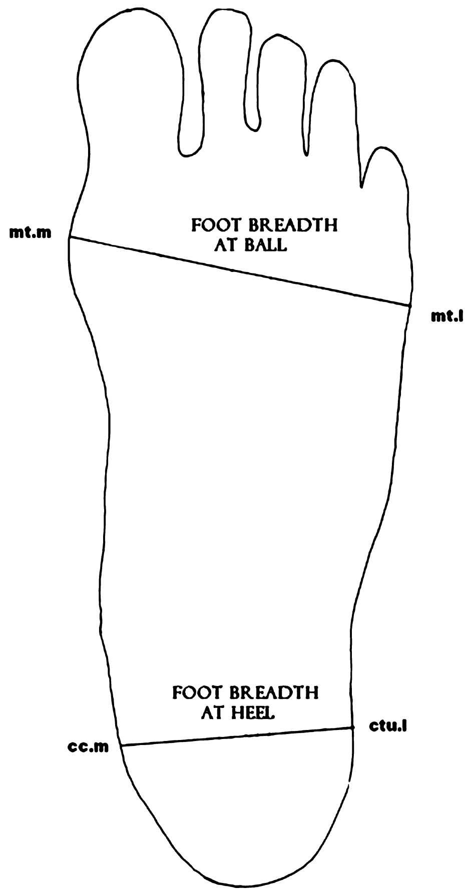

FIG. 1—*Diagram of foot showing the landmarks and measurements.*

Foot Breadth at Ball (BBAL = mt.l − mt.m)

Foot BBAL was measured between the metatarsal lateral (mt.l), the most lateral point on the metatarso-phalangeal joint of toe-five and the metatarsal medial (mt.m), the most medial point of the metatarso-phalangeal joint of toe-one. This forms the widest part of the foot at the ball.

Foot Breadth at Heel (BHEL = ctu.l − cc.m)

The heel is composed of the calcaneum (calcaneous) bone. It contains bony projections or tubercles on its medial and lateral sides in the posterior aspect of the bone. The landmarks on the heel are associated with these identifiable points of reference on the calcaneum. Foot BHEL was measured between the calcaneal tubercle lateral (ctu.l), the most lateral side of the calcaneum and calcaneal concavity medial (cc.m), the most medial side of the calcaneum. This forms the widest part of the foot at the heel.

All the measurements were taken by a trained physical anthropologist (NP) using standard instruments; the anthropometric rod and sliding caliper. Measurements were recorded in centimeters to the nearest millimeter.

Statistical Analysis

The data obtained were computed and analyzed using Statistical Package for Social Sciences (SPSS, version 11.0) computer software (SPSS, Inc., Chicago, IL). The HB index was derived by the formula BHEL × 100/BBAL. The significance of results was tested using Student's *t*-test. A paired *t*-test was performed to compare the foot dimensions of the right and left side. Karl Pearson's correlation coefficient was derived to find a correlation between stature, weight, and foot dimensions in an individual. *p*-Value of <0.05 was considered as significant.

Results and Discussion

Descriptive statistics for the foot measurements are presented in Table 2. Stature, weight, and foot measurements were significantly larger in men than women ($p < 0.001$). Our findings in this regard are consistent with those reported in earlier studies on foot dimensions worldwide (9,20–24). However, in contrast to our study on the 13–18 years age group, the earlier studies were conducted on different adult age groups; Fessler et al. (20) on Americans, Kanchan et al. (21) on North Indian Gujjars aged between 18 and 80 years, Agnihotri et al. (22,23) on Mauritians aged between 18 and 30 years, and Krishan and Sharma (9) on North Indian Rajputs aged between 17 and 20 years. Our study thus suggests that the men–women differences in foot dimensions are well established in the adolescent group. In adolescents, the foot measurements are naturally correlated with age, but the phenomenon is complicated by differences in rates of growth between the individuals (25). The average adult length of foot is attained by the age of 16 years in men and 14 years in women (26,27).

Right–left differences in the BBAL and BHEL are shown in Table 3. BBAL was larger on the left, and BHEL was larger on the right side in both men and women. Both the foot measurements (BBAL and BHEL) showed a statistically significant bilateral asymmetry ($p < 0.001$) in women. Among men, however,

TABLE 2—*Descriptive statistics of foot dimensions (cm) in men and women.*

	Men (n = 154)			Women (n = 149)			
	Range	Mean	SD	Range	Mean	SD	*t*-Value
RBBAL	8.0–11.9	9.9	0.7	7.6–10.1	8.9	0.5	14.659*
LBBAL	8.0–11.6	9.9	0.7	7.7–10.3	9.1	0.5	13.734*
RBHEL	5.0–7.4	6.4	0.5	5.1–6.7	5.9	0.4	10.600*
LBHEL	4.9–7.4	6.3	0.5	4.9–6.8	5.7	0.4	10.440*

SD, standard deviation; RBBAL, right foot breadth at the ball (mt.m − mt.l); LBBAL, left foot breadth at the ball (mt.m − mt.l); RBHEL, right foot breadth at heel (cc.m − ctu.l); LBHEL, left foot breadth at heel (cc.m − ctu.l).

*$p < 0.001$.

TABLE 3—*Side (right–left) differences in foot dimensions (cm) among men and women.*

	Men (n = 154)		Women (n = 149)	
Right–Left	t-Value	p-Value	t-Value	p-Value
BBAL	−0.449	0.654	−4.554	<0.001
BHEL	6.551	<0.001	5.586	<0.001

BBAL, foot breadth at the ball (mt.m − mt.l); BHEL, foot breadth at heel (cc.m − ctu.l).

significant right–left differences were only observed for BHEL. BBAL was significantly larger on the left side in women, while BHEL was larger on the right side in men and women. The foot bears the weight of the body and the act of walking itself is a continuous strain over the heel and foot. It is therefore not surprising to note that the foot that is under more stress during walking and weight-bearing becomes physically better developed (4). The heel stabilizes the weight of the whole body as we walk or perform activities like twisting and dancing, while the ball region is exposed to increased stress during running. We propose these to be the likely contributors in the asymmetry of ball and heel regions. The exact cause for asymmetry on a particular side in our study, however, cannot be explained and is a matter of further investigation.

The HB index was derived and the descriptive statistics for the index, stature, and weight are shown in Table 4. The mean HB index was larger in women than men in both feet. However, the HB index showed statistically significant sex differences in the right foot only. An overlapping of men and women values for HB index was observed. The degree of correlation was estimated between stature, weight, foot dimensions, and HB index. It was apparent that while the foot dimensions showed a positive correlation with stature and weight, the HB index did not show any correlation with the stature and weight of an individual (Table 5). Thus, while the sex differences in foot measurements are dependent on the body build of an individual, the HB index is independent of these variables.

In the past, studies have been conducted on the foot with regard to forensic examinations where the authors have worked on sexual dimorphism (12,20,22,24), stature estimation (9,21), and uniqueness of the foot and footprints (28,29). Other areas include the association of the foot with the footwear at the crime scene (30,31), radiographic and anatomic examination of foot bones in forensic examinations (32–39), and correlation of hand and foot dimensions for personal identification in mass disasters (5). Moudgil et al. (17) have studied the foot index as a possible parameter to determine sex in forensic examinations. Krishan et al. (12) in a study conducted on Rajputs of North India demonstrated that the sex can be determined from the foot dimensions using sectioning point and regression analysis with reasonable accuracy. The study indicated that foot breadth had a better accuracy in sex determination than

TABLE 5—*Pearson's correlation (r) between stature, weight, foot measurements, and derived indices in right and left foot* (n = *303).*

	Right Foot		Left Foot	
Variable	Stature	Weight	Stature	Weight
BBAL	0.683*	0.656*	0.682*	0.670*
BHEL	0.657*	0.683*	0.665*	0.683*
HB index	0.008	0.079	0.049	0.100

BBAL, foot breadth at the ball (mt.m − mt.l); BHEL, foot breadth at heel (cc.m − ctu.l); HB, heel ball.
*p < 0.001.

foot length and that the foot index was a poor sex indicator. In the present study, the mean HB index was larger in women than men in both feet. Because no attempt has been ever made to devise an index such as the proposed HB index in the present study, findings of the present study can not be compared *per se*.

Conclusion

DNA analysis in forensic identification provides the most reliable results. However, it is yet to be used routinely in the developing countries owing to its lack of cost-effectiveness at this time. Standard techniques in forensic anthropology, hence, continue to play a foremost role in the identification of human remains.

It has been observed that the HB index is independent of the stature and weight of an individual. It can be considered a better sex determinant because it is not influenced by the body build of an individual. However, in medico-legal investigations, the significance of the HB index in sex determination remains limited because of significant overlapping of the men and women values. Further studies on larger samples are proposed to confirm the findings on this preliminary study. The HB index needs further exploration on footprints so that the comparison of this index on feet and footprints can be made.

Acknowledgments

This study is a part of Master's Degree dissertation submitted to the Department of Anthropology, Panjab University, Chandigarh, India. The authors are thankful to the department for funding data collection and providing all the facilities for conducting this research. Many thanks to the Principals of Government Schools located in villages Nanakpur, Marranwala and Bassolan of Tehsil Kalka, District Panchkula in Haryana state of North India for allowing data collection. The authors gratefully acknowledge the voluntary participation and cooperation of the subjects during data collection. Thanks are also due to honorable Padamshree Professor R.C. Sobti, Vice-Chancellor of Panjab University, for constant encouragement of research and

TABLE 4—*Descriptive statistics for stature (cm), weight (kg), and derived indices in men and women.*

	Men (n = 154)			Women (n = 149)			
	Range	Mean	SD	Range	Mean	SD	t-Value
Stature	134.4–184.7	163.1	10.1	141.7–183.9	154.3	5.9	9.264**
Weight	25.0–76.0	45.0	9.7	28.0–64.0	40.9	6.9	4.254**
RHB index	55.7–79.6	64.3	3.7	58.8–72.6	65.5	3.0	2.980*
LHB index	55.7–72.6	63.1	3.3	55.8–72.2	63.7	3.3	1.687

SD, standard deviation; RHB, right heel ball; LHB, left heel ball.
**p < 0.001, *p < 0.05.

its publication in American journals of international repute like the *Journal of Forensic Sciences*.

References

1. DiMaggio JA. Forensic podiatry—an emerging new field. J Forensic Identif 1995;45:495–7.
2. Vernon DW, McCourt FJ. Forensic podiatry—a review and definition. Br J Podiatry 1999;2:45–8.
3. Krogman WM, Iscan YM. The human skeleton in forensic medicine, 2nd edn. Springfield, IL: Charles C. Thomas Pub Ltd, 1986.
4. Krishan K. Determination of stature from foot and its segments in a North Indian population. Am J Forensic Med Pathol 2008;29:297–303.
5. Kanchan T, Krishan K, Sharma A, Menezes RG. A study of correlation of hand and foot dimensions for personal identification in mass disasters. Forensic Sci Int 2010;199:112.e1–6.
6. Kanchan T, Menezes RG, Moudgil R, Kaur R, Kotian MS, Garg RK. Stature estimation from foot length using universal regression formula in a North Indian population. J Forensic Sci 2010;55:163–6.
7. D'Août K, Meert L, Van Gheluwe B, De Clercq D, Aerts P. Experimentally generated footprints in sand: analysis and consequences for the interpretation of fossil and forensic footprints. Am J Phys Anthropol 2010;141:515–25.
8. Sen J, Ghosh S. Estimation of stature from foot length and foot breadth among the Rajbanshi: an indigenous population of North Bengal. Forensic Sci Int 2008;181:55.e1–6.
9. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in North Indian population. J Forensic Leg Med 2007;14:327–32.
10. Ozden H, Balci Y, Demirustu C, Turgut A, Ertugrul M. Stature and sex estimate using foot and shoe dimensions. Forensic Sci Int 2005;147:181–4.
11. Sanli SG, Kizilkanat ED, Boyan N, Ozsahin ET, Bozkir MG, Soames R, et al. Stature estimation based on hand length and foot length. Clin Anat 2005;18:589–96.
12. Krishan K, Kanchan T, Sharma A. Sex determination from hand and foot dimensions in a North Indian population. J Forensic Sci 2011;56(2):453–9.
13. Zeybek G, Ergur I, Demiroglu Z. Stature and gender estimation using foot measurements. Forensic Sci Int 2008;181:54.e1–5.
14. Robinson C, Eisma R, Morgan B, Jeffery A, Graham EA, Black S, et al. Anthropological measurement of lower limb and foot bones using multi-detector computed tomography. J Forensic Sci 2008;53:1289–95.
15. Atamturk D, Duyar I. Age-related factors in the relationship between foot measurements and living stature and body weight. J Forensic Sci 2008;53:1296–300.
16. Grivas TB, Mihas C, Arapaki A, Vasiliadis E. Correlation of foot length with height and weight in school age children. J Forensic Leg Med 2008;15(2):89–95.
17. Moudgil R, Kaur R, Menezes RG, Kanchan T, Garg RK. Foot index: is it a tool for sex determination? J Forensic Leg Med 2008;15:223–6.
18. Robbins RM. Footprints—collection, analysis and interpretation. Springfield, IL: Charles C. Thomas, 1985.
19. Vallois HV. Anthropometric techniques. Curr Anthropol 1965;6:127–44.
20. Fessler DM, Haley KJ, Lal RD. Sexual dimorphism in foot length proportionate to stature. Ann Hum Biol 2005;32:44–59.
21. Kanchan T, Menezes RG, Moudgil R, Kaur R, Garg RK. Stature estimation from foot dimensions. Forensic Sci Int 2008;179:241.e1–5.
22. Agnihotri AK, Purwar B, Googoolybe K, Agnihotri S, Jeebun N. Estimation of stature by foot length. J Forensic Leg Med 2007;14:279–83.
23. Agnihotri AK, Shukla S, Purwar B. Determination of sex from foot measurements. Internet J Forensic Sci 2007;2(1), http://www.ispub.com/journal/the_internet_journal_of_forensic_science/volume_2_number_2_18/article/determination_of_sex_from_the_foot_measurements.html (accessed April 28, 2010).
24. Bob-Manuel IF, Didia BC. Sexual dimorphism in foot dimensions among adult Nigerians. Internet J Biol Anthropol 2009;3(1), http://www.ispub.com/journal/the_internet_journal_of_biological_anthropology/volume_3_number_1_63/article/sexual-dimorphism-in-foot-dimensions-among-adult-nigerians.html (accessed April 28, 2010).
25. Scheuer L. Application of osteology to forensic medicine. Clin Anat 2002;15:297–312.
26. Anderson M, Blais M, Green WT. Growth of the normal foot during childhood and adolescence—length of the foot and interrelations of foot, stature and lower extremity as seen in serial records of children between 1–18 years of age. Am J Phys Anthropol 1956;14:287–308.
27. Blais MM, Green WT, Anderson M. Lengths of the growing foot. J Bone Jt Surg 1956;38A:998–1000.
28. Robbins LM. The individuality of human footprint. J Forensic Sci 1978;23:778–85.
29. Krishan K. Individualizing characteristics of footprints in Gujjars of North India-forensic aspects. Forensic Sci Int 2007;169:137–44.
30. DiMaggio JA. The role of feet and footwear in medico legal investigations. In: Rich J, Dean DE, Powers RH, editors. Forensic medicine of the lower extremity: human identification and trauma analysis of the thigh, leg and foot. Clifton, NJ: Humana Press, 2005;375–400.
31. Vernon W. The development and practice of forensic podiatry. J Clin Forensic Med 2006;13:284–7.
32. Sudimack JR, Lewis BJ, Rich J, Dean DE, Fardal PM. Identification of decomposed human remains from radiographic comparisons of an unusual foot deformity. J Forensic Sci 2002;47:218–20.
33. Rich J, Dean DE, Cheung YY. Forensic implications of the foot and ankle. J Foot Ankle Surg 2003;42:221–5.
34. Cordeiro C, Muñoz-Barús JI, Wasterlain S, Cunha E, Vieira DN. Predicting adult stature from metatarsal length in a Portuguese population. Forensic Sci Int 2009;193:131.e1–4.
35. Abdel Moneim WM, Abdel Hady RH, Abdel Maaboud RM, Fathy HM, Hamed AM. Identification of sex depending on radiological examination of foot and patella. Am J Forensic Med Pathol 2008;29:136–40.
36. Case DT, Ross AH. Sex determination from hand and foot bone lengths. J Forensic Sci 2007;52:264–70.
37. Gualdi-Russo E. Sex determination from the talus and calcaneus measurements. Forensic Sci Int 2007;171:151–6.
38. Dean DE, Tatarek NE, Rich J, Brogdon BG, Powers RH. Human identification from the ankle with pre- and postsurgical radiographs. J Clin Forensic Med 2005;12:5–9.
39. Bidmos MA, Dayal MR. Further evidence to show population specificity of discriminant function equations for sex determination using the talus of South African blacks. J Forensic Sci 2004;49:1165–70.

Additional information and reprint requests:
Dr. Kewal Krishan
Sr. Assistant Professor
Department of Anthropology
(UGC Centre for Advanced Studies and FIST Department)
Punjab University
Sector-14
Chandigarh-160 014
India
E-mail: gargkk@yahoo.com