Brazilian Journal of Forensic Sciences, Medical Law and Bioethics

Journal homepage: www.ipebj.com.br/forensicjournal

Estimation of Stature from Various Body Parameters in Population of Vidharbha, Maharashtra

Marvel G. Bhosle[1], Malojirao S. Bhosale[2,3], Tanu Y. Padole[2], Yashwanth Jalagari[2], Priyavandana Kavalampet[2], Deepika Bhandari[3,*]

[1] *Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India*

[2] *Government Institute of Forensic Science, Nagpur, India*

[3] *Institute of Forensic Science, Mumbai, India*

* Corresponding author. E-mail: *deepikabhandari2910@gmail.com*

Received 02 December 2022; Accepted 26 November 2024

Abstract. In cases of a person found mutilated and dismembered or where a skeleton has parts missing, stature is a crucial parameter for identifying the deceased. This study aims to derive regression equations for numerous body parameters while identifying the most accurate body parameter for measuring stature. Fourteen body parameters from the upper and lower extremities were carefully measured, along with hip size, which had not been included in previous studies. The study involved a population sample of 150 females and 150 males from the Vidarbha region of Maharashtra. The present study demonstrated that upper as well as lower extremities have positive correlation with stature. However, lower extremity had higher correlation with stature as compared to upper extremity. Compared to other body parameters, iliac to foot had lowest Standard Error of the Estimate (SEE) in males (SEE±3.49) and females (SEE±3.38) and highest correlation with stature in males (r^2= 0.7) and females (r^2=0.63). Thus, Iliac to foot was considered as the best parameter to estimate stature. On the other hand, hip size had highest SEE in males (SEE ±6.99) and females (SEE ±5.46) and very less correlation in males (r^2=0.00) and females (r^2=0.04). Thus, hip size was considered as worst body parameter to estimate stature in both males and females. Also, regression equations derived in this study could be successfully and reliably used to estimate stature in population of Vidharbha, Maharashtra.

Keywords: Body parameters, Stature, Correlation, Regression.

http://dx.doi.org/10.17063/bjfs12(3)y2024291-302

1. Introduction

In forensic medicine cases, stature is one of the key indicators of a person's identity. In cases of accidents, terrorist attacks, large-scale natural disasters like floods and earthquakes, and assault cases where the body is dismembered and mutilated to conceal the identity of the victim, estimation of stature from decomposed bodies and incomplete skeletons is essential for identification.

The relationship between stature and other body components is often influenced by biological and genetic factors. Researchers have identified this connection, and it is frequently modeled using linear regression equations to predict stature based on measurements of other body parts. This approach allows for a more accurate estimation of height, taking into account variations in body proportions across different populations. Regression is a statistical method to determine the relationship between two or more variables[1]. Stature estimation can be approached through anatomical and mathematical methods. The anatomical method, also known as the whole skeleton method, involves calculating the sum of the vertical measurements of all bones contributing to stature, directly using a formula or incorporating a correlation factor to account for soft tissue[2,3,4,5]. This procedure requires a relatively full skeleton, which is challenging in forensic circumstances. A mathematical method is used in the current study to estimate stature. This approach is predicated on a mathematical correlation between stature and body parts, where taller people tend to have longer body parts than shorter persons[6,15]. The fundamental benefit of the mathematical approach is that it only needs one bone or body part. However, because there is such a broad variation in body proportions within and between groups, this method's forecasting accuracy is less precise.

Regression analysis and multiplication factors are both used for estimating stature. In terms of mathematical methodology, regression analysis is a more effective and trustworthy instrument than multiplication factor analysis[7,8]. Different equations are needed for various populations and various body parts or bones. Because of the ethnic heterogeneity in body dimensions caused by inherited traits and environmental factors, regression models developed for one community cannot be applied to another[6]. The genetic make-up of an individual, geographic location, environment, and climatic conditions all play a role in how tall a person is. Regression models should therefore be used with caution when assessing the stature of people from varied racial and geographical backgrounds.

The forensic scientist can more precisely identify the deceased with the use of an estimated stature. Identification of the deceased is crucial for official, legal, and statistical reasons. In the clinical setting for nutrition and health studies, stature is a crucial predictor of growth and development[9]. Stature is a crucial factor when determining basal energy expenditure, body mass index, basal metabolic rate, body composition, vital capacity, and estimates of nutrient requirements along with body weight[9]. As a result, the objectives of the current study include establishing the optimal body metrics that can be used to estimate stature as well as developing regression models for a variety of body parameters. The current study was specifically conducted on the population of the Vidarbha region, located in the eastern part of Maharashtra, India. This region is known for its distinct cultural, geographic, and demographic characteristics, making it an ideal focus for developing region-specific anthropometric models. By concentrating on this population, the study aimed to address the lack of localized data for stature estimation and to highlight the importance of tailoring regression formulas to suit the unique attributes of specific ethnic and regional groups. This focused approach enhances the relevance and applicability of the findings within the Vidarbha population while contributing to the broader understanding of anthropometric variations in India.

2. Materials and methods

The current study focused on the population of the Vidarbha region in Maharashtra, India. A total of 300 individuals (150 males and 150 females) aged 18 to 40 years participated, all of whom were in good health and free from physical abnormalities. Each participant provided written consent and detailed personal information, including their place of origin, to confirm their association with the Vidarbha population. This ensured that all individuals selected for the study authentically represented the region. Anthropometric measurements were conducted using precise instruments, including a stadiometer (Prime Surgical India; least count = 0.5 cm), Osteometric board (Desco Medical India), vernier caliper (Labworld Matt Vernier Slide Caliper; least count = 0.1 mm), measuring tape (Freemans Microfibre Centiflex; least count = 1 mm), scale (Global Art), and digital weighing balance (Omron).

A comprehensive set of 15 body measurements was recorded, including height, total arm length, upper arm length, ulnar length, wrist breadth, hand length, hand breadth, iliac to foot, iliac to patella, lower leg length, leg length, foot height, foot breadth, foot length, and hip size. Height was measured using the Uhrová and Sanli methods, with participants standing upright on a stadiometer[10,11].

Measurements such as total arm length, upper arm length, ulnar length, iliac to foot, iliac to patella, and hip size were taken in a standing position using a measuring tape. Lower leg length, leg length, and foot height were assessed in a sitting position using an osteometric board, vernier calliper, and measuring tape. Bone anthropological landmarks were utilized to ensure accuracy, adhering to methodologies outlined in prior studies.

The study employed Kamal and Yadav's approach for total arm length, Ahmed's[1] method for upper arm length, ulnar length, and wrist breadth, and Kanchan et al.'s technique for hand length and handbreadth[1,12,13]. Ozaslan et al.'s methods were referenced for trochanteric height (iliac to foot), thigh length (iliac to patella), lower leg length, leg length, and foot height[8]. Kim's method was used to measure foot length and breadth, while hip size was determined by assessing the horizontal width of the pelvis[14]. Figures 1 and 2 provide detailed representations of all the measured parameters.

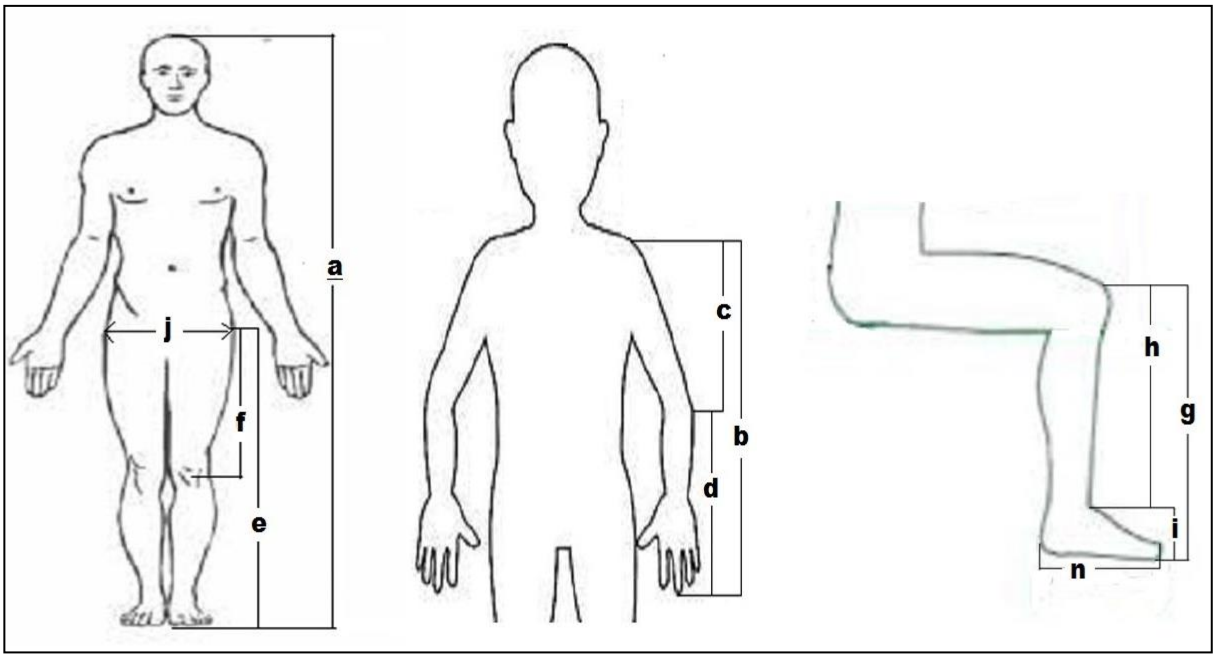

Figure 1. Body Parameters used in study [a-Height, b-Total arm length, c-Upper arm length , d-Ulnar length, e-Iliac to foot , f-Iliac to patella, g-Lower leg length, h-Leg length , i-Foot height, j-Hip size].

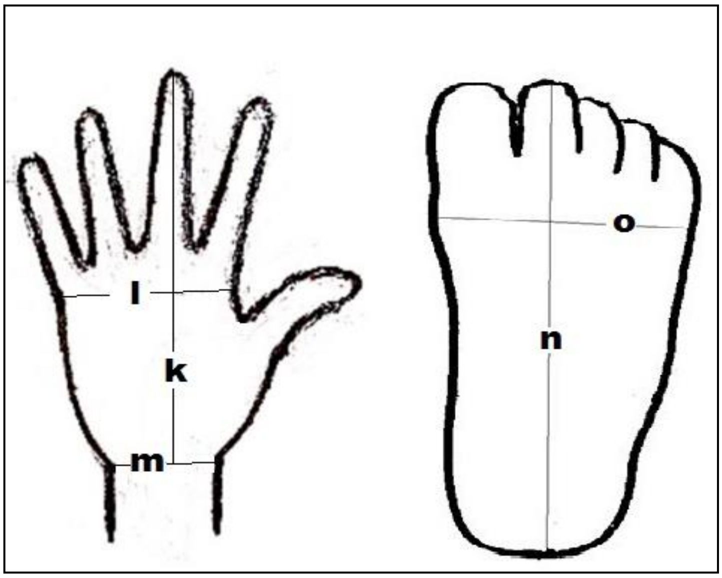

Figure 2. Body Parameters used in study [k - Hand length, l -Hand breadth, m- Wrist breadth, n - Foot length, and o -Foot breadth].

2.1. Statistical analysis

The median, maximum, minimum, standard error, correlation coefficient (r^2), and standard error of the estimate (SEE) were used to present the data. Software called RStudio was used for statistical analysis. To examine the statistical significance of differences in the regression equation affecting stature, the paired t-test was used. If the results had a p-value less than 0.05, the results were deemed significant.

3. Results

Table 1 shows descriptive statistics of parameters (median, minimum, maximum, standard error and r^2) studied in 150 males. This table shows that in males, iliac to foot length had a greater correlation value (r^2=0.76) with stature. Also, foot breadth (r^2=0.04) and hip size (r^2=0.04) were found to have the lowest correlation with stature. The body parameters that had the highest correlation value with stature in males in increasing order were observed as:

Iliac –foot> Total Arm Length>Iliac –patella> Upper Arm Length> Lower Leg Length> Foot length.

Iliac to foot was found to be the best body parameter whereas hip size and foot breadth to be the worst body parameters correlated with stature in males based on correlation values shown in the table.

Table 1. Descriptive statistics of parameters in 150 males.

Parameters	Min	Median	Max	Standard Error±	r^2
Total arm length	-11.75	0.04	7.95	3.94	0.69
Upper arm length	-16.34	0.65	9.46	5.0	0.51
Ulnar length	-14.1	0.28	12.69	5.67	0.3
Wrist breadth	-12.6	-0.98	13.47	6.53	0.16
Hand length	-11.5	-0.06	10.79	5.61	0.38
Hand breadth	-14.26	-0.50	17.83	6.99	0.046
Iliac –foot	-7.72	0.037	13.78	3.49	0.76
Iliac –patella	-6.70	-0.694	12.31	4.17	0.66
Lower leg length	-15.32	0.694	10.07	5.48	0.41
Leg length	-17.12	-0.499	12.58	5.75	0.35
Foot height	-14.512	0.076	16.55	6.71	0.12
Foot breadth	-15.27	-0.43	17.76	6.98	0.04
Foot length	-12.52	-0.076	14.41	5.46	0.41
Hip size	-14.9	-0.35	15.49	6.99	0.04
Stature	156.2	169.5	189.9	-	-

Table 2 shows descriptive statistics of parameters (median, minimum, maximum, standard error and r^2) studied in 150 females. This table showed that in females, iliac to foot length had a greater correlation (r^2=0.6) with stature. Also, foot breadth (r^2= 0.35) and hip size (r^2= 0.00) were found to have the lowest correlation with stature. The body parameters that had the highest correlation value with stature in females in increasing order were observed as:

Iliac –foot > Hand Length> Lower Leg Length> Total arm length >Leg Length> Ulnar length.

Iliac to foot was found to be the best body parameter whereas foot breadth and hip size were the worst body parameters correlated with stature in females based on correlation values shown in the table.

Table 3 shows derived linear regression equation to estimate stature from different body parameters in males. Similarly, Table 4 shows derived linear regression equations to estimate stature in females. These tables give regression equations which are derived using y = ax +c formula, where ax is slope and c is the intercept. Regression equations derived were applied to all body parameters. SEE was added and subtracted in derived regression equations to estimate stature [12] of males and females.

Table 2. Descriptive statistics of parameters in 150 females.

Parameters	Min	Median	Max	Standard Error±	r^2
Total arm length	-10.96	0.12	12.82	3.98	0.49
Upper arm length	-14.5	0.29	12.26	4.50	0.36
Ulnar length	-10.98	-0.04	11.81	4.37	0.39
Wrist breath	-11.47	0.24	13.83	5.47	0.05
Hand length	-8.27	-0.04	12.88	3.55	0.60
Hand breadth	-11.58	0.07	14.61	5.63	-0.005
Iliac –foot	-9.37	0.43	9.25	3.38	0.63
Iliac –patella	-12.48	-019	13.13	4.52	0.35
Lower leg length	-9.93	-0.30	9.88	3.65	0.58
Leg length	-10.46	-0.30	13.85	4.16	0.45
Foot height	-11.27	-0.07	15.20	5.61	0.003
Foot breadth	-9.96	0.05	14.15	4.52	0.35
Foot length	-9.96	0.05	14.15	4.52	0.35
Hip size	-11.7	-0.08	14.63	5.64	0.00
Stature	143.9	155.5	170.2	-	-

Table 3. Simple linear regression equations to estimate stature from different body parameters in males.

Parameter	Regression equation	±SEE	r^2	p -value
Iliac –foot	Stature =49.13+1.23×Bone length	±3.49	0.76	< 2.2 e-16
Iliac to patella	Stature =61.77+2.21 ×Bone length	±4.17	0.66	< 2.2 e-16
Total arm length	Stature = 50.527+1.57 ×Bone length	±3.94	0.69	< 2.2 e-16
Upper arm length	Stature =90.124+2.34×Bone length	±5.0	0.512	1.402 e-11
Lower leg length	Stature = 109.09+1.19 ×Bone length	±5.48	0.41	5.61
Foot length	Stature =81.46+3.42 ×Bone length	±5.46	0.41	4.63 e-09

Estimated statures calculated by using derived regression equations had a greater resemblance to the actual statures presented in Table 5 and Table 6 Estimated error values were found to be extremely low and produced values that were close to those of real stature when applying the regression equation approach.

For males, the estimated stature based on bodily measurements i.e., total arm length and foot length, matched the actual stature. Stature estimated through upper arm length was found very close to actual stature in males. Similarly, stature estimated through body parameters i.e., lower leg length and iliac to foot length were fairly accurate with actual stature in females.

Table 4. Simple linear regression equations to estimate stature from different body parameters in females.

Parameter	Regression equation	±SEE	r^2	p -value
Iliac –foot	Stature =55.82+1.11×Bone length	±3.38	0.63	< 2.2 e-16
Hand length	Stature =155.6+1.0×Bone length	±3.55	0.6	< 2.2 e-16
Lower leg length	Stature = 58.52+ 1.96×Bone length	±3.65	0..58	< 2.2 e-16
Total arm length	Stature = 68.48+1.24 ×Bone length	±3.98	0.49	< 2.2 e-16
Leg length	Stature = 73.5+1.88 ×Bone length	±4.16	0.45	5.61
Ulnar length	Stature =90.73+ 2.61 ×Bone length	±4.37	0.39	4.63 e-09

Table 5. Differences in estimated and actual stature by using derived regression equation from various body parameters in males.

Parameter	Regression equation	Actual Stature	Estimated Stature	Error in cm
Iliac –foot	Stature =49.13+1.23×Bone length	169	165	4
Iliac to patella	Stature =61.77+2.21 ×Bone length	169	164	5
Total arm length	Stature = 50.527+1.57 ×Bone length	169	169	0
Upper arm length	Stature =90.124+2.34×Bone length	169	168	1
Lower leg length	Stature = 109.09+1.19 ×Bone length	169	173	4
Foot length	Stature =81.46+3.42 ×Bone length	169	169	0

Table 6. Differences in estimated and actual stature by using derived regression equation from various body parameters in females.

Parameter	Regression equation	Actual Stature	Estimated Stature	Error in cm
Iliac –foot	Stature =55.82+1.11×Bone length	162	160.7	2
Hand length	Stature =155.6+1.0×Bone length	162	172	10
Lower leg length	Stature = 58.52+ 1.96×Bone length	162	161	1
Total arm length	Stature = 68.48+1.24 ×Bone length	162	158	4
Leg length	Stature = 73.5+1.88 ×Bone length	162	159	3
Ulnar length	Stature = 90.73+ 2.61 ×Bone length	162	158	4

4. Discussion

In the present study, the iliac-to-foot measurement demonstrated the strongest correlation with stature, with a correlation coefficient of r^2=0.76 in males and r^2=0.63 in females. This parameter also showed the lowest Standard Error of the Estimate (SEE), with values of SEE±3.49SEE for males and SEE±3.38 for females. Similar findings were reported in a study by Ahmed on the Sudanese Arab population, where the r^2 values were 0.58 for males and 0.43 for females, with SEE±43.01 and SEE±48.8SEE respectively[1].

Additionally, total arm length exhibited a strong correlation with stature, with a correlation coefficient of r^2=0.69 and a low SEE of SEE±3.94 in males. Comparable results were observed in a study by Kamal and Yadav on the Kori population of North India, which reported r^2=0.44, SEE±0.07 in males, and r^2=0.72, SEE±0.1 in females.[12] These findings reinforce the reliability of these parameters for stature estimation across different populations.

The iliac-to-patella parameter exhibited the highest correlation with stature in males, with a correlation coefficient of r2=0.6. Additionally, the iliac-to-foot measurement demonstrated the lowest Standard Error of the Estimate (SEE), with a value of SEE± 4.17 in males. Similar observations were reported in Özaslan's study on adult Turks residing in Istanbul, where the iliac-to-foot parameter showed a correlation coefficient of r^2=0.20 and a SEE of SEE± 59.4 in males[8].

In this study, hand length exhibited the strongest correlation with stature in females, with a correlation coefficient of r^2=0.60. Comparable findings were reported in Kim's study on the Korean population, which recorded a correlation coefficient of r^2=0.2 and a Standard Error of the Estimate (SEE) of SEE±5.18.[14] Similarly, Ahmed's study observed a correlation coefficient of r^2=0.37 and a SEE of SEE±4.53.[1] Additionally, Krishan's research on the Rajputs of Himachal Pradesh reported closely aligned results, with a correlation coefficient of r^2=0.7 and a SEE of SEE±0.74.[7] These consistent findings across diverse populations highlight the reliability of hand length as a parameter for stature estimation in females.

Foot breadth was identified as the least reliable parameter for predicting stature in both males and females. It showed the lowest correlation coefficient values, with r^2=0.04 in males and r^2=0.05 in females. This result aligns with findings from a previous study by Kamal and Yadav, which reported similarly low correlation coefficients of r^2=0.3 in males and r^2=0.4 in females[12].

Additionally, handbreadth was found to be the poorest parameter for estimating stature in females, with the lowest correlation coefficient of r^2=0.04. Comparable results were observed in the study by Kamal and Yadav, which reported r^2=0.08 in males and r^2=0.16 in females[12]. These findings underscore the limited utility of both foot breadth and hand breadth as predictors of stature.

In the current study, hip size, a parameter not considered in previous research, was found to be the least effective for predicting stature in both males and females. The correlation coefficient values were r^2=0.04 for females and r^2=0.000 for males, indicating its minimal predictive value for stature estimation.

5. Conclusion

The current study demonstrates a positive correlation between stature and both the upper and lower extremities, with the lower extremity showing a stronger correlation than the upper extremity. The results revealed that stature was most strongly associated with body measurements such as iliac to foot, iliac to patella, total arm length, upper arm length, lower leg length, and foot length in males, and iliac to foot, hand length, lower leg length, total arm length, leg length, and ulnar length in females. These measurements exhibited very low Standard Error of the Estimate (SEE) values.

When the derived regression equations were applied to estimate stature, the results were highly accurate, with minimal differences between the estimated and actual stature. The regression equations developed in this study can, therefore, be effectively used to estimate the stature of individuals in the Vidarbha region of Maharashtra.

Reliable stature estimation plays a critical role in forensic identification, particularly in cases involving unidentified remains. The development of population-specific regression equations enhances the precision of forensic investigations by providing tailored tools for estimating stature in the Vidarbha region. This ensures a more accurate identification process, contributing to the broader field of forensic science and justice.

However, it is important to acknowledge some limitations, such as potential variability in body proportions among different subpopulations within Maharashtra. Future studies could further validate these models by testing the equations across different age groups or applying them to a larger, more diverse demographic sample. This would not only confirm the accuracy of the equations but also promote further research in this area.

Acknowledgements

The authors express their heartfelt gratitude to the faculty of the Government Institute of Forensic Science, Nagpur, Maharashtra, for their invaluable insights and guidance throughout the completion of this work. Special thanks are extended to Miss Shraddha Mulmule and Miss Arundhati Deo from the Department of Statistics at the Institute of Science, Nagpur, for their expertise and support in conducting the statistical analysis for this study. The authors also deeply appreciate the voluntary participation of all the participants who contributed to this research.

References

1. Ahmed AA. Estimation of stature from the upper limb measurements of Sudanese adults. Forensic Sci Int. 2013;228(1-3):178.e1-7. https://doi.org/10.1016/j.forsciint.2013.03.008
2. Fully G. Une nouvelle methode de determination de la taille. Ann Med Leg Criminol. 1956;36:266-73.
3. Stewart TD. Essentials of forensic anthropology: especially as developed in the United States. Springfield, IL: Charles C. Thomas; 1979.

4. Lundy JK. A report on the use of Fully's anatomical method to estimate stature in military skeletal remains. J Forensic Sci. 1988;33(2):534-9. https://doi.org/10.1520/JFS11969J
5. Raxter MH, Auerbach BM, Ruff CB. Revision of the Fully technique for estimating statures. Am J Phys Anthropol. 2006;130(3):374-84. https://doi.org/10.1002/ajpa.20361
6. Christensen A, Passalacqua N, Bartelink E. Forensic anthropology: current methods and practice. Oxford, San Diego, CA: Academic Press; 2014. https://doi.org/10.1016/B978-0-12-418671-2.00005-7
7. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in a North Indian population. J Forensic Leg Med. 2007;14(6):327-32. https://doi.org/10.1016/j.jcfm.2006.10.008
8. Ozaslan A, İşcan MY, Ozaslan İ, Tugcu H, Koç S. Estimation of stature from body parts. Forensic Sci Int. 2003;132(1):40-5. https://doi.org/10.1016/S0379-0738(02)00425-5
9. Pal A, De S, Sengupta P, Maity P, Dhara PC. Estimation of stature from hand dimensions in Bengalee population, West Bengal, India. Egypt J Forensic Sci. 2016;6(2):90-8. https://doi.org/10.1016/j.ejfs.2016.03.001
10. Uhrova P, Benus R, Masnicova S, Obertova Z, Kramarova D, Kyselicova K, Nescakova E. Estimation of stature using hand and foot dimensions in Slovak adults. Leg Med (Tokyo). 2014;17(2):92-7. https://doi.org/10.1016/j.legalmed.2014.10.005
11. Sanli SG, Kizilkanat ED, Boyan N, Ozsahin ET, Bozkir MG, Soames R, Oguz O. Stature estimation based on hand length and foot length. Clin Anat. 2005;18(8):589-96. https://doi.org/10.1002/ca.20146
12. Kamal R, Yadav PK. Estimation of stature from different anthropometric measurements in Kori population of North India. Egypt J Forensic Sci. 2016;6(4):468-77. https://doi.org/10.1016/j.ejfs.2016.12.001
13. 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(1-3):112.e1-6. https://doi.org/10.1016/j.forsciint.2010.03.002
14. Kim W, Kim YM, Yun MH. Estimation of stature from hand and foot dimensions in a Korean population. J Forensic Leg Med. 2018;55:87-92. https://doi.org/10.1016/j.jflm.2018.02.011
15. Willey P. Stature estimation. In: Smith C, editor. Encyclopedia of Global Archaeology. Cham: Springer; 2020. p. 1-5. https://doi.org/10.1007/978-3-030-30018-0_142